Regional Geological of the Biga Peninsula

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Biga Peninsula is a geologically diverse and complex peninsula that has been exposed to a series of tectonic events during its lengthy history. It represents the western section of the Sakarya Zone (S Pontide Domain) along the boundary between Gondwana and Laurasia and consists of numerous tectonic units, representing both continental and oceanic assemblages. The tectonic activity of the Biga Peninsula is primarily impacted by the motion occurring along the North Anatolian Fault Zone.

Keywords: geochemistry ; Biga Peninsula ; Regional geology

1. Introduction

Skarn deposits, which are predominantly classified as Fe-skarns and Cu-skarns, are a significant mineral deposit located on the Biga Peninsula of Turkey (**Figure 1**). Fe-skarns are the most abundant type of skarn deposit in western Anatolia. They arise when plutonic rocks such as granodiorite, monzodiorite, quartz diorite, or diorite intrusions emplace into metamorphosed sedimentary to volcanosedimentary rocks [1]. These skarns frequently co-generate with porphyry Cu deposits or epithermal Au deposits. This suggests that the Fe-skarns in the Biga Peninsula are an outcome of the broader magmatic–hydrothermal systems developed in high-level porphyry settings [1]. They are distinguished by economically valuable Cu mineralization that occurs as veins or irregular pockets that extend across magnetite ore bodies. These deposits are related to the Oligocene to Lower Miocene granitoids, particularly diorite and monzodiorite dike-like bodies close to the intersection of graphitic recrystallized limestone [1]. The deposits, including Uskufcu, Demirtepe, Evciler, and Bakirlik, frequently coexist with high-level porphyry systems as well (**Figure 1**). The Cu-skarns in the Biga Peninsula are made up of garnet–pyroxene and wollastonite–garnet skarns in endoskarn zones and wollastonite–garnet skarns in exoskarn zones [1]. However, Fe-skarns in the Biga Peninsula include magnetite, phlogopite, and actinolite and exhibit the alteration of magnetite to hematite, leading to supergene copper enrichment. There is also economically significant gold mineralization in the altered prograde skarns of certain deposits; this mineralization appears as magnetite and chalcopyrite lenses or pockets [1]. The region also has Mo-skarns, yet these are rather less prevalent than Fe-skarns and are typically regarded as being unprofitable. These Mo-skarns frequently include W and Cu mineralization and are mostly found in the regions of Soğucak, Sofular, Ayvalik, and Çakiroba. Their grade ranges from 0.1% to 0.6% Mo. These diverse skarns demonstrate how the Biga Peninsula is mineral-rich and how important it is for mining exploration and development [1].

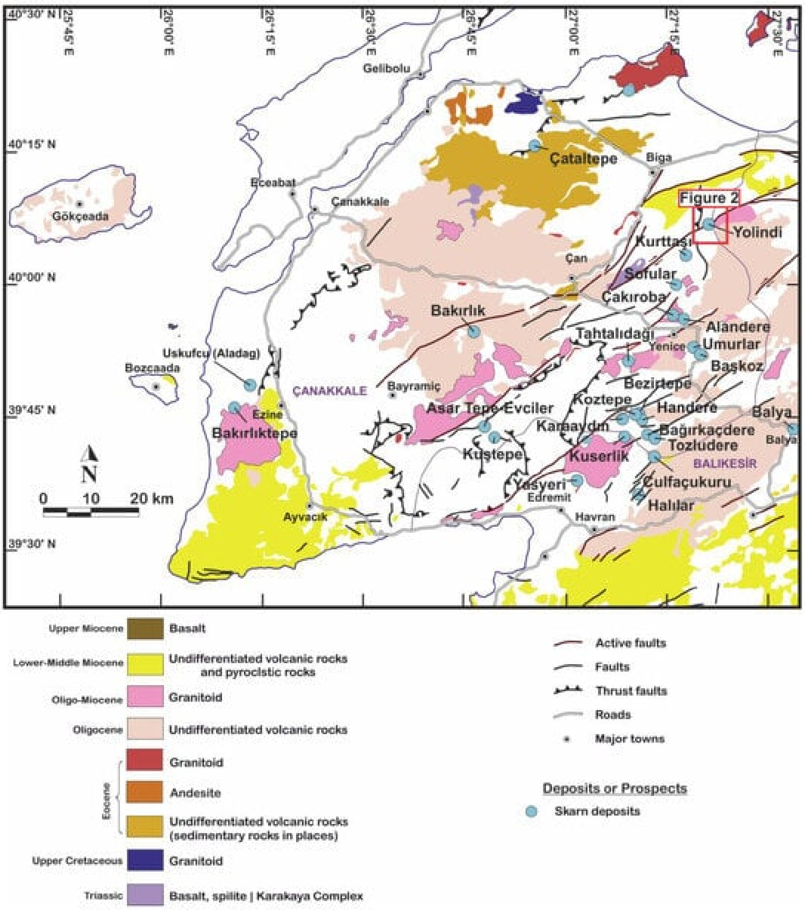

Figure 1. Distributions of the skarn deposits in the Biga Peninsula, NW Turkey, modified according to Yigit [2] and Kuşcu [1].

