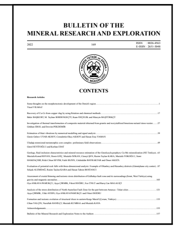
Bull. Min. Res. Exp. (2022) 169: 135-154

Bulletin of the Mineral Research and Exploration

http://bulletin.mta.gov.tr



Formation and tectonic evolution of structural slices in eastern Kargı Massif (Çorum, Türkiye)

Cihan YALÇIN[a*], Nurullah HANİLÇİ[b], Mustafa KUMRAL[c] and Mustafa KAYA[c]

[a]*Republic of Türkiye Ministry of Industry and Technology, General Directorate of Industrial Zones, Ankara, Türkiye*
[b]*İstanbul University-Cerrahpaşa, Department of Geological Engineering, İstanbul, Türkiye*
[c]*İstanbul Technical University, Department of Geological Engineering, Faculty of Mines, İstanbul, Türkiye*

Research Article

Keywords:
Central Pontides, Tectonic Slice, Accretionary Complex, Geodynamic, Kargı, Çorum.

Received Date: 02.07.2021
Accepted Date: 02.02.2022

ABSTRACT

The closure of Tethys Ocean has led to shaping the Central Pontides together with different types of rocks. In the east of Kargı (Gökçedoğan), which is located in the Central Pontides, allochthonous rocks of Late Palaeozoic- Early Cenozoic age and autochthonous units exist together, and allochthonous rocks present various tectono-stratigraphical sequences. Distinctive tectonic slices developed in the area as a consequence of the thrusting of the Permian carbonates from the north towards the south over the Middle Jurassic accretionary Complex (Kunduz Metamorphites) that form the basement of the area, and also because of the thrusting of the units of the Kirazbaşı Complex (ophiolitic melange) and Mesozoic carbonate rocks over this basement from the south towards the north because of the closure of Tethys Ocean. This paper presents whole-rock geochemical data, which suggest that the metabasites and the ophiolitic basalts are tholeiitic. The Jurassic metabasites from the Kunduz Unit and basalts from ophiolitic melange are characterized by the mid-ocean ridge basalt (MORB) and within plate tholeiites. This paper highlights the occurrence of the tectonic slices in the area is closely related to the tectonic evolution of the Tethys Ocean.

1. Introduction

The Pontides comprise an east-west trending mountain belt in the northern Türkiye and are accepted as a 1500 km long part of the Alpine-Himalayan belt by Ketin (1966). The Pontides separated from the edge of Southern Eurasia in Late Barremian or Aptian times, during the subsidence of the Black Sea Basin (Finetti et al., 1988; Görür, 1988; Robinson et al., 1996; Rice et al., 2006; Hippolyte et al., 2010; Nikishin et al., 2015). Later that sequence deformed by colliding with Kırşehir and Anatolide-Taurid microcontinents with the closure of branches of the Tethys Ocean (Şengör and Yılmaz, 1981; Şengör et al., 1982; Okay et al., 1994; Lefebvre et al., 2013).

The Pontide Belt is commonly classified as the western, the central, and the eastern Pontides (Okay et al., 1994), and is also divided into the İstanbul, the Istranca, and the Sakarya zones. Due to the closure of Paleotethys Ocean and Intra-Pontide Ocean, the suture zones formed in this belt (Okay et al., 2013).

The Central Pontides consist of metamorphic, magmatic, oceanic, and sedimentary rock groups, ranging in age from Late Paleozoic to Early Cenozoic

Citation Info: Yalçın, C., Hanilçi, N.,Kumral, M., Kaya, M. 2022. Formation and tectonic evolution of the tectonic slices in the eastern Kargı Massif (Çorum, Türkiye). Bulletin of the Mineral Research and Exploration 169, 135-154.
https://doi.org/10.19111/bulletinofmre.1067604

*Corresponding author: Cihan YALÇIN, cihan.yalcin@sanayi.gov.tr

(Robertson, 2002; Robertson and Ustaömer, 2004; Robertson et al., 2006; Okay et al., 2006, 2013; Okay and Nikishin, 2015; Aygül et al., 2015*b*, 2016).

Pre-Jurassic high pressure-low temperature (HP/LT) metamorphic rock units and younger ophiolitic rock units outcropping in the wide areas in the south of the Central Pontides are the products of the subduction-accretional complex which emerged with the closure of Tethys ocean (Okay et al., 2006, 2013; Marroni et al., 2014; Aygül et al., 2015*a*, 2015*b*, 2016; Çelik et al., 2016, 2018). This zone has been referred as being tectonic complexes and as metamorphic complexes (Domuzdağ, Kunduz, Çangaldağ, Saka, Middle Jurassic Accretionary Complex) by many researchers (Tüysüz, 1990; Ustaömer and Robertson, 1997; Yılmaz et al., 1997; Okay et al., 2006, 2013; Çelik et al., 2016; Altherr et al., 2020). These areas which include Middle Jurassic and Cretaceous Accretionary Complex are also named as Central Pontide Supercomplex (Figure 1a) (Okay et al., 2013; Marroni et al., 2014; Okay and Nikishin, 2015) or Central Pontide Structural Complex (CPSC) (Tekin et al., 2012; Çimen et al., 2016, 2017, 2018). The area has undergone metamorphism in greenschist facies in general with the emplacement of Tethyan ophiolites (Okay and Göncüoğlu, 2004). This change was reported to occur in the Albian stage under low pressure and temperature conditions (LP, LT) in consideration of the results obtained by finding the 107.0 ± 4.6 Ma – 114.1 ± 3.3 Ma age from the metamorphic rocks in greenschist facies (Okay et al., 2013).

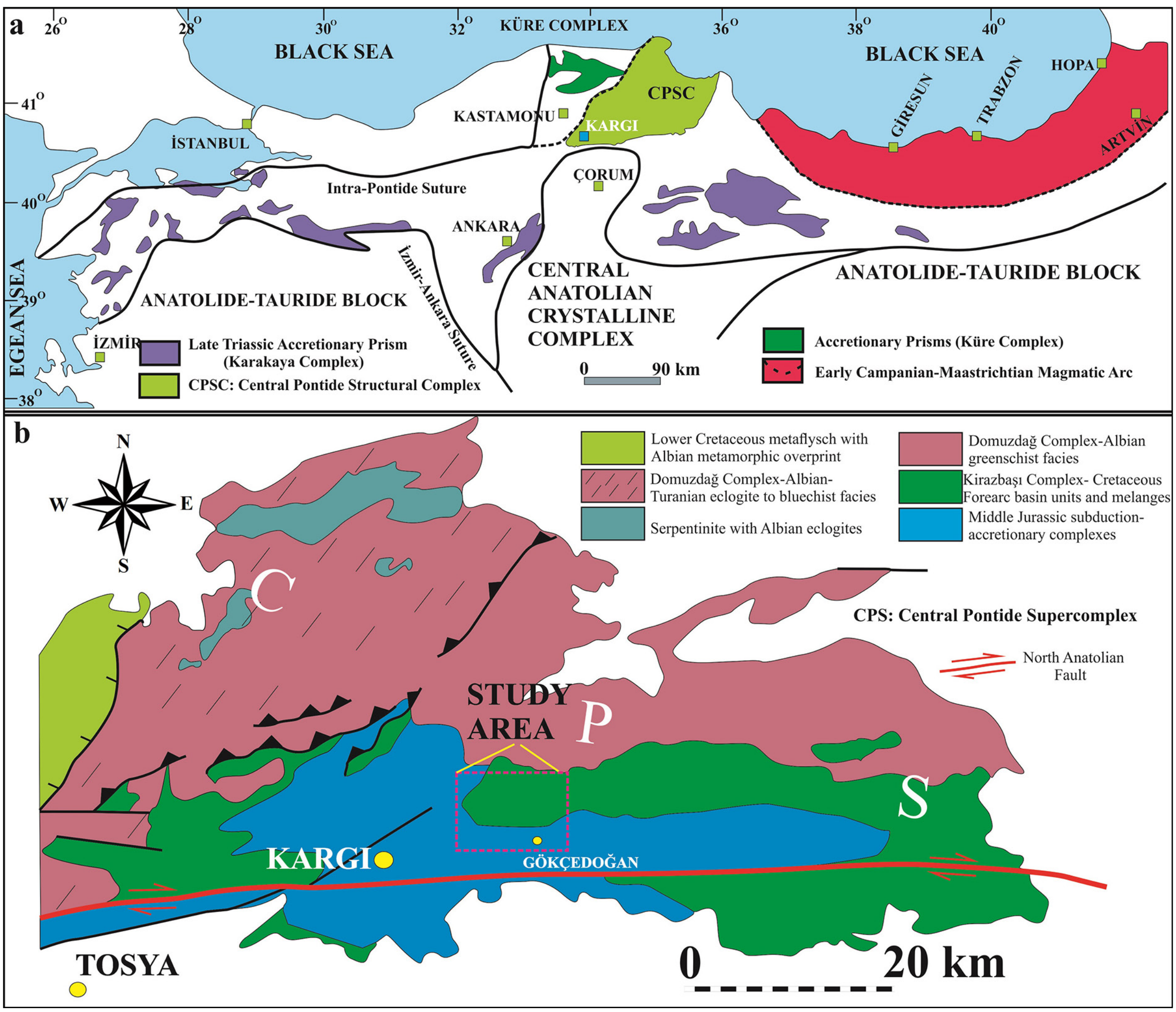


Figure 1- a) Position of the study area between Türkiye's structural zones (Göncüoğlu, 2010; Eyüboğlu et al., 2014; Çimen et al., 2017; Günay et al., 2018), and b) position of the study area in the Central Pontide Supercomplex (Tüysüz, 1990; Okay et al., 2013, 2014; Aygül et al., 2016).

