Journal of Engineering Research and Applied Science
Available at www.journaleras.com
Volume 9 (1), June 2020, pp 1299-1307
ISSN 2147-3471 © 2020

Geochronological age relationships of Carboniferous Plutons in the Eastern Pontides (NE Turkey)

A.Kaygusuz

Gumushane Unversity, Faculty of Engineering and Natural Science, Trabzon, Turkey.

Accepted 10 January 2020

Abstract
Many plutonic rocks of varying age, size and composition exist in the Paleozoic to Cenozoic times in the Eastern Pontides. Especially Carboniferous aged plutons are observed in the larger masses and more commonly in the southern part, while they are seen in the smaller bodies and a lesser extent in the northern part of the Eastern Pontides. Carboniferous plutons are generally granite and granodiorite in composition and vary in size from 1 to 400 km^2. They exhibit low to high-K calc-alkaline and metaluminous to slightly peraluminous characters. The rocks show a wide range of variations in $^{87}Sr/^{86}Sr_{(i)}$ (0.69454 to 0.71057) and a narrow variation in $\varepsilon Nd_{(i)}$ (−0.1 to −8.0) values. Carboniferous plutons in the Eastern Pontides, at least those with precise radiometric age data available, formed between 348 to 298 Ma. These rocks represent a late stage of Hercynian magmatism in the northern and southern part of the Eastern Pontides. Compared with Eocene and Late Cretaceous plutons in the Eastern Pontides, Carboniferous plutons has very coarse texture, lesser amount of mafic magmatic enclaves (MMEs) and mafic minerals, higher ratios of $^{87}Sr/^{86}Sr_{(i)}$ and lower values of $eNd_{(i)}$.

Keywords: Carboniferous; plutonic rocks; geochronology; eastern pontides.

1. Introduction

Turkey is located on an east–west trending segment of the Alpine–Himalayan orogenic belt. The Pontides, a part of the Alpine–Himalayan orogenic belt, extend along the southern coast of the Black Sea. The Pontide tectonic unit [1] includes various extrusive and intrusive rocks, many of which are related to the convergence of Gondwana and Eurasia. The crystallization ages of the intrusive bodies range from Paleozoic [2-7] through Jurassic-Early Cretaceous [3, 8, 10-11] and Late Cretaceouse–Paleocene [12-17] to Eocene–Oligocene [18-24] (Figure 1).

Many of the earlier studies in the eastern Pontides have adressed the general characteristics of the plutons in the overall framework of the geological evolution of the region. However, studies on various aspects of plutonic rocks (such as tectonic setting, age, geochemical and isotopic evolution, and source) is rather scarce. In addition to data from the literature, new U-Pb zircon data for the Alazlı pluton are presented.

2. Geolegical setting

Based on lithological and structural differences, the eastern Pontides are generally divided into a southern and a northern zone (Figure 1b) [27-28]. Carboniferous plutons are observed both northern and southern zones (Figure 1c).

The basement rocks of the Eastern Pontides consist of Early Carboniferous metamorphic rocks [29] and Late to Early Carboniferous Plutonic rocks that are calc-alkaline in composition [3-6, 30]. These basement rocks are overlain by the Early and Middle Jurassic volcano-sedimentary rocks [31-33] and cut by Mid to Late Jurassic plutons [8-11]. All these rocks are overlain by the Late Jurassic to Early Cretaceous carbonates. The Late Cretaceous units are unconformably overlie these carbonate rocks and consist of plutonic, volcanic and sedimentary rocks [16-17, 34-39]. The Eastern Pontides were above sea level probably due to the collision between the Pontides magmatic arc and the Tauride-Anatolide block from Paleocene to Early Eocene [18, 29]. The Eocene volcanic and volcanoclastic rocks overlie the Late Cretaceous series [40-43] and are intruded by plutons of similar age [17, 19-21, 23, 44-47]. Post-

Corresponding author; abdullah.kaygusuz@gmail.com

Eocene uplift and erosion brought clastic input into locally developed basins [48]. The Miocene and post-Miocene magmatisms are characterized by calc-alkaline to mildly alkaline compositions [42, 46, 49-52]. Quaternary units comprise alluvium and terraces.