2. Regional Geological Background of the Biga Peninsula

Biga Peninsula (**Figure 1**) is a geologically diverse and complex peninsula that has been exposed to a series of tectonic events during its lengthy history. It represents the western section of the Sakarya Zone (S Pontide Domain) along the boundary between Gondwana and Laurasia [3] and consists of numerous tectonic units, representing both continental and oceanic assemblages [4]. The tectonic activity of the Biga Peninsula is primarily impacted by the motion occurring along the North Anatolian Fault Zone [5]. This fault zone divides into two primary branches, namely, the northern and southern branches, located in the eastern area of Marmara. The southern branch of the fault system has a trajectory that extends in the direction of the Biga Peninsula. This region is distinguished by a stress regime that involves strike-slip and oblique normal faulting, particularly in its center-to-northern portion. The region located in the southernmost portion of the peninsula has a stress regime that is mostly characterized by normal to oblique faulting [5]. Okay, et al. [6] identified four distinct NE–SW trending zones within the Biga and Gelibolu peninsulas These zones, listed in order from northwest to southeast, are referred to as the Gelibolu, Ezine, Ayvacık-Karabiga, and Sakarya zones. The oldest rocks in the Biga Peninsula are metamorphic basement rocks that formed during the Precambrian to Early Paleozoic era. These basement rocks consist primarily of gneisses, schists, and marbles that underwent multiple metamorphic events under high-pressure and high-temperature conditions [7]. The peninsula also has plutonic and related volcanic rocks, ophiolites, and amphibolite to granulite facies metamorphic rocks [8][9]. Furthermore, the area has two major thrusted basement rock groups: the Kazdağ metamorphic units and the Çamlıca metamorphic unit with high-pressure assemblages, as well as the Kemer metamorphics [10]. In other words, the metamorphic rocks are split into two major zones: the Ezine zone with the Çamlıca Metamorphic unit in the northwest region of the Biga Peninsula and Kazdag Group and Karakaya Complex zone in the southeast region of the Biga Peninsula, which serve as the basement of the Rhodope and Sakarya zones, respectively [2]. Other metamorphic units occurred in the Biga Peninsula, such as the Çamlik and Yolindi Metagranodiorite, which was exposed north of the northeast region and intruded into the Kalabak Formation [11]. The main tectono-stratigraphic units in the area of the Biga Peninsula are Denizgoren ophiolite and Çetmi ophiolitic mélange, which occurred in the SW and N of the Biga Peninsula, respectively [2][6]. The Biga Peninsula observed extensive tectonic processes throughout the Mesozoic era, including sedimentation, ophiolite emplacement, and the development of volcanic island arcs [3]. Sedimentation had a significant effect in creating the geology of the area throughout the Triassic era. During this period, extensive deposition of carbonate rocks such as limestones and dolomites occurred in shallow marine environments [3][12]. These carbonate rocks give evidence of Triassic marine environments on the Biga Peninsula [12]. As the Mesozoic period gave way to the Jurassic and Cretaceous periods, tectonic activity spread ophiolite complexes over the continent, as well as flysch and mélange deposits. These ophiolites and associated deposits reveal geological events such as oceanic crust formation, subduction, and accretionary processes in the area. Therefore, they are predominantly Permo-Triassic carbonates and clastic rocks of the Karakaya Complex, with Mid-Triassic to Jurassic neritic limestones of the Çetmi Ophiolitic Mélange occurring as part of several Formations, including the Bayırköy Formation, Bilecik Limestone, and Vezirhan Formation [6].