After the age determination studies carried out in the before-mentioned supercomplex in recent years, 3 distinctive units are identified; 1: Middle Jurassic subduction/accretionary complex in the south part; 2: Kirazbaşı Complex formed by an ophiolitic melange and; 3: Domuzdağ Complex with varying metamorphism conditions towards the north have been identified in the eastern Kargı area (Figure 1b) (Aygül et al., 2016). Çelik et al. (2016) conducted an age determination of $^{40}Ar/^{39}Ar$ from the amphiboles of Jurassic metabasites in the Accretionary Complex and determined that the cooling age is in between 159.4 ± 0.4 Ma and 163.5 ± 0.8 Ma. Owing to the coexistence of allochthonous rocks and autochthonous units of Late Palaeozoic–Early Cenozoic age range in the area, there are various tectono-stratigraphical sequences in the east of Kargı (Gökçedoğan).

Uğuz and Sevin (2009) reported that the allochthonous rocks are formed by lower and upper tectonic slices in the area and that the metamorphic rocks (Bekirli Formation) are autochthonous. Some researchers argue that the metamorphic complexes identified in the Central Pontides have allochthonous nature (Ustaömer and Robertson, 1997, 1999; Okay et al., 2006, 2013; Çimen et al., 2016). Certain kinds of stratigraphic sequences have been formed in the study area together with the thrust of Palaeozoic and Mesozoic carbonate rocks over the units which belong to the Middle Jurassic accretionary Complex and the Kirazbaşı Complex (Okay et al., 2013). Geological mapping, new geochemical data, and isotopic age data in the Central Pontides in recent years have revealed different geodynamic models (Okay et al., 2014; Aygül et al., 2015*b*; Gücer et al., 2016; Çimen et al., 2016, 2017, 2018; Günay et al., 2018). For this reason, more detailed mapping studies should be done and associated with these regions. In addition, there are Cyprus type and Besshi type massive sulphide mineralizations associated with mafic tholeiitic volcanism, metavolcaniclastics, and metaclastics also there are arc-back arc geochemical signatures in the Central Pontides (Çakır, 1995; Altun et al., 2015; Çimen et al., 2016; Akbulut et al., 2016; Günay et al., 2018, 2019; Yalçın, 2018).

This study describes for the first time the tectonic slices formed by Gökçedoğan and adjacent lithostratigraphic units, a detailed geology map, and a structural element map with a scale of 1/25.000. The main objective of this paper is to exhibit the relationship of the rocks in the field. Then we model their tectonic evolution with the help of geochemical analysis of basalts in different ages within the detailed geological information.

2. Geology

The Küre volcanogenic massive sulphide (VMS) Cu deposit (Kastamonu), established in the Central Pontides is held in the Cyprus type (Ustaömer and Robertson, 1997; Çakır, 1995; Altun et al., 2015; Akbulut et al., 2016) or Besshi type (Koç et al., 1995). Another VMS deposit is located 54 km north of the study area was observed within the metamorphic rocks in the Çangaldağ complex (Dönmez et al., 2013; Günay et al., 2018). Yalçın (2018) identified that stratiform type Cu-Zn mineralization occurred in metamorphic rocks on Gökçedoğan (Kargı-Çorum) and explained the formation of the ore. Geological informations declared that the mineralization is metamorphosed VMS deposit and is complementary to the Besshi-type Cu-Zn deposits (Yalçın, 2018). Günay et al. (2019) identified Zeybek VMS deposit in the Central Pontides near the study area. Detailed geological maps and supporting geochemical data will constantly be required, as the relevant VMS deposits in this province are recognized.

Various types of Paleozoic, Cenozoic and Quaternary rock groups showing structural and stratigraphic contacts are present in the study area (Figure 2). Different tectono-stratigraphic sequences have occurred in the region where carbonate rocks are thrusted not only to units belonging to the ophiolitic mélange (Figure 3a, b) but also to the Kunduz Metamorphics of the ophiolitic mélange (Figure 3c, d).

2.1. Allochthonous Units

Allochthonous rock groups are extensively observed in the study area and are represented by the Kunduz metamorphites and the ophiolitic melange. All these rocks are covered by the Permian and Jurassic-Cretaceous carbonate rocks. Allochthonous rocks overlained by autochthonous units.

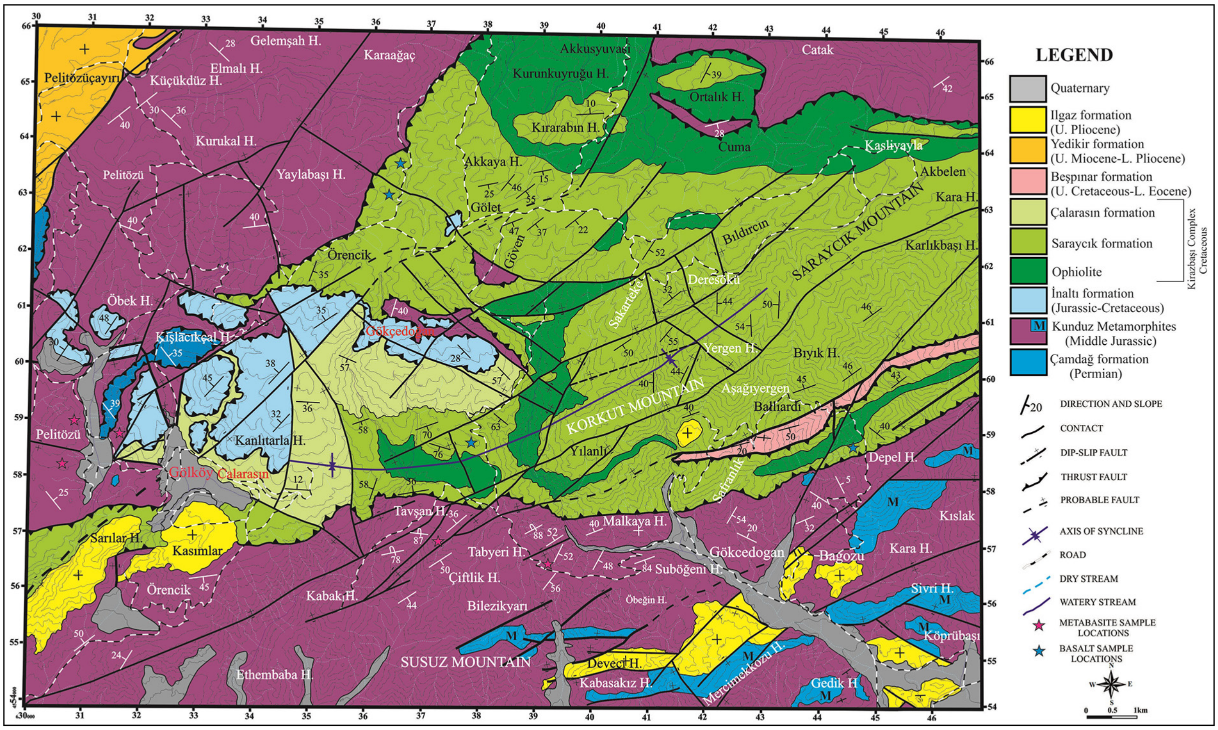


Figure 2- Geology map of the study area.