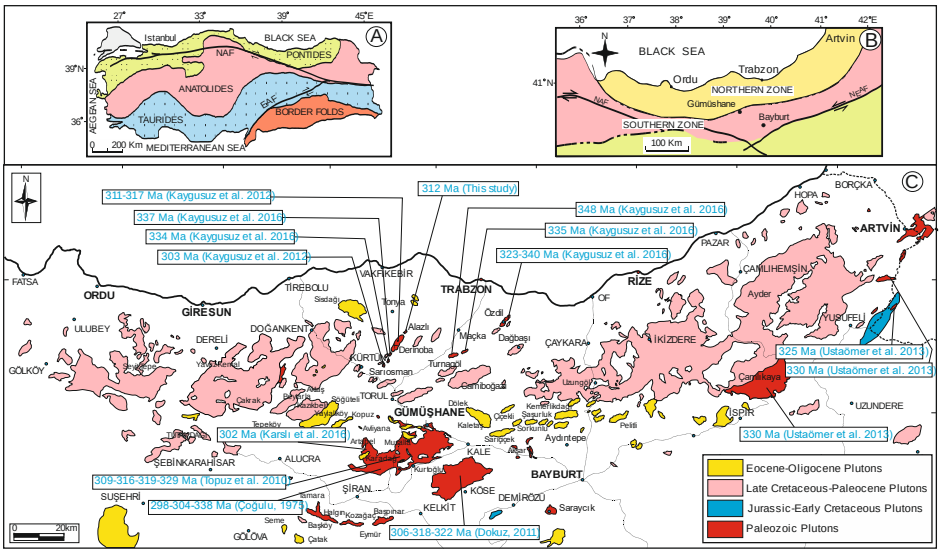

Figure 1. (a) Tectonic map showing the major sutures and continental blocks of Turkey and surrounding regions (modified after [25]), (b) Major structures of the Eastern Pontides and (c) Simplified geological map showing the main granitoid distribution and geochronological ages in the Eastern Pontides (modified after [26]).

3. Analytical methods

Zircon grains from the Alazlı pluton were selected by heavy-liquid and magnetic separation methods and the grains were purified by hand-picking under a binocular microscope. The selected grains were mounted on an epoxy resin and polished until halfway through. U-Pb dating of zircon was performed at the Geologic Lab Center, China University of Geosciences (Beijing) using LA-ICP-MS. A quadrupole ICP-MS (Agilient 7500a) was connected with a UP-193 solid-state laser and an automatic positioning system. U–Pb isotope fractionation effects were corrected using zircon 91500 [53] as external standard. Zircon standard TEMORA (417 Ma, [54]) was also used as a secondary standard to determine the deviation of age measurement/calculation. Isotopic ratios and element concentrations of zircons were obtained with the GLITTER software (Macquarie University). Concordia ages and diagrams were calculated using Isoplot/Ex (3.0) [55]. Common lead was corrected using the method of [56]. Analytical details for isotope analyses are reported in [5].

4. Results

4.1. U–Pb zircon dating

Prior to this study, knowledge about the emplacement age of the Alazlı Pluton was insufficient for the reconstruction of their geological history. Considering the stratigraphic criteria and contact relationships, the age of the Alazlı Pluton was accepted an Late Cretaceous age by [26]. In the field studies conducted by us, it was determined that the pluton was undertaken by the Liassic units and its age was accepted as Paleozoic.

U-Pb zircon analysis of granite sample of the Alazlı pluton was performed. The analysed zircons are colourless and in the form of short to long prismatic crystals (50 to 200 μm) with aspect ratios of 1 to 3. They show pyramidal terminations and oscillatory zoning in CL image, displaying a magmatic origin [57]. A total of 21 spots for granite sample from the Alazlı Pluton provides a weighted $^{206}Pb/^{238}U$ mean age of 312.1±2.1 Ma (MSWD = 1.3). Therefore, the weighted mean U–Pb age from the Alazlı pluton is consistent with a magma emplacement age during the Late Carboniferous period. This age data is also consistent with our field observations and local stratigraphy (Figure 1).

4.2 Geochemical characteristics

The Carboniferous plutons in the eastern Pontides have a large range in SiO_2 from 49 to 79 wt% (Figure 2a), corresponding to a compositional variation from gabbro to granite [58]. All samples are sub-alkaline and calc-alkaline in characters. They show low to high-K features (Figure 2b). The majority of samples are Mg-rich, whereas some samples are Fe-rich in the classification diagram of [59] (Figure 3a). The samples are metaluminous to peraluminous, with values of alumina saturation index (ASI) ranging from 0.78 to 1.38 (Figure 3b).