Aside from the metamorphic basement rocks, the Biga Peninsula has an extensive record of magmatic and volcanic activity dating back to the Pre-Cenozoic and Cenozoic eras (**Figure 1**). Granitic intrusions and volcanic rocks were emplaced on the Biga Peninsula during the Late Paleozoic era as a result of the closure of the Paleo-Tethys Ocean and the formation of the supercontinent Pangea [13]. They also took place in an extensional tectonic regime, which is characterized by the stretching and thinning of the Earth's crust. This extensional tectonic regime resulted in various unique tectonic settings such as the back-arc basin [4]; orogenic collapse [14]; slab breakoff [15]; and single-subduction zone [16]. The formation of the back-arc-type extension in the Aegean area may be attributed to the rollback of the Hellenic subduction zone [4][17][18]. However, the orogenic collapse of the high topography thickened crust during the Eocene also contributed to the extension in the Aegean area [14]. Additionally, slab break-off, convective removal, or partial delamination of the lithosphere are the driving mechanisms responsible for syn-convergent extension and magma generation [15]. The granitic intrusions found on the Biga Peninsula are frequently accompanied with mineralization, suggesting that they might have formerly acted as a source of important metallic minerals [2]. The Late Cretaceous Şevketiye Pluton (Delaloye and Bingöl, 2000) represents the Pre-Cenozoic era in the northern part of the Biga peninsula (**Figure 1**). In contrast, the Cenozoic era is characterized by a variety of intrusions across the Eocene to the Oligo-Miocene, including Dikmen, Evciler, Eybek, Kestanbol, Kuşçayir, Şaroluk, and Yenice, which are mainly concentrated in the central and southern regions of the peninsula, along with the Kapidağ and Karabiga plutons in the north [19][20][21][22][23][24]. The volcanic rocks that originated on the Biga Peninsula during this time period provide valuable insights into the ancient volcanic arcs that formed due to the subduction processes of the Neo-Tethyan oceanic lithosphere in Anatolia [25]. These volcanic rocks, together with the related mineral deposits, give vital information on the tectonic and magmatic processes that occurred in the region during the Late Paleozoic period [2]. Pre-Cenozoic volcanic rock assemblages are dominated by Triassic basic volcanic rocks such as basalts and spilites. These are found with ophiolitic mélanges, a chaotic mix of rock types, and the Karakaya Complex [2]. The Cenozoic period, on the other hand, observed the formation of Ayvacik volcanic rocks, Ezine basalt, and Taştepe basalt, all with calc-alkaline to alkaline affinities, indicating a diverse magmatic history [20][26][27]. In addition to their geological significance, the Cenozoic plutons and volcanic successions of the Biga peninsula are economically significant. The majority of the metallic mineral resources and industrial materials that have aided its economy are related to these Cenozoic formations [2][28] (**Figure 1**).

References

1. Kuşcu, İ. Skarns and skarn deposits of Turkey. In Mineral Resources of Turkey; Pirajno, F., Ünlü, T., Dönmez, C., Şahin, M.B., Eds.; Modern Approaches in Solid Earth Sciences; Springer: Berlin/Heidelberg, Germany, 2019; Volume 16, pp. 283–336.
2. Yigit, O. A prospective sector in the Tethyan Metallogenic Belt: Geology and geochronology of mineral deposits in the Biga Peninsula, NW Turkey. Ore Geol. Rev. 2012, 46, 118–148.
3. Beccaletto, L. Geology, Correlations, and Geodynamic Evolution of the Biga Peninsula (NW Turkey); Université de Lausanne: Lausanne, Switzerland, 2003.
4. Okay, A.I.; Satir, M. Coeval plutonism and metamorphism in a latest Oligocene metamorphic core complex in northwest Turkey. Geol. Mag. 2000, 137, 495–516.
5. Özden, S.; Över, S.; Poyraz, S.A.; Güneş, Y.; Pınar, A. Tectonic implications of the 2017 Ayvacık (Çanakkale) earthquakes, Biga Peninsula, NW Turkey. J. Asian Earth Sci. 2018, 154, 125–141.
6. Okay, A.; Siyako, M.; Burkan, K. Geology and tectonic evolution of the Biga Peninsula, northwest Turkey. Bull.-Technol. Univ. Istanb. 1991, 44, 191–256.
7. Yiğitbaş, E.; Tunç, İ. Pre-cambrian metamorphic rocks of the Sakarya Zone in the Biga Peninsula; late Ediacaran Gondwanaland active continental margin. Turk. Jeol. Bul.-Geol. Bull. Turk. 2020, 63, 277–302.
8. Yiğitbaş, E.; Tunc, I.; Sengun, F. Some Major Geological Problems in the Biga Peninsula: The Cetmi Melange. In Proceedings of the EGU General Assembly Conference Abstracts, Vienna, Austria, 19–24 April 2009; p. 2468.