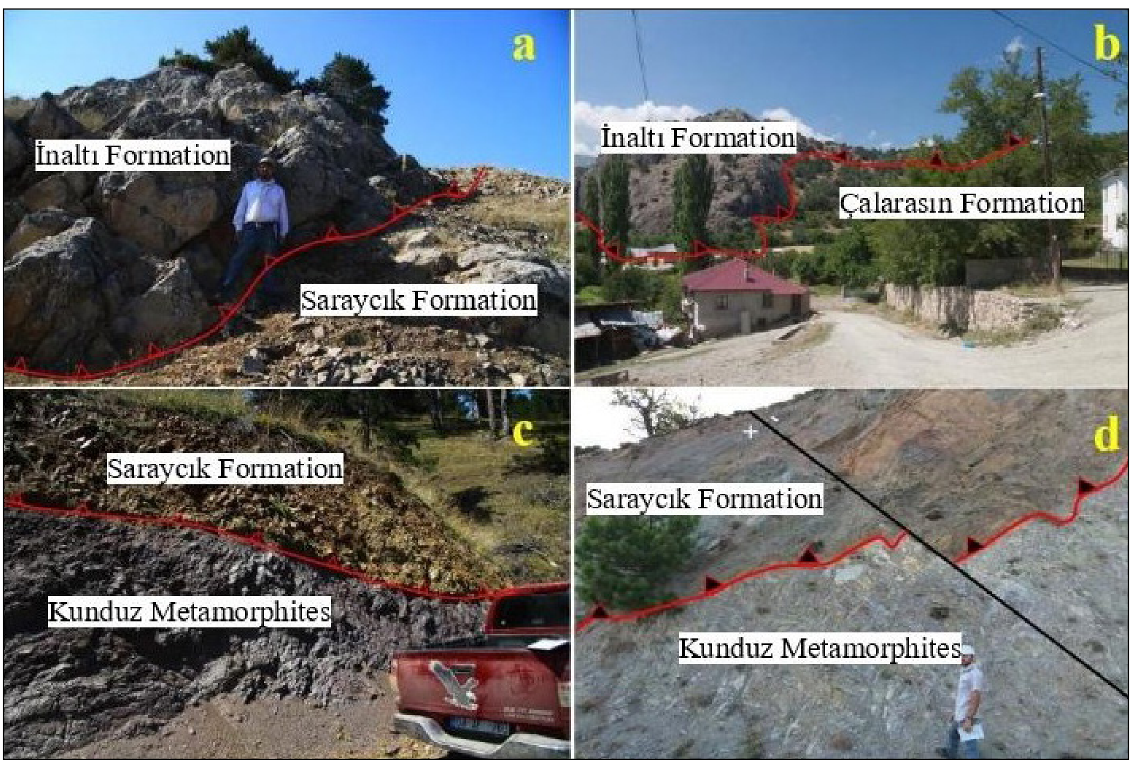


Figure 3- Observed thrusts in the study area; a) carbonate rocks belonging to the İnaltı Formation thrusting onto the Saraycık Formation west of Gölet, looking northwest from the southeast, b) thrusting of carbonate rocks belonging to the İnaltı Formation to the Çalarasın Formation in the neighborhood of Çalarasın and around Gölköy, looking northwest from the southeast, c) thrusting of Saraycık Formation to Kunduz metamorphites in the northeast of Gökçedoğan plateau, looking northwards from the south, and d) thrusting of Saraycık Formation to Kunduz metamorphites southeast of Kasımlar, looking northwards from the south).

2.1.1. Kunduz Metamorphites

Kunduz Metamorphites which form the basement of the area and is composed of metamorphic rocks (Tüysüz, 1990) expands over a large part of the study area (Figure 2). It is composed mainly of mica-rich metasandstone, quartzite, phyllite, metabasite, mica schist, gneiss, marble blocks, amphibole schist and metachert, (Yılmaz and Tüysüz, 1984). Middle Jurassic age has been determined for this unit located in the accretionary complex belonging to the Central Pontide Supercomplex (Marroni et al., 2014; Okay et al., 2013; Okay and Nikishin, 2015) and this unit can be corelated with Bekirli Formation described by Yılmaz and Tüysüz (1984). Martin Complex, which is showing geological features similar to Kunduz Metamorphites, consists of an interlayers of metabasite and chert, which is composed of similar lithologies and possibly deposited in an oceanic environment (Okay et al., 2013).

This unit is overlain by Middle Eocene Beşpınar Formation with angular unconformity near the study area (Uğuz and Sevin, 2009) and by ophiolitic melange, Jurassic-Cretaceous İnaltı Formation, and Permian Çamdağ Formation with a tectonic contact (Figure 2).

2.1.2. Ophiolitic Melange (Kirazbaşı Complex)

Ophiolitic Melange which belongs to the Kirazbaşı Complex (Tüysüz, 1990; Rice et al., 2006; Aygül et al., 2016) is composed of Kargı Ophiolite, Saraycık and Çalarasın Formation. Kargı Ophiolite consists of dunite, serpentinite, spilitic lava on gabbro (Yılmaz ve Tüysüz, 1984; Uğuz and Sevin, 2009), Saraycık Formation consists of metadiabase, metabasalt, radiolarite, chert, mudstone and pelagic limestones (Yılmaz and Tüysüz, 1984; Okay et al., 2006; Rice et al., 2006) and Çalarasın Formation consists of thin bedded, siltstone intercalated with sandstone-shale and mudstone alternation (Yılmaz and Tüysüz, 1984) respectively. The contact relations between these units are tectonic in some areas and generally lateral-vertical transition. On the other hand, the ophiolite and ophiolitic melange units in the accretionary complexes in the Central Pontides are also defined as the Kızılırmak Ophiolite or the Kirazbaşı Complex (Tüysüz, 1990; Yılmaz et al., 1997; Ustaömer and Robertson, 1997; Tüysüz and Tekin, 2007).

Yılmaz and Tüysüz (1984) stated that the fossils in the carbonate rocks within the mélange are of Upper Cretaceous age. The ophiolitic melange is tectonically overlain by Paleozoic metamorphosed carbonates and Mesozoic carbonate rocks and this unit overlies Kunduz metamorphites and Beşpınar Formation with a tectonic contact (Figure 2).

2.1.3. İnaltı Formation

İnaltı Formation is composed of fossiliferous limestones and recrystallized limestones which was named as İnaltı limestone for the first time by Ketin and Gümüş (1963) is observed in the study area around Gölköy, Gökçedoğan plateau, Öbek hill, Gölet plateau, in the north of Çalarasın neighbourhood and around Kanlıtarla Hill (Figure 2). The age of the unit which has a massive appearance and contains plenty of fossil was determined as Jurassic-Cretaceous by Sütçü et al. (1994), as Late Jurassic by Aydın et al. (1995) and as Late Jurassic-Early Cretaceous by Derman and Sayılı (1995) and Tüysüz (1999). Contact relations of the Formation are primarily tectonic and the unit thrusts over ophiolitic melange and Kunduz Metamorphites with tectonic contact. Since its relationship with Permian aged recrystallized limestones is not observed in the study area, the base contact relationship has not been determined.

2.1.4. Çamdağ Formation

The Permian Çamdağ Formation consists mainly of neritic limestone and recrystalised limestone (Özgül et al., 1981; Uğuz and Sevin, 2009). Its main outcrops lie in Kışlacıkçal hill, in the north of Pelitözü neighbourhood and in the west of Kozulca (Figure 2). The age of the sequence which is also seen in marble levels due to metamorphism is Permian (Uğuz and Sevin, 2009). Contact relations of the unit are primarily tectonic. Since the base levels of Permian aged carbonates could not be traced, the base contact relationship could not be determined in the study area. The unit thrusts over Kunduz Metamorphites in the north of Pelitözü and in the west of Pelitözü plateau with tectonic contact (Figure 2).

2.2. Autochthonous Units

The autochthonous units overlie the units older than themselves with angular unconformity. They are Beşpınar Formation, Yedikır Formation, Ilgaz Formation and Quaternary clastics.

The Beşpınar Formation consists mainly of sandstone, conglomerate, limestone and marl (Yılmaz and Tüysüz, 1984), and observed along the NE-SW direction starting from the northern Safranlık ridge to the Tiridinkıran hill in the study area (Figure 2). The unit is tectonically overlain by the allochthonous Saraycık Formation to the north of the Safranlık ridge. The age of the unit was determined as Upper Cretaceous-Lower Eocene (Yılmaz and Tüysüz, 1984) and this unit can be corelated Kadıkızı Formation described by Rice et al. (2006) whose age is Middle Eocene by the age of the nummulites.

The Yedikır Formation, consisting of sandstone, marl, and limestone, was named by Gümüşsu (1980). It is observed to the NW of the study area and overlies the Kunduz metamorphites and the Çamdağ Formation with the angular unconformity. The age of the unit has been determined as Upper Miocene-Lower Pliocene by Genç et al. (1991).