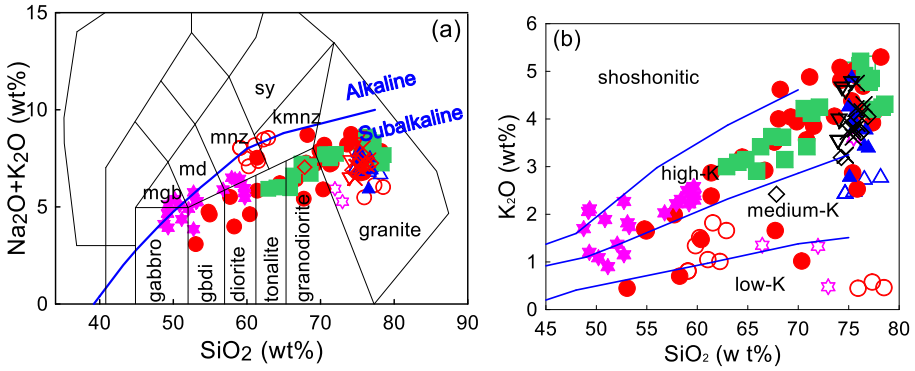

Figure 2. (a) Chemical classification diagram [58], (b) SiO_2 vs. K_2O diagram [60] from Carboniferous plutons in the eastern Pontides. References for Carboniferous Plutons in the eastern Pontides: [2-7, 9, 30].

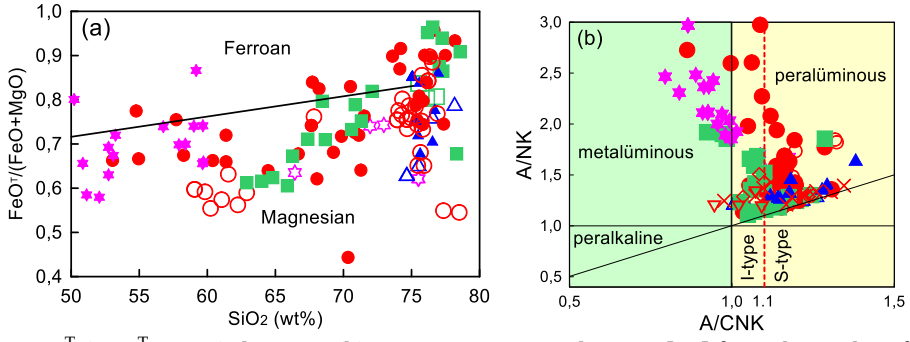

Figure 3. (a) SiO_2 vs. $FeO^T/(FeO^T+MgO)$ diagram, (b) A/CNK vs. A/NK diagram [61] from the Carboniferous plutons.

4.3 Sr-Nd isotopic characteristics

The Carboniferous plutons in the eastern Pontides show significant variations in $^{87}Sr/^{86}Sr_{(i)}$ (0.69454 to 0.71057) and small variation in $\varepsilon Nd_{(i)}$ values (−0.1 to −8.0). The Köse Pluton display higher $^{87}Sr/^{86}Sr_{(i)}$ and lower $\varepsilon Nd_{(i)}$ values, whereas the Gümüşhane Pluton display lower $^{87}Sr/^{86}Sr_{(i)}$ and higher $\varepsilon Nd_{(i)}$ values than the other Carboniferous plutons (Figure 3a).

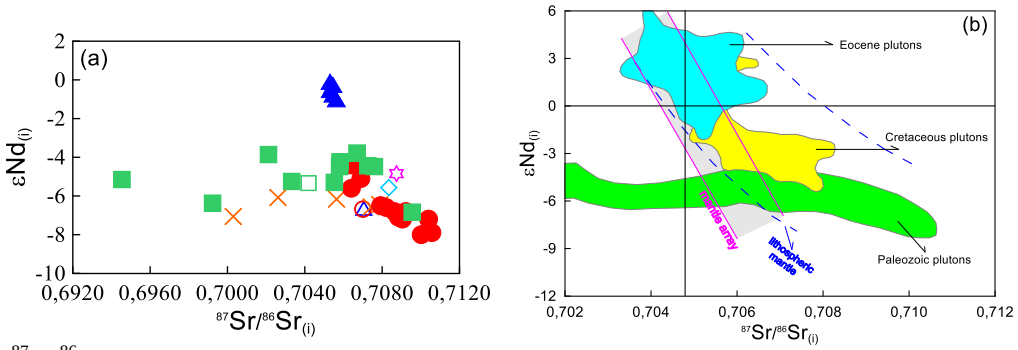

Figure 4. (a-b) $(^{87}Sr/^{86}Sr)_{(i)}$ vs. $\varepsilon Nd_{(i)}$ diagram for Carboniferous plutons. (a) References for Carboniferous plutons in the eastern Pontides: [2-6, 9, 30]. (b) The areas of the Paleozoic, Cretaceous and Eocene plutons from [46].