9. Şengün, F.; Yiğitbaş, E.; Tunc, I.O. Geology and tectonic emplacement of eclogite and blueschists, Biga peninsula, northwest Turkey. Turk. J. Earth Sci. 2011, 20, 273–285.
10. Bonev, N.; Beccaletto, L.; Robyr, M.; Monié, P. Metamorphic and age constraints on the Alakeçi shear zone: Implications for the extensional exhumation history of the northern Kazdağ Massif, NW Turkey. Lithos 2009, 113, 331–345.
11. Okay, A.; Satir, M.; Siebel, W. Pre-Alpide Palaeozoic and Mesozoic orogenic events in the Eastern Mediterranean region. Geol. Soc. Lond. Mem. 2006, 32, 389–405.
12. Afridi, B.Z. Sedimentology, Cyclostratigraphy, Sequence Stratigraphy and Geochemistry of the Middle Eocene Lacustrine-Marine Oil-Shales Transition, Mudurnu Göynük basin, NW Anatolia, Turkey. Ph.D. Thesis, Graduate School of Natural and Applied Sciences. Geological Engineering. Middle East Technical University, Ankara, Turkey, 2019.
13. Göncüoğlu, M.C. Introduction to the Geology of Turkey: Geodynamic Evolution of the Pre-Alpine and Alpine Terranes; Ankara, Turkey; ODTU Jeoloji Müh. Bölümü: Ankara, Turkey, 2010; pp. 1–66.
14. Seyitoğlu, G.; Scott, B.C. The cause of N-S extensional tectonics in western Turkey: Tectonic escape vs back-arc spreading vs orogenic collapse. J. Geodyn. 1996, 22, 145–153.
15. Dilek, Y.; Altunkaynak, Ş. Cenozoic crustal evolution and mantle dynamics of post-collisional magmatism in western Anatolia. Int. Geol. Rev. 2007, 49, 431–453.
16. Jolivet, L.; Brun, J.-P. Cenozoic geodynamic evolution of the Aegean. Int. J. Earth Sci. 2010, 99, 109–138.
17. Le Pichon, X.; Angelier, J. The Aegean Sea. Philosophical Transactions of the Royal Society of London. Ser. A Math. Phys. Sci. 1981, 300, 357–372.
18. Buick, I. The late Alpine evolution of an extensional shear zone, Naxos, Greece. J. Geol. Soc. 1991, 148, 93–103.
19. Birkle, P.; Satir, M.; Erler, A.; Ercan, T.; Bingol, E.; Orcen, S. Dating, geochemistry and geodynamic significance of the Tertiary magmatism of the Biga Peninsula, NW Turkey. In Geology of the Black Sea Region: Ankara, Turkey; Erler, A., Ed.; Mineral Research and Exploration Institute of Turkey (MTA): Ankara, Turkey, 1995; pp. 171–180.
20. Yılmaz, Y.; Genç, Ş.; Karacık, Z.; Altunkaynak, Ş. Two contrasting magmatic associations of NW Anatolia and their tectonic significance. J. Geodyn. 2001, 31, 243–271.
21. Özdamar, Ş.; Roden, M.F.; Zou, H.; Billor, M.Z.; Hames, W.; Georgiev, S.; Dunkl, I. Petrogenesis of oligocene plutonic rocks in western Anatolia (NW Turkey): Insights from mineral and rock chemistry, Sr-Nd isotopes, and U-Pb, Ar-Ar and (U-Th)/He geochronology. Geochemistry 2021, 81, 125747.
22. Özdamar, Ş.; Zou, H.; Billor, M.Z.; Hames, W.E. Petrogenesis of mafic microgranular enclaves (MMEs) in the oligocene-miocene granitoid plutons from northwest Anatolia, Turkey. Geochemistry 2021, 81, 125713.
23. Abdelnasser, A.; Kumral, M.; Zoheir, B.; Yilmaz, H. Evolution of the Tepeoba porphyry-skarn Cu-Mo-Au deposit, NW Turkey: New mineralogical and geochemical findings. Ore Geol. Rev. 2022, 147, 104967.
24. Karaman, M.; Kumral, M.; Yildirim, D.K.; Doner, Z.; Afzal, P.; Abdelnasser, A. Delineation of the porphyry-skarn mineralized zones (NW Turkey) using concentration–volume fractal model. Geochemistry 2021, 4, 125802.
25. Altunkaynak, Ş.; Genç, Ş.C. Petrogenesis and time-progressive evolution of the Cenozoic continental volcanism in the Biga Peninsula, NW Anatolia (Turkey). Lithos 2008, 102, 316–340.
26. Genç, Ş.; Altunkaynak, Ş. On the Eybek granite (Biga Peninsula, NW Anatolia): A new evaluation in the light of new geochemical data. J. Earth Sci. Appl. Res. Cent. Hacet. Univ. 2007, 28, 75–98.
27. Yılmaz, Y.; Karacık, Z. Geology of the northern side of the Gulf of Edremit and its tectonic significance for the development of the Aegean grabens. Geodin. Acta 2001, 14, 31–43.
28. Yigit, O. Mineral deposits of Turkey in relation to Tethyan metallogeny: Implications for future mineral exploration. Econ. Geol. 2009, 104, 19–51.