The Upper Pliocene Ilgaz Formation consists of sandstones, conglomerates, and siltstones (Hakyemez et al., 1986; Türkecan et al., 1991). This unit unconformably overlies ophiolitic melange rocks and the Kunduz Metamorphites in the south of the field area.

Slope debris and alluvium are composed of unconsolidated mixtures of gravel, block, sand, silt, and clay.

2.3. Tectono-stratigraphy

Allochthonous units, which are made up of rock associations representing various geotectonic environments, present various stratigraphic sequences in accordance with their structural locations (Figure 4). These sequences have been identified as three different tectonic slices: Gölköy Tectonic Slice (GTS), Pelitözü Tectonic Slice (PTS), and Ophiolitic Melange Slice (OMS) (Figure 5). The metamorphic basement rocks located in accretionary complexes in the Central Pontides is tectonically overlain by ophiolite and ophiolitic melange units (Yiğitbaş et al., 1990; Okay et al., 2006; Tüysüz and Tekin, 2007; Tüysüz, 2017). In addition, Paleozoic and Mesozoic carbonate rocks thrusts over the Kunduz Metamorphites and Ophiolitic Melange in the study area. These imbrication structures led to different tectono-stratigraphic sequences.

The GTS is represented by the tectonic contacts of Kunduz Metamorphites, the Ophiolitic Melange, and the İnaltı Formation (Figure 6). The PTS has

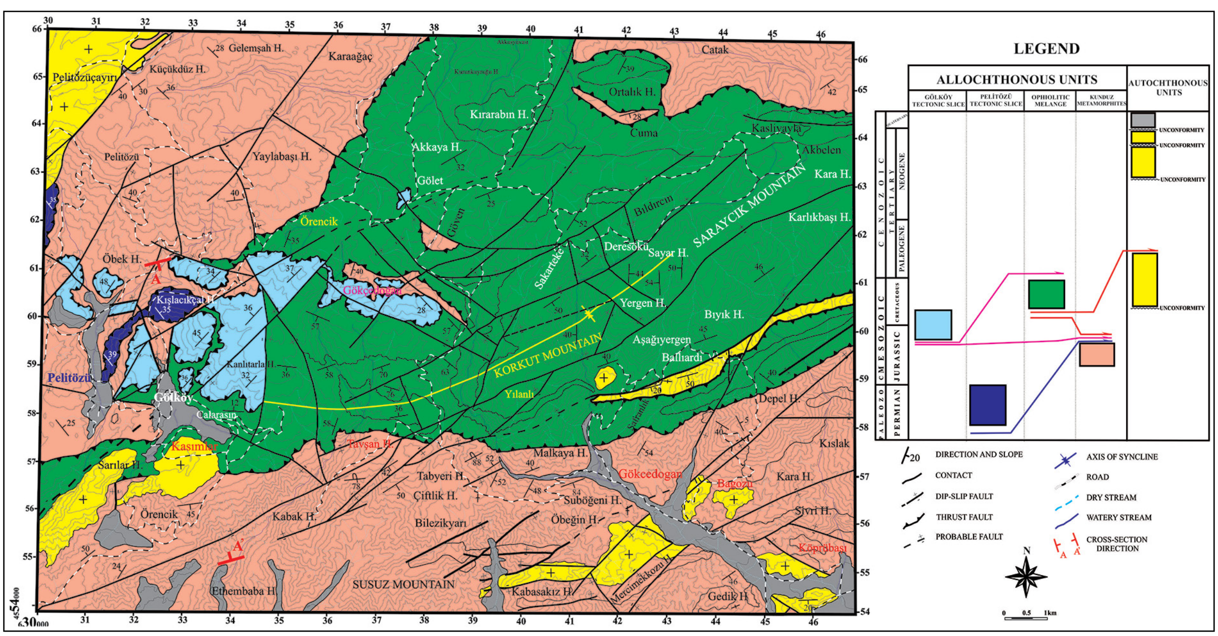


Figure 4- Structural map of the study area.

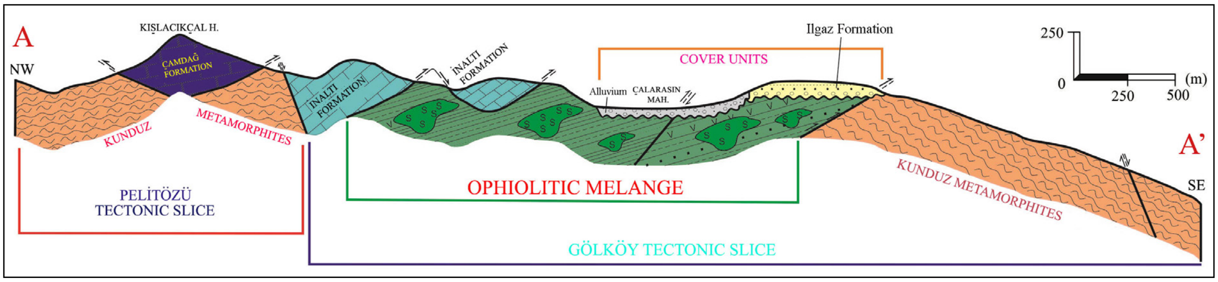


Figure 5- Cross-section through the study area.

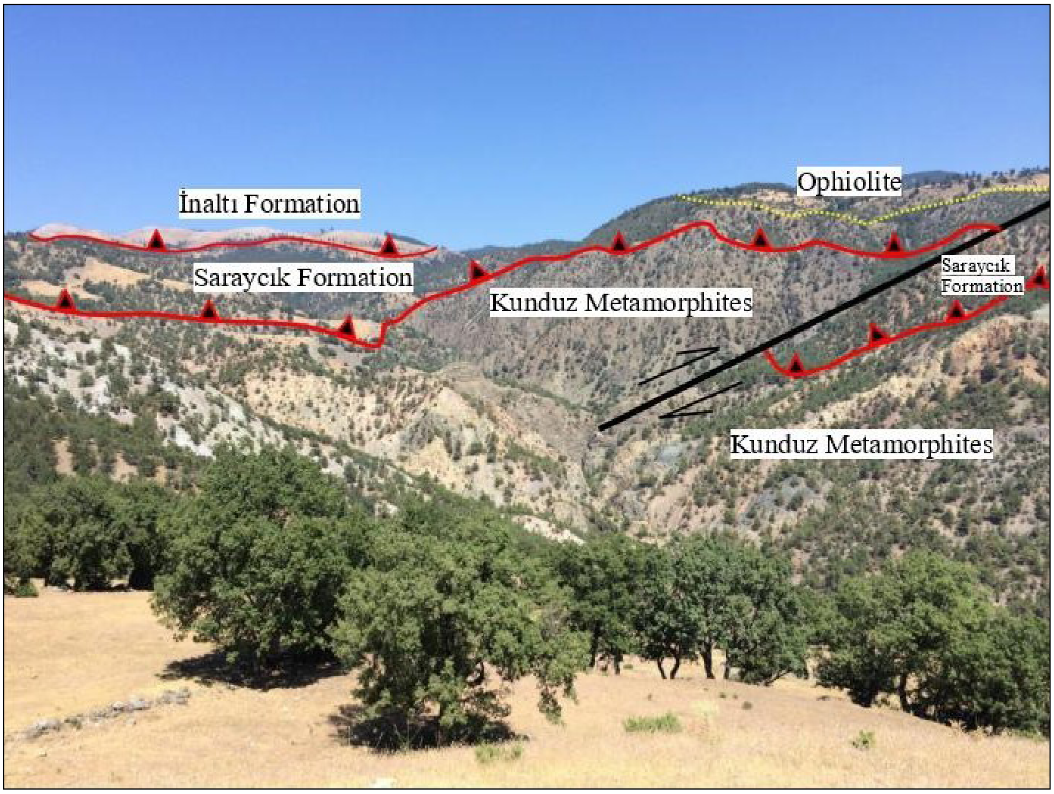


Figure 6- General view of the units forming the Gölköy tectonic slice in the field (looking northwards from Malkaya Hill).

been formed by Çamdag Formation and Kunduz Metamorphites (Figure 7) and the OMS has been formed by Ophiolitic Melange, Beşpınar Formation, and Kunduz Metamorphites (Figure 8) via tectonic contacts.

3. Sampling and Analytical Methods

In the study area, 9 metabasites from Kunduz Metamorphics and 14 basalt samples from ophiolitic melange were collected due to the presence of basalts of different origin in the study area. X-ray Fluorescence (XRF) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) analyses of the samples were performed at Istanbul Technical University Geochemistry Research Laboratory (ITU-JAL).