5. Discussion

5.1 Age constraints

The well-developed oscillatory growth zoning and relatively high Th/U ratios in the zircon from the Alazlı pluton demonstrate that the zircons are all magmatic in origin. New U–Pb zircon ages also indicated that the Alazlı pluton (312 Ma) are older than other adjacent Carboniferous plutons, such as Çamlık Pluton (302 Ma [30]) and Kayadibi Pluton (303 Ma [5]) but slightly younger than Carboniferous Derinoba Pluton (avg. 314 Ma, [5]), Köse Pluton (avg. 315 Ma [4]), Gümüşhane Pluton (avg. 313 Ma [2]; avg. 318 Ma [3]), Çamlıkaya Pluton (330 Ma [9]), Narlık Pluton (330 Ma [9]), Özdil Pluton (avg. 332 Ma [6]), Demirkent Pluton (325 Ma [9]), Şahmetlik Pluton (334 Ma [6]), Seslikaya Pluton (335 Ma [6]), Kızılağaç Pluton (337 Ma [6]) and Soğuksu Pluton (348 Ma [6]) (Table 1). As can be seen in Table 1, the Kayadibi (303 Ma) and Çamlık (302 Ma) plutons are the youngest plutons, and Soğuksu Pluton (348 Ma) is the oldest pluton for Carboniferous plutons in the eastern Pontides.

The crystallization ages of plutons in the Eastern Pontides range from Paleozoic to Eocene–Oligocene. Taking into account geochronological data indicated that the plutons formed during the Paleozoic (348 to 298 Ma), Triassic-Jurassic-Early Cretaceous (188 to 104 Ma), Late Cretaceous (89 to 66 Ma) to Paleocene-Eocene-Oligocene (57 to 36 Ma). Our U–Pb zircon age (312 Ma) for Alazlı pluton are cohorent with the major plutonic phase during the Carboniferous (Table 1).

Table 1. Geochronological ages of Carboniferous plutons in the Eastern Pontides.

Era/Age	Pluton/Location	Age (Ma)	Method	Reference
Carboniferous	Köse (Gümüşhane)	322.2±3.8	Ar-Ar	[4]
Carboniferous	Köse (Gümüşhane)	306.6±4.2	Ar-Ar	[4]
Carboniferous	Köse (Gümüşhane)	318±2.4	Ar-Ar	[4]
Carboniferous	Gümüşhane	298	U/(Th-Pb)	[2]
Carboniferous	Gümüşhane	304	U/(Th-Pb)	[2]
Carboniferous	Gümüşhane	338	U/(Th-Pb)	[2]
Carboniferous	Gümüşhane	309.2±5.3	Ar-Ar	[3]
Carboniferous	Gümüşhane	316.8±2.9	Ar-Ar	[3]
Carboniferous	Gümüşhane	319±5	U-Pb	[3]
Carboniferous	Gümüşhane	329±6	U-Pb	[3]
Carboniferous	Çamlık (Gümüşhane)	302.01±0.68	U-Pb	[30]
Carboniferous	Alazlı (Tonya-Trabzon)	312.1±2.1	U-Pb	This study
Carboniferous	Derinoba (Tonya-Trabzon)	317.2±3.5	U-Pb	[5]
Carboniferous	Derinoba (Tonya-Trabzon)	311.1±2.0	U-Pb	[5]
Carboniferous	Kayadibi (Kürtün-Gümüşhane)	303.8±1.5	U-Pb	[5]
Carboniferous	Özdil (Yomra-Trabzon)	340.7±1.8	U-Pb	[6]
Carboniferous	Özdil (Yomra-Trabzon)	323.1±1.5	U-Pb	[6]
Carboniferous	Seslikaya (Maçka-Trabzon)	335.4±1.4	U-Pb	[6]
Carboniferous	Soğuksu (Maçka-Trabzon)	348.4±1.6	U-Pb	[6]
Carboniferous	Şahmetlik (Tonya-Trabzon)	334.5±1.4	U-Pb	[6]
Carboniferous	Kızılağaç (Tonya-Trabzon)	337.2±0.69	U-Pb	[6]
Carboniferous	Çamlıkaya (Yusufeli-Artvin)	330±4.0	U-Pb	[9]
Carboniferous	Demirkent (Yusufeli-Artvin)	325±3.0	U-Pb	[9]
Carboniferous	Narlık (Yusufeli-Artvin)	330±19	U-Pb	[9]

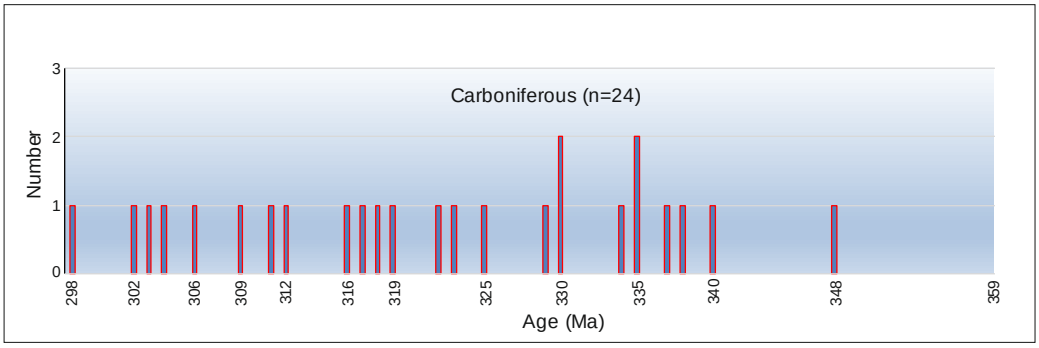

Figure 5. Histogram showing the age range of Carboniferous plutons in the Eastern Pontides.

Concerning the distribution of the eastern Pontide plutons, it is interesting to note that there is no spatial and temporal relationship from east to west, and north to south. Instead, magmatism becomes older from the centre (Özdil and Seslikaya plutons) of the eastern Pontides (Figure 3).

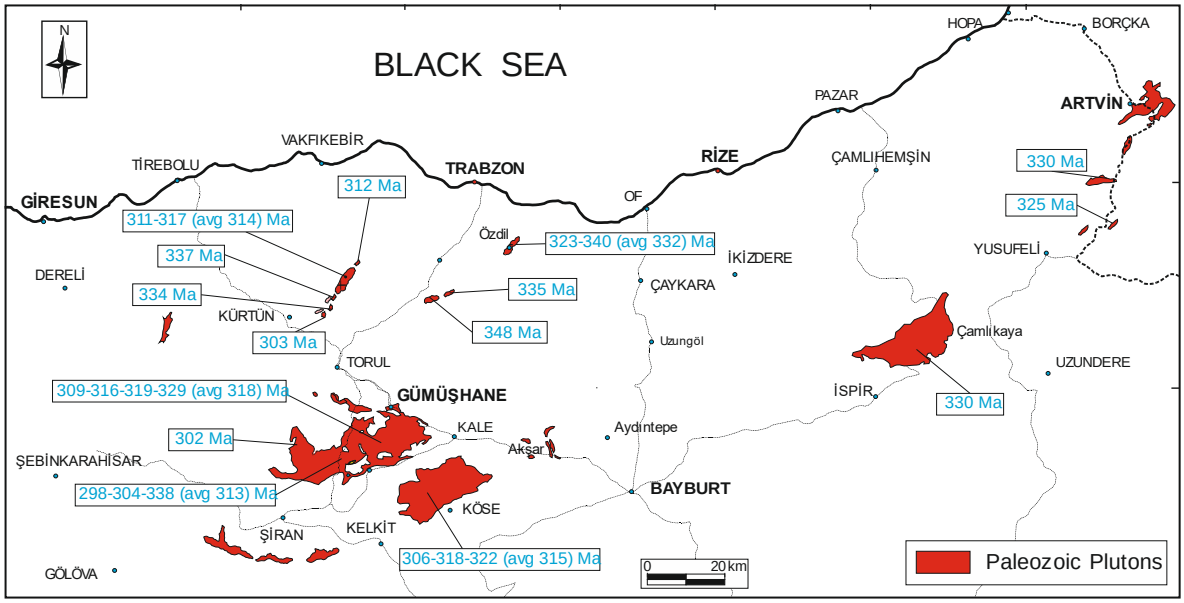

Figure 6. Age-time distribution of Carboniferous plutonic rocks in the Eastern Pontides.

6. Conclusions

Carboniferous plutons are found both northern and southern zones of the Eastern Pontides. They have low to high-K calc-alkaline and peraluminous features. These plutons also have a relatively wide range of $^{87}Sr/^{86}Sr_{(i)}$ ratios and a narrow range of $\varepsilon Nd_{(i)}$ values.

Including presently available geochronological age data, the Carboniferous plutonic rocks in the Eastern Pontides are dominantly 348 to 298 Ma in age. As becomes apparent from the existing data, a major pulse of igneous activity occurred around 302 to 340 Ma, and the age of the Alazlı pluton presented in this study (312 Ma) coincides with this peak. The age compilation also shows that there was continuous magmatic activity between 298 to 348 Ma. Considering the geochronological ages made up to this time of Carboniferous plutons in the Eastern Pontides, the Kayadibi (303 Ma) and Çamlık (302 Ma) plutons are the youngest, and Soğuksu Pluton (348 Ma) is the oldest pluton from Carboniferous plutons in the eastern Pontides.

Concerning the distribution of the eastern Pontide plutons, it is interesting to note that there is no spatial and temporal relationship from north to south, and east to west. Instead, magmatism becomes older from the centre (Özdil and Seslikaya plutons) of the eastern Pontides.

Acknowledgement

The author sincerely thanks Bin Chen for providing U-Pb zircon dating. Also thanks the editor and the anonymous reviewer for their improvement of the manuscript.