Geochemical analysis of the samples was performed via BRUKER S8 TIGER model X-ray fluorescence spectrometer (XRF) and PerkinElmer ELAN 6000 DRC-e model Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). Before the ICP-MS analysis, milled samples were completely decomposed in an acid mixture on BERGHOF speed wave TM MWS-3+ model microwave device. Also, to validation of XRF, microwave digestion, and ICP-

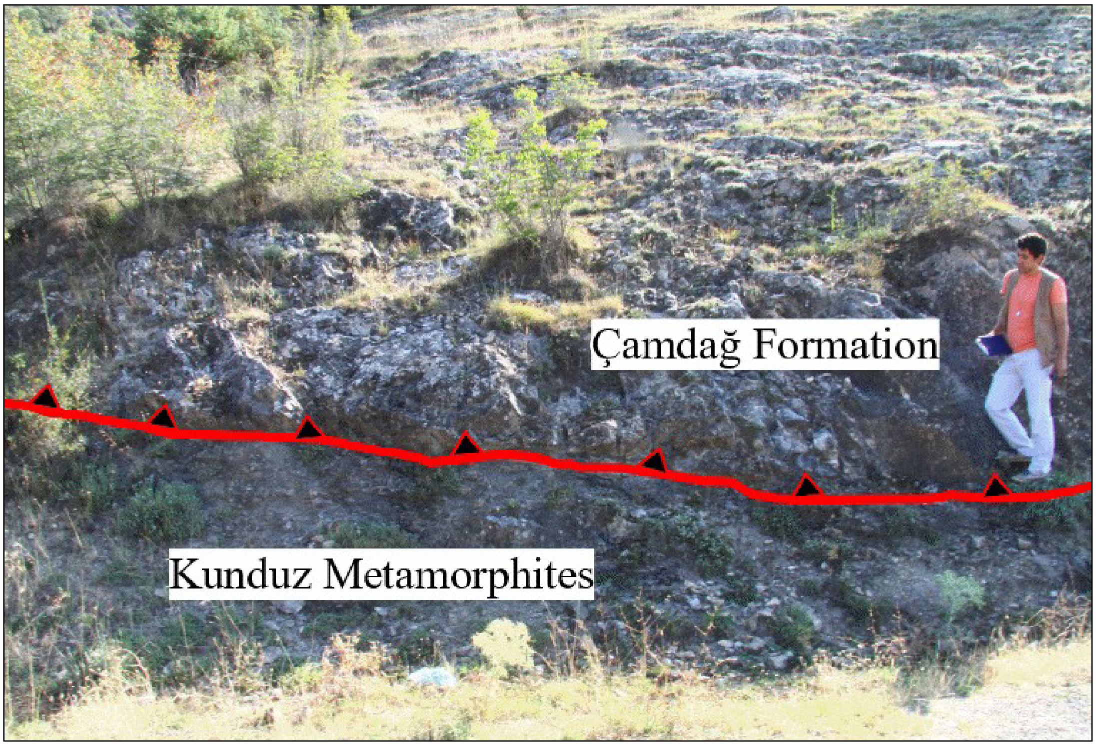


Figure 7- General view of the units forming the Pelitözü tectonic slice (looking eastward from the west at southern of Kışlacıkçal Hill).

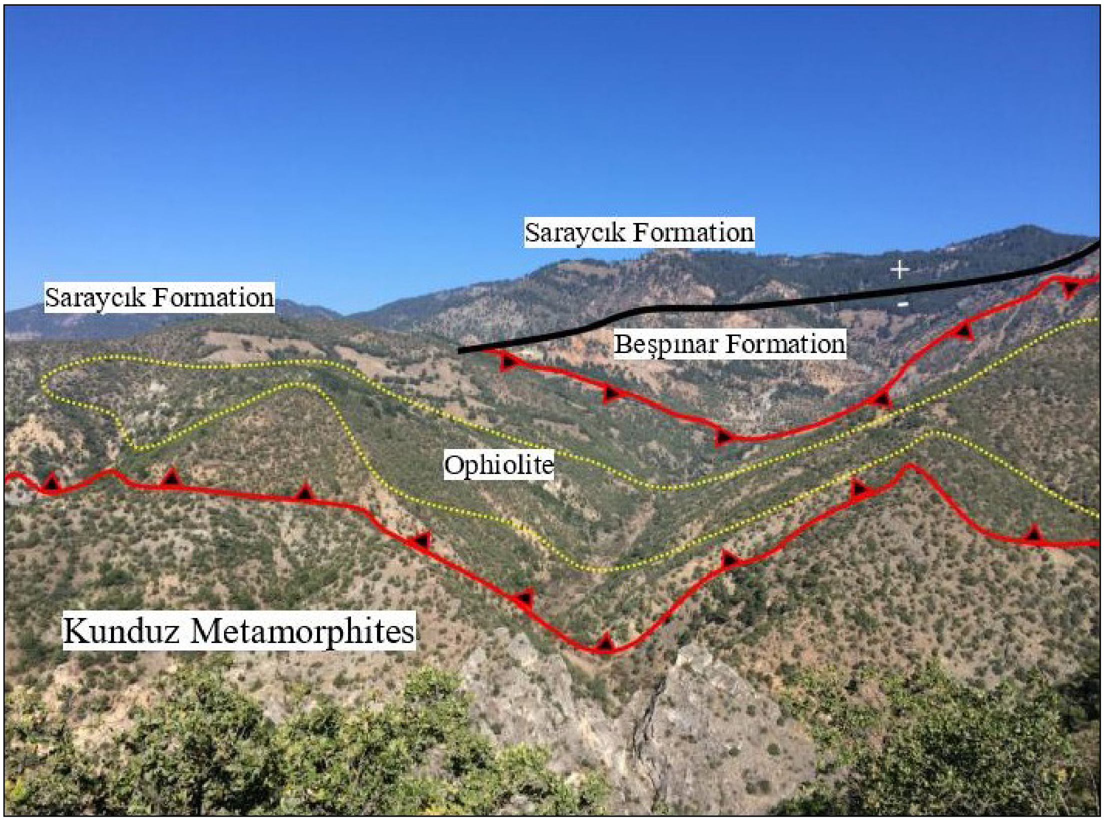


Figure 8- General view of the tectonic slice formed by Ophiolitic Melange (looking northwards from the south at southern of Safranlık Hill).

MS methods the certified reference material (CRM) was used.

The reagents were all of the certified analytical-grade purity. Pure water was obtained with Zeneer UP 900 model water purification system. The maximum resistivity of pure water was 18.3 $M_{\Omega cm}$. Hydrochloric acid (HCL) 37% (w/v), nitric acid (HNO_3) 65%, (w/v), hydrofluoric acid (HF) 38-40% (w/v) and boric acid (H_3BO_3) were supplied by Merck. The mix standard solution of 10 mg/l of yttrium (Y), thorium (Th), lanthanum (La), samarium (Sm), and ytterbium (Yb,) and as 225 an internal standard, 1000 mg/l of rhenium (Re) solution were supplied by PerkinElmer. The CRM is (GSP-2) from the United States Geological Survey (USGS).

Samples were crushed by a jaw crusher. The material was then dried in an oven at 105 ºC for 24 hours. After the drying process, the grain sizes of 10-15 g samples were reduced to 177 µm by using RETSCH (RS-200) model milling device. The milling process was carried out for 1-2 min at 1250 rpm. All dried and powdered samples were stored in a desiccator to protect them from humidity.

XRF analysis was used to determine major oxides and niobium (Nb), zirconium (Zr). The milled samples were pressed, pelleted then analyzed to determine major and some of trace elements concentration by using XRF (Detection limits for S8 TIGER XRF; Y-Th: 0.3 ppm).

Microwave digestion process was effectuated in two steps. The microwave digestion steps were performed with the described program (power 90%, temperature 180 ºC, pressure 20-30 bar, ramp time 10 minutes, hold time 20-25 minutes). In the first step which all samples were decomposed; approximately 100-200 mg of milled sample was weighed to high-pressure digestion on teflon vessel. Then, 8 ml of aqua regia (3:1, HCl: HNO_3) and 1 ml of HF were added to each vessel. Subsequently, the vessels were closed tightly and placed in the microwave device. When the first step finished, the vessels were cooled and carefully opened at the fume hood. In the second step, the excess of HF was removed to prevent damage to glass and quartz parts of ICP-MS equipment. For this purpose, 6 ml of H_3BO_3 5% (w/v) solution was added to each vessel. Then, the vessels were closed tightly and placed in the microwave. The damaging effect of HF has been eliminated after the occurrence of the following reaction (Equations 1 and 2) ;

$$H_3BO_3 + 3HF \rightarrow HBF_3(OH) + 2H_2O \quad (1)$$

$$HBF_3(OH) + HF \rightarrow HBF_4 + H_2O \quad (2)$$

After the second step finished, the vessels were cooled and carefully opened. Each digested sample was transferred by washing pure water to a 50 mL volumetric flask. Thus, solutions of samples were obtained. By the same digestion method, the same acid mixture was added to the empty vessel to prepare the blank solution for ICP-MS analysis.

ICP-MS analysis was used to determine Y, Th, La, Sm, and Yb. As an internal standard, 50 µg/l of Re solution was added to the sample solutions which were obtained by microwave digestion. The calibration standards were prepared from the stock mix solutions. The calibration points of graphs were 5, 10, 50 and 100 µg/l. Calibration graphs were linear and the square of the correlation coefficient (R^2) was at least 0,999 for each element. Solutions of standards, sample, and CRM were diluted and they were analyzed three times. Relative standard deviation (RSD) % values were kept below 5% throughout the analysis. Also, after all three samples, contamination was checked by analyzing the blank solution (Detection Limits for ELAN DRC-e ICP-MS; Y-Th-La-Sm-Yb: 0.0005 ppb).

4. Petrography

Metabasites crop out in and around Pelitözü and west of Gökçedoğan districts. Although the weathered surface of metabasites is gray, greenish-gray and dark green, the freshly fractured surface is green, greenish-white, and gray (Figure 9a, b). The metabasites around Pelitözü are thickly bedded (Figure 9a), while the metabasites west of Gökçedoğan are thinly bedded (Figure 9b). The metabasites of western Gökçedoğan are still extremely well foliated correlated to the metabasites around Pelitözü (Figure 9b). Banded pyrite levels are farther prevalent in this zone and limonitic zones are still observed depending on the mineralization.

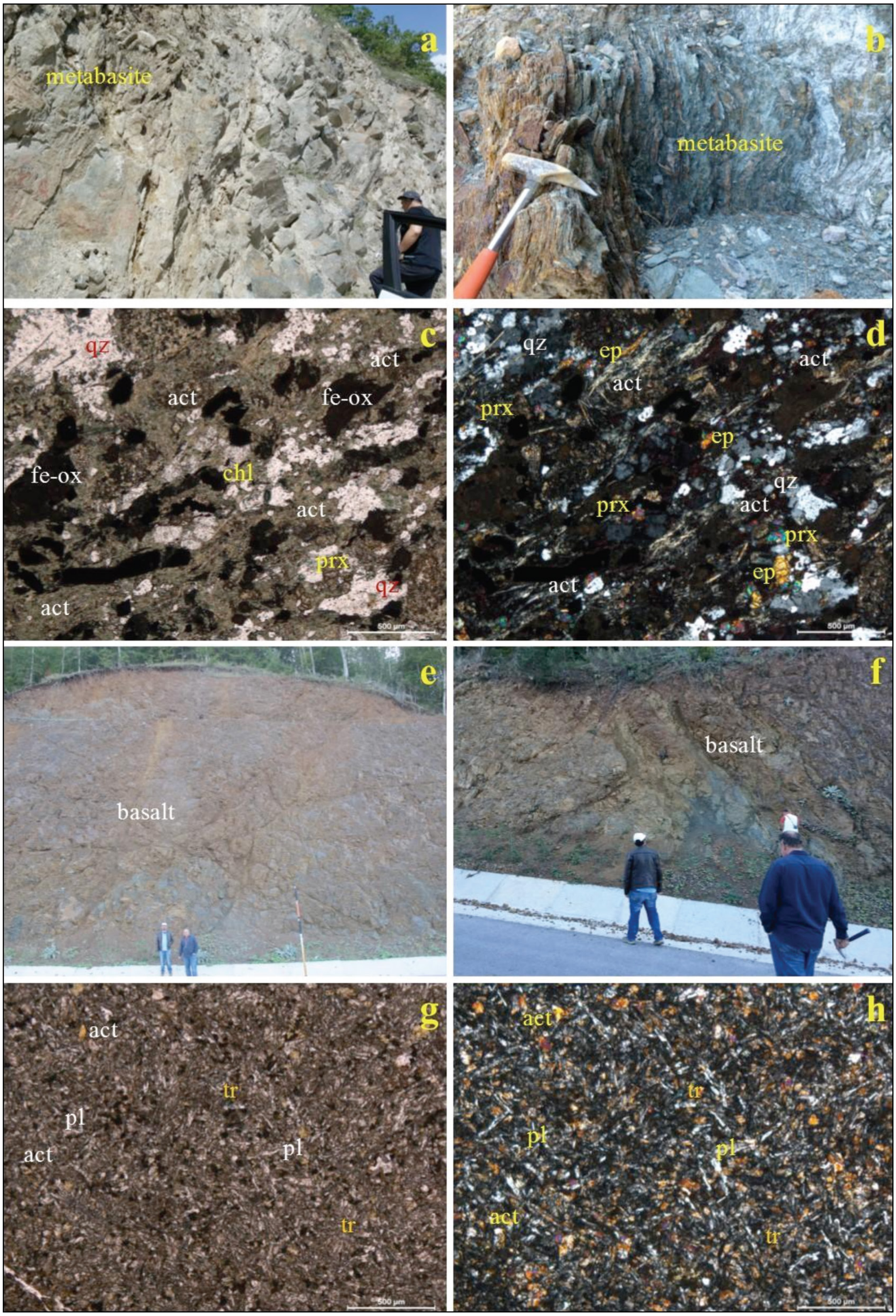


Figure 9- a), b) Field view of metabasites belonging to the Kunduz metamorphites, c), d) polarizing microscope images of metabasites belonging to the Kunduz metamorphites, e), f) field view of basalts belonging to the Ophiolitic Melange, g), h) polarizing microscope images of basalts belonging to the Ophiolitic Melange, Abbreviations: (act) actinolite, (Fe-ox) iron oxide, (prx) pyroxene, (chl) chlorite, (ep) epidote, (qz) quartz, (pl) plagioclase, (tr) tremolite.

In the petrographic study of the metabasites in the Kunduz metamorphics, it was seen that the major mineral was actinolite. In supplement, pyroxene, quartz, muscovite, epidote minerals, and Fe-oxide are still staged in the rock (Figure 9c, d). Actinolite minerals were oriented by the deformation effect and nematoblastic and fibroblastic textures developed in the rock. In general, as a result of the alternation of quartz and actinolite, it was ascertained that the grano-nematoblastic texture was predominant in the rock (Figure 9c, d).

The weathering color of the pillow basalts outcropping around the Devebağırdığı creek is gray and brown. Basalts show a relatively thick sequence in this district. Since it is in the zone adjacent to the thrust zone, crushed zones have developed within the unit (Figure 9d, e).

In the petrographic examination of basalts applying to the ophiolitic melange, mineral paragenesis consists of plagioclase, tremolite, actinolite, and volcanic glass. The main texture in basalts is in the form of pilotaxitic character (Figure 9g, 9h).

5. Whole Rock Geochemistry

In order to reveal the origins and geotectonic positions of the rocks major, trace and rare earth element analysis of the data obtained from metabasite of the Kunduz Metamorphites (Table 1, 2, 3) and from the basalt belonging to ophiolitic melange (Table 4, 5, 6) was carried out and presented in diagrams.

In the Zr/Ti versus Nb/Y diagram (Pearce, 1996) metabasite and basalt samples plot in the basalt area (Figure 10). Protoliths of the Kunduz metamorphites and basalts from the ophiolitic melange exhibit the tholeiitic character in Nb/Yb versus TiO_2/Yb diagram (Pearce, 2008) (Figure 11). The TiO_2/Yb and Nb/Yb ratios of metabasites are greater than basalts. Metabasites represent deep melting in the ocean island basalt (OIB) area. Basalts of the ophiolitic melange are settled in the normal mid-ocean ridge basalt (NMORB) area in this diagram and display shallow melting (Figure 11).

Chondrite normalized trace element trends display enrichment in the Light Rare Earth Elements (LREE's e.g., La, Ce, Nd) for metabasites of the Kunduz Metamorphites relative to basalts belonging to the Ophiolitic mélange. The Heavy Rare Earth Elements (HREE's e.g., Er, Tm, Yb, Lu) exhibits almost flat trends for each unit (Figure 12).

The metabasites of Kunduz Formation and the basalts of ophiolitic melange display with MORB

Table 1- Major oxide analysis results of the metabasites belonging to the Kunduz Metamorphites.