References

[1] Ketin, İ. Anadolunun tektonik birlikleri: MTA Dergisi 1966; 66: 22–34.

[2] Çoğulu, E. Gümüşhane ve Rize granitik plütonlarının mukayeseli petrojeolojik ve jeokronometrik etüdü, Doçençtlik Tezi 1975, İ.T.Ü. Maden Fakültesi, İstanbul (Yayınlanmamış).

[3] Topuz, G., Altherr, R., Wolfgang, S., Schwarz, W.H., Zack, T., Hasanözbek, A., Mathias, B., Satır, M., Şen, C. Carboniferous high-

potassium I-type granitoid magmatism in the Eastern Pontides: The Gümüşhane pluton (NE Turkey), Lithos 2010; 116: 92–110.

[4] Dokuz, A. A slab detachment and delamination model for the generation of Carboniferous high-potassium I-type magmatism in the Eastern Pontides, NE Turkey: Köse composite pluton, Godwana Research 2011; 19: 926–944.

[5] Kaygusuz, A., Arslan, M., Siebel, W., Sipahi, F., İlbeyli, N. Geochronological evidence and tectonic significance of Carboniferous magmatism in the southwest Trabzon area, eastern Pontides, Turkey", International Geology Rew 2012; 54 (15): 1776–1800.

[6] 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: 327–346.

[7] Vural, A., Kaygusuz, A. Petrology of the paleozoic plutons in Eastern pontides: artabel pluton (Gümüşhane, NE Turkey). Journal of Engineering Research and Applied Science 2019; 8 (2): 1216-1228.

[8] Dokuz, A., Karslı, O., Chen, B., Uysal, İ. Sources and petrogenesis of Jurassic granitoids in the Yusufeli area, Northeastern Turkey: Implications for pre-and post-collisional lithospheric thinning of the Eastern Pontides, Tectonophysics 2010; 480: 259–279.

[9] Ustaömer, T., Robertson, A.H.F., Ustaömer, P.A., 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. In Robertson, A.H.F., Parlak, O., Ünlügenç, U.C. (eds). Geological Development of Anatolia and the Easternmost Mediterranean Region.Geological Society, London. Special Publications 2013; 372: 49–74.

[10] Eyuboğlu, Y., Dudas, F.O., Santosh, M., Zhu, D.C., Yi, K., Chatterjee, N., Akaryalı, E., Liu, Z. Cenozoic forearc gabbros from the northern zone of the Eastern Pontides Orogenic Belt, NE Turkey: Implications for slab window magmatism and convergent margin tectonics, Gondwana Research 2016; 33: 160–190.

[11] 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: 1–27.

[12] Yılmaz, A., Adamia, S., Chabukiani, A., Chkhotua, T., Erdoğan, K., Tuzcu, S., Karabıyıkoğlu, M. Structural correlation of the southern Transcaucasus (Georgia), Eastern Pontides (Turkey): In: Bozkurt, E., Winchester, J.A., Piper, J.D.A., (Eds), Tectonics and Magmatism in Turkey and surrounding area: Geological Society of London, Special Publication 2000; 173: 171–182.

[13] Boztuğ, D., Erçin, A.İ., Kuruçelik, M.K., Göç, D., Kömür, İ., İskenderoğlu, A. Geochemical characteristics of the composite Kaçkar batholith generated in a Neo-Tethyan convergence system, Eastem Pontides, Turkey, Journal of Asian Earth Sciences 2006; 27: 286–302.

[14] 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: 739–764.

[15] Kaygusuz, A., Chen, B., Aslan, Z., Siebel, W., Şen, C. U-Pb SHRIMP zircon ages, geochemical and Sr–Nd isotopic compositions of the Late Cretaceous I-type Sarıosman pluton, Eastern Pontides, NE Turkey, Turkish Journal of Earth Sciences 2009; 18: 549–581.

[16] Karslı, O., Dokuz, A., Uysal, İ., Aydın, F., Kandemir, R., Wijbrans, R.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: 109–120.

[17] 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, Journal of Asian Earth Sciences 2019; 171: 305–320.

[18] Boztuğ, D., Jonckheere, R.C, Wagner, G.A., Yeğingil, Z. Slow Senonian and fast Paleocene-early Eocene uplift of the granitoids in the Central Eastern Pontides, Turkey: Apatite fission-track results, Tectonophysics 2004; 382: 3/4, 213–228.

[19] Topuz, G., Alther, R., Schwarz, W.H., Siebel, W., Satır, M., Dokuz, A. Post-

collisional plutonism with adakite-like signatures: the Eocene Saraycık Granodiorite (Eastern Pontides, Turkey), Contributions to Mineralogy and Petrology 2005; 150: 441–455.