Sample	K2-13	K2-28	KGD-303	KGD-336	KGD-565	KGD-567	KGD-622	KGD-626	KGD-627
Latitude (^{0}N)	36.800	39.420	39.430	39.374	42.551	42.655	30.987	36.003	36.003
Longitude (^{0}E)	56.816	56.728	56.910	56.885	57.016	57.029	58.800	63.818	63.815
Major Oxides (%)									
SiO_2	41.16	44.49	44.18	47.59	46.59	39.34	42.63	45.12	46.64
Al_2O_3	11.06	12.07	11.62	10.59	13.58	12.72	12.46	13.01	11.07
Fe_2O_3	14.32	13.93	14.61	13.24	15.50	14.36	15.06	14.89	12.82
MgO	9.94	9.21	9.18	10.52	11.41	10.74	10.77	9.61	8.97
CaO	10.19	10.86	11.87	10.66	10.50	9.80	9.66	7.84	10.08
Na_2O	2.86	2.74	2.46	2.72	1.34	2.58	2.67	2.58	2.21
K_2O	0.29	0.08	0.05	0.07	0.23	0.48	0.08	0.40	0.32
TiO_2	1.67	1.64	1.32	1.94	4.56	3.52	2.18	2.92	3.69
P_2O_5	0.19	0.14	0.15	0.05	0.45	0.75	0.25	0.36	0.39
MnO	0.21	0.21	0.22	0.23	0.30	0.29	0.21	0.23	0.28
Cr_2O_3	0.41	0.03	0.05	0.00	0.21	0.00	0.03	0.00	0.00
LOI	7.51	3.48	3.24	3.07	3.90	5.08	3.78	2.66	1.96
TOTAL	99.8	98.88	99.68	99.68	99.57	99.67	99.78	99.62	99.56

Table 2- Trace element analysis results of the metabasites belonging to the Kunduz Metamorphites.

Trace Elements (ppm)	K2-13	K2-28	KGD-303	KGD-336	KGD-565	KGD-567	KGD-622	KGD-626	KGD-627
Sc	98.35	81.05	141.79	97.10	140.68	107.22	79.32	80.91	52.30
Y	27.47	25.01	23.38	23.16	22.48	27.82	23.80	23.05	23.24
Th	0.57	0.49	0.45	0.10	1.42	1.75	0.64	0.56	0.17
Li	19.06	12.05	12.47	9.91	15.45	13.43	42.84	13.85	1.75
Be	0.80	0.90	0.90	0.24	1.30	1.04	0.55	1.02	0.61
Ga	16.27	16.34	14.01	11.98	17.39	17.91	16.20	14.16	1.84
V	374.00	356.00	6188.00	509.00	781.00	6365.00	0.00	0.00	651.00
As	73.00	63.72	34.82	17.96	42.10	45.01	23.21	7.54	48.72
Se	7.59	6.33	0.00	0.61	25.28	5.49	2.00	0.00	0.00
Rb	4.92	1.57	0.19	0.58	2.95	4.79	0.94	4.48	1.13
Ag	0.41	0.34	1.01	0.53	0.00	0.00	0.11	0.40	0.52
Cd	1.20	2.36	0.86	0.13	0.17	0.04	0.10	0.05	0.29
In	0.08	0.08	0.07	0.04	0.07	0.04	0.05	0.11	0.00
Cs	0.60	0.09	0.00	0.10	0.11	0.76	0.08	0.80	0.49
Nb	6	7	6	3	8	7	6	6	7
Tl	0.03	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zr	82	86	80	74	106	131	140	158	156
Ti	10009	9830	7912	11628	27332	21098	13066	17502	22117
Hf	1.14	1.13	0.90	0.79	1.83	1.68	0.36	6.81	0.00
Ir	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.02	0.00
Sb	0.54	0.95	0.94	0.45	0.55	3.58	0.65	5.99	0.21
Sn	1.25	1.05	0.84	0.59	1.98	0.90	2.30	2.73	0.53
Te	0.06	0.07	0.10	0.08	0.05	0.06	0.07	0.09	0.08
Ta	0.40	0.44	0.50	0.39	0.41	0.56	0.38	0.49	0.50
Nb/Y	0.21	0.27	0.25	0.12	0.35	0.25	0.25	0.25	0.30
Zr/Ti	0.008	0.008	0.010	0.006	0.003	0.006	0.010	0.090	0.007
Nb/Yb	6.02	7.20	5.92	3.07	3.29	3.79	4.57	3.05	3.74
TiO_2/Yb	1.67	1.68	1.30	1.98	1.87	1.90	1.66	1.48	1.97

Table 3- Rare earth element analysis results of the metabasites belonging to the Kunduz Metamorphites.

REE (ppm)	K2-13	K2-28	KGD-303	KGD-336	KGD-565	KGD-567	KGD-622	KGD-626	KGD-627
La	6.62	6.26	5.64	9.45	17.95	22.56	7.07	9.85	6.05
Ce	17.08	15.57	14.16	14.70	39.86	49.64	17.10	24.75	12.10
Pr	2.33	2.10	2.05	2.95	5.14	6.47	3.52	5.80	2.01
Nd	11.59	10.62	9.96	9.09	23.09	29.30	15.20	25.55	10.03
Sm	3.41	3.20	2.95	2.15	5.52	6.82	5.34	9.28	6.01
Eu	1.17	1.19	1.10	0.88	2.02	2.59	1.95	3.31	1.01
Gd	4.87	4.63	4.34	3.36	6.83	8.47	7.49	12.85	3.01
Tb	0.78	0.75	0.67	0.70	0.88	1.06	1.58	2.62	1.00
Dy	5.17	4.82	4.22	4.45	4.85	5.85	8.60	14.13	4.02
Ho	1.06	0.99	0.87	1.07	0.88	1.08	2.13	3.53	1.01
Er	3.05	2.84	2.45	2.94	2.39	2.88	5.44	8.83	3.02
Tm	0.41	0.38	0.33	0.48	0.29	0.34	0.92	1.48	0.61
Yb	0.99	0.97	1.01	0.98	2.43	1.85	1.31	1.97	1.87
Lu	0.33	0.30	0.29	0.43	0.23	0.25	0.84	1.39	0.31

Table 4- Major oxide analysis results of the basalts belonging to ophiolitic melanges.

Sample	K2-37	K2-38	K3-39	K2-43	K2-44	K2-45	K2-46	K2-47	KGD-625	KGD-629	KGD-913A	KGD-913B	KGD-913C	KGD-914
Latitude (^{0}N)	36.471	36.471	36.471	36.457	36.457	36.457	36.457	36.457	36.601	36.617	36.581	36.581	36.581	36.640
Longitude (^{0}E)	63.186	63.186	63.186	63.122	63.122	63.122	63.122	63.122	63.810	63.791	63.845	63.845	63.845	63.726
Major Oxides (%)														
SiO_2	41.55	40.67	40.68	42.20	44.37	45.01	44.80	46.22	43.52	46.78	43.18	44.11	45.11	44.19
Al_2O_3	11.66	11.99	10.10	10.31	10.92	10.85	10.41	11.97	10.91	10.31	10.10	10.22	10.30	13.03
Fe_2O_3	17.54	21.20	18.01	17.37	16.92	17.21	12.68	16.98	18.52	20.14	18.38	19.20	18.04	16.11
MgO	5.06	5.99	4.40	5.94	6.50	8.05	7.02	7.41	5.69	5.66	7.90	6.79	6.67	8.50
CaO	12.39	8.72	14.19	9.70	10.52	10.27	12.75	12.00	10.45	6.61	9.71	8.28	8.55	10.38
Na_2O	2.27	2.19	2.78	2.72	2.84	2.21	3.42	3.65	2.66	2.83	3.16	3.22	3.71	3.31
K_2O	1.44	0.94	0.04	0.31	0.44	0.57	0.14	0.07	0.07	0.15	0.15	0.14	0.14	0.09
TiO_2	3.07	3.28	2.86	1.17	1.01	1.24	1.47	1.94	3.70	3.37	3.65	3.70	3.59	3.33
P_2O_5	0.26	0.29	0.21	0.10	0.10	0.17	0.19	0.09	0.39	0.35	0.43	0.44	0.41	0.17
MnO	0.21	0.20	0.21	0.19	0.15	0.29	0.13	0.14	0.25	0.29	0.30	0.30	0.31	0.23
Cr_2O_3	0.00	0.00	0.00	0.04	0.06	0.06	0.04	0.06	0.00	0.01	0.01	0.00	0.00	0.04
LOI	3.39	4.23	6.24	7.03	4.02	3.87	4.8	4.23	2.97	2.06	2.23	2.99	2.03	4.49
TOTAL	98.83	99.70	99.74	99.84	99.85	99.79	99.86	99.77	99.12	99.55	99.18	99.40	98.86	99.85

Table 5- Trace element analysis results of the basalts belonging to ophiolitic melanges.