[20] Arslan, M., Aslan, Z. Mineralogy, petrography and whole-rock geochemistry of the Cenozoic granitic intrusions in the Eastern Pontides (Turkey), Journal of Asian Earth Sciences 2006; 27: 177–193.

[21] Karslı, O., Chen, B., Aydın, F., Şen, C. Geochemical and Sr-Nd-Pb isotopic compositions of the Eocene Dölek and Sarıçiçek 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.

[22] Kaygusuz, A., Öztürk, M. Geochronology, geochemistry, and petrogenesis of the Eocene Bayburt intrusions, Eastern Pontide, NE Turkey: implications for lithospheric mantle and lower crustal sources in the high-K calc-alkaline magmatism, Journal of Asian Earth Sciences 2015; 108: 97–116.

[23] Eyuboğlu, Y., Dudas, F.O., Thorkelson, D., Zhu, D.C., 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: 311–345.

[24] Temizel, İ., Abdioğlu Yazar, E., Arslan, M., Kaygusuz, A., Aslan, Z. Mineral chemistry, whole-rock geochemistry and petrology of Eocene I-type Shoshonitic plutons in the Gölköy area (Ordu, NE Turkey), Bulletin of the Mineral Research and Exploration 2018; 157: 121-152.

[25] Okay, A.İ., Tüysüz, O. Tethyan sutures of northern Turkey. Journal of Geological Society of London Special Publication 1999; 156: 475–515.

[26] Güven, İ.H. Doğu Pontidler'in 1/ 250 000 ölçekli kompilasyonu, MTA Genel Müdürlüğü 1993, Ankara.

[27] Özsayar, T., Pelin, S., Gedikoğlu, A. Doğu Pontidler'de Kretase, KTÜ Yerbilimleri Dergisi 1981; 2: 65–114.

[28] 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.

[29] Topuz, G., Altherr, R., Kalt, A., Satır, M., Werner, O., Schwarz, W.H. Aluminous granulites from the Pulur complex, NE Turkey: a case of partial melting, efficient melt extraction and crystallization, Lithos 2004; 72: 183–207.

[30] 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: 98–114.

[31] Ağar, U. Demirözü (Bayburt) ve Köse (Kelkit) Bölgesinin Jeolojisi. Doktora Tezi 1977, İstanbul Üniversitesi, İstanbul (unpublished).

[32] Kandemir, R., Yılmaz, C. Lithostratigraphy, facies, and deposition environment of the lower Jurassic Ammonitico Rosso type sediments (ARTS) in the Gümüşhane area, NE Turkey: Implications for the opening of the northern branch of the Neo-Tethys Ocean. Journal of Asian Earth Sciences 2009; 34: 586-598.

[33] Gücer, M.A., Arslan, M., Sherlock, S., Larry M. Heaman4Permo-Carboniferous granitoids with Jurassic high temperature metamorphism in Central Pontides, Northern Turkey. Miner Petrol 2016; 110: 943–964.

[34] Kaygusuz, A., Siebel, W., İlbeyli, N., Arslan, M., Satır, M., Şen, C. Insight into magma genesis at convergent plate margins. a case study from the eastern Pontides (NE Turkey), Neues Jahrbuch Für Mineralogie 2010; 187/3: 265–287.

[35] Kaygusuz, A., Aydınçakır, E. Mineralogy, whole-rock and Sr-Nd isotope geochemistry of mafic microgranular enclaves in Cretaceous Dağbaşı Granitoids, Eastern Pontides, NE Turkey: evidence of magma mixing, mingling, and chemical equilibration", Chemie der Erde Geochemistry 2009; 69: 247–277.

[36] Kaygusuz, A., Aydınçakır, E. Petrogenesis of a Late Cretaceous composite pluton from the eastern Pontides: the Dağbaşı pluton, NE Turkey, Neues Jahrbuch Für Mineralogie 2011; 188/3: 211–233.

[37] Saydam Eker, Ç., Korkmaz, S. Mineralogy and whole rock geochemistry of late Cretaceous sandstones from the eastern Pontides (NE Turkey), Neues Jahrb. Mineral. Abh. 2011; 188 (3): 235–256.

[38] 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. Chemie der Erde Geochemistry 2012; 72: 167–177.

[39] Aydınçakır, E. Subduction-related Late

Cretaceous high-K volcanism in the Central Pontides orogenic belt: Constraints on geodynamic implications, Geodinamica Acta 2016; 28(4): 379-411.

[40] Arslan, M., Temizel, İ., Abdioğlu, E., Kolaylı, H., Yücel, C., Boztuğ, D., Şen, C. ^{40}Ar-^{39}Ar 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: 113–142.

[41] Eyuboğlu, Y., Dudas F.O., Santosh, M., Y.I.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: 742–766.

[42] 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: Mineralogy and Petrology 2014; 108: 245–267.

[43] Temizel İ., Arslan M., Yücel C., Abdioğlu Yazar E., Ruffet G. Geochronology and geochemistry of Eocene-aged volcanic rocks around the Bafra (Samsun, N Turkey) area: constraints for the interaction of lithospheric mantle and crustal melts: Lithos 2016; 258/259: 92–114.

[44] Akaryalı, E. Geochemical, fluid inclusion and isotopic (O, H and S) constraints on the origin of Pb–Zn ± Au vein-type mineralizations in the Eastern Pontides Orogenic Belt (NE Turkey). Ore Geology Reviews 2016; 74: 1–14.

[45] Kaygusuz, A., Yücel, C., Arslan, M., Sipahi, F., Temizel, İ., Çakmak, G., Güloğlu, Z.S. Petrography, mineral chemistry and crystallization conditions of Tertiary plutonic rocks located to the north of Bayburt (Eastern Pontides, Turkey), Bulletin of the Mineral Research and Exploration 2018; 157: 75–102.

[46] Kaygusuz, A., Yücel, C., Arslan, M., Temizel, İ., Yi, K., Jeong, Y-J., 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, International Geology Review 2020; doi.org/10.1080/00206814.2019.1647468.

[47] Vural, A., Ersen, F. Geology, mineralogy and geochemistry of manganese mineralization in Gumushane, Turkey. Journal of Engineering Research and Applied Science 2019; 8: 1051–1059.

[48] Korkmaz, S., Tüysüz, N., Er, M., Musaoğlu, A., Keskin, İ. Stratigraphy of Eastern Pontides, NE Turkey. In: Erler, A., et al. (Eds.), Geology of Black Sea Region: Proceedings of the International Symposium on the Geology of Black Sea Region 1995; 59–66, MTA, Ankara.

[49] Aydın, F., Karslı, O., Chen, B. Petrogenesis of the Neogene alkaline volcanics with implcations for post collisional lithospheric thinning of the Eastern Pontides, NE Turkey: Lithos 2008; 104: 249–266.

[50] Yücel. C., Arslan, M., Temizel, İ., Abdioğlu, E. Volcanic facies and mineral chemistry of Tertiary volcanics in the northern part of the Eastern Pontides, northeast Turkey: implications for pre-eruptive crystallization conditions and magma chamber processes: Mineralogy and Petrology 2014; 108: 439–467.

[51] Yücel, C., Arslan, M., Temizel, İ., Yazar, E.A., 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.

[52] Kaygusuz, A. K/Ar ages and geochemistry of the post-collisional volcanic rocks in the Ilıca (Erzurum) area, eastern Turkey. Neues Jahrbuch Für Mineralogie 2009; 186/1: 21–36.

[53] Wiedenbeck, M., Alle, P., Corfu, F., Griffin, W.L., Meier, M., Oberli, F., Vonquadt, A., Roddick, J.C., Speigel, W. Three natural zircon standards for U–Th–Pb, Lu–Hf, traceelement and REE analyses. Geostandards Newsletter 1995; 19: 1–23.

[54] Black, L.P., Kamo, S.L., Allen, C.M., Aleinikoff, J.N., Davis, D.W., Korsch, R.J., Foudoulis, C. Temora 1: a new zircon standard for Phanerozoic U–Pb geochronology. Chemical Geology 2003; 200: 155–170.

[55] Ludwig, K.R. User's Manual for isoplot 3.0: a geochronological toolkit for Microsoft Excel. Berkeley Geochronology Center, Special publication 2003; 4: 1–71.

[56] Andersen, T. Correction of common lead in U–Pb analyses that do not report ^{204}Pb. Chemical Geology 2002; 192: 59–79.

[57] Pupin, J.P. Zircon and granite petrology: Contributions to Mineralogy and Petrology 1980; 73: 207–220.

[58] Middlemost, E.A.K. Naming materials in the

magma/igneous rock system: Earth Science Review 1994; 37: 215–224.

[59] Frost, B. R., Barnes, C. G., Collins, W. J., Arculus, R. J., Ellis, D.J. Frost, C.D. A geochemical classifi cation for granitic rocks. Journal of Petrology 2001; 42: 2033–2048.

[60] Peccerillo, R., Taylor, S.R. Geochemistry of Eocene calc-alkaline volcanic rocks from the Kastamonu area, northern Turkey: Contributions to Mineralogy and Petrology 1976; 58: 63–81.

[61] Shand, S.J. Eruptive rocks. Their genesis, composition, classification and their relation to ore-deposits: 3rd ed J Wiley Sons 1947; New York.