Trace Elements (ppm)	K2-37	K2-38	K3-39	K2-43	K2-44	K2-45	K2-46	K2-47	KGD-625	KGD-629	KGD-913A	KGD-913B	KGD-913C	KGD-914
Sc	106.65	102.85	131.36	153.70	108.98	90.08	86.40	86.41	81.39	72.04	84.14	162.14	209.83	162.24
Th	0.33	0.36	0.25	0.10	0.49	0.19	0.16	0.11	0.72	0.56	0.60	0.55	0.60	0.11
Li	17.18	27.36	12.12	22.96	12.44	14.39	21.20	15.68	9.32	11.58	5.04	14.70	9.17	10.16
Be	0.86	2.09	1.31	0.46	0.51	0.74	1.14	0.64	1.29	1.09	1.62	1.58	1.49	0.94
Ga	20.02	23.15	17.33	15.14	16.44	16.98	15.20	12.67	24.20	15.11	19.44	21.46	17.21	10.37
As	49.31	26.53	56.58	72.66	64.57	55.90	31.85	54.35	11.44	14.96	20.32	24.52	25.11	21.97
Se	3.60	0.00	4.77	0.00	0.29	1.02	0.00	1.39	0.00	0.00	8.06	7.04	3.20	1.29
Rb	23.86	19.09	1.25	2.75	3.55	3.81	1.71	1.18	1.20	1.61	1.57	2.39	1.77	0.99
Sr	81.55	74.67	76.87	56.73	139.55	124.29	126.18	153.50	39.62	70.42	85.78	58.59	69.65	45.13
In	0.11	0.04	0.07	0.05	0.05	0.05	0.00	0.04	0.12	0.20	0.13	0.13	0.14	0.03
Cs	0.83	1.12	0.20	0.19	0.22	0.29	0.26	0.15	0.12	0.18	0.20	0.16	0.15	0.11
Ba	61.58	19.39	25.75	53.02	23.27	84.19	15.33	42.62	12.52	16.65	16.96	6.06	6.23	0.00
Tl	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pb	7.68	37.85	6.90	7.51	12.20	4.69	30.14	12.82	7.16	3.78	5.15	0.00	0.00	0.00
V	611	711	599	311	283	296	109	146	659	0	0	0	0	0
Hf	5.91	6.12	4.87	1.52	1.28	1.92	2.52	1.10	8.09	7.16	8.58	7.67	7.87	2.24
Ir	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.03	0.01
Sb	0.19	0.23	0.22	0.18	0.19	3.20	0.15	0.13	1.04	0.18	0.72	0.60	1.86	0.61
Sn	2.80	2.39	1.56	1.05	0.77	0.98	1.13	0.86	3.44	3.08	2.77	1.87	1.94	0.82
Te	0.06	0.22	0.05	0.09	0.04	0.07	0.05	0.05	0.10	0.07	0.03	0.05	0.07	0.04
Ta	0.21	0.30	0.50	0.40	0.12	0.24	0.40	0.39	0.51	0.54	0.31	0.27	0.13	0.22
Y	47.71	63.19	45.65	24.71	18.24	23.00	23.48	15.54	62.92	47.83	56.29	105.11	110.89	34.28
Nb	7	5	6	4	6	4	3	4	5	5	6	6	6	3
Zr	231	239	223	78	59	96	109	146	248	241	263	259	249	230
Ti	18401	19660	17142	7012	6053	7432	8811	11628	22177	20199	21878	22177	21518	19960
Nb/Y	0.14	0.07	0.13	0.16	0.32	0.17	0.12	0.25	0.07	0.10	0.10	0.05	0.05	0.08
Zr/Ti	0.012	0.012	0.013	0.011	0.009	0.012	0.012	0.012	0.011	0.011	0.012	0.011	0.011	0.011
Nb/Yb	1.21	0.72	1.05	1.16	1.71	0.99	0.62	0.64	0.78	0.77	0.94	0.90	0.88	0.46
TiO_2/Yb	0.52	0.47	0.49	0.33	0.28	0.30	0.30	0.31	0.57	0.51	0.56	0.55	0.52	0.51

Table 6- Rare earth element analysis results of the basalts belonging to ophiolitic melanges.

REE (ppm)	K2-37	K2-38	K3-39	K2-43	K2-44	K2-45	K2-46	K2-47	KGD-625	KGD-629	KGD-913A	KGD-913B	KGD-913C	KGD-914
La	5.54	7.74	5.56	2.14	3.42	3.07	3.18	1.45	12.67	9.34	8.70	10.74	10.61	3.90
Ce	17.94	24.05	17.22	9.12	8.38	9.55	10.95	4.96	29.94	24.61	25.24	36.48	38.08	12.84
Pr	3.02	3.79	2.90	1.32	1.18	1.47	1.68	0.77	7.17	5.74	5.23	6.51	6.75	2.21
Nd	16.26	20.27	15.85	7.83	6.03	8.10	9.26	4.44	31.42	25.48	25.53	35.44	37.01	11.73
Sm	5.54	6.70	5.24	2.71	2.02	2.69	2.94	1.58	11.27	9.18	8.83	12.00	12.58	3.90
Eu	1.86	2.21	1.78	1.10	0.89	0.98	1.15	0.61	3.93	3.19	2.94	3.88	4.11	1.46
Gd	8.03	10.04	7.55	3.96	3.00	3.84	4.11	2.39	15.67	12.70	12.67	17.05	17.73	5.62
Tb	1.39	1.69	1.31	0.69	0.50	0.65	0.68	0.42	3.18	2.62	2.33	2.86	3.04	0.94
Dy	9.09	11.18	8.43	4.46	3.25	4.27	4.37	2.81	17.28	14.22	14.23	18.86	20.02	6.05
Ho	1.90	2.34	1.77	0.91	0.68	0.88	0.91	0.61	4.39	3.51	3.30	3.95	4.21	1.27
Er	5.63	6.88	5.14	2.61	1.98	2.55	2.64	1.78	11.30	8.78	9.21	11.72	12.45	3.66
Tm	0.80	0.97	0.72	0.36	0.28	0.36	0.37	0.25	1.97	1.49	1.41	1.69	1.80	0.53
Yb	5.80	6.97	5.72	3.46	3.51	4.06	4.81	6.25	6.43	6.49	6.41	6.69	6.80	6.53
Lu	0.79	0.90	0.69	0.30	0.26	0.33	0.34	0.24	1.91	1.40	1.36	1.65	1.76	0.48

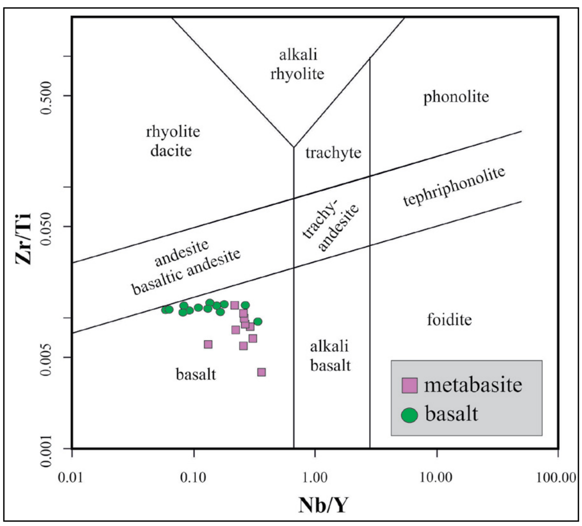


Figure 10- Positions of metabasites and basalts in the Nb/Y-Zr/Ti diagram (Pearce, 1996).

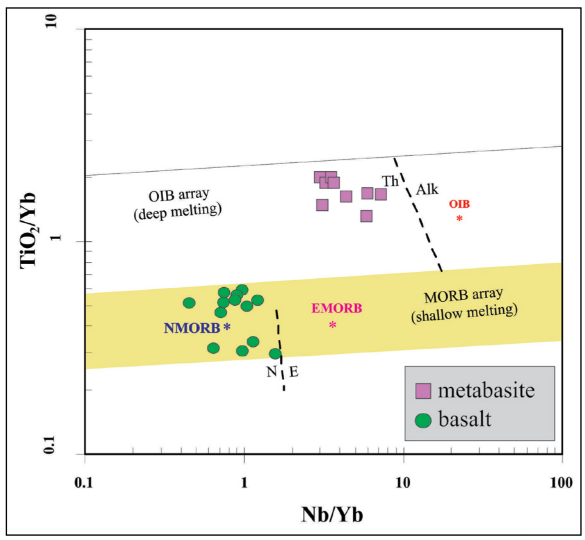


Figure 11- Nb/Yb-TiO_2/Yb diagram belonging to metabasites and basalts (Pearce, 2008).

and within-plate tholeiites character, based on the Ti versus Zr diagram of Pearce (1982) (Figure 13). The metabasites from the Kunduz Unit and the basalts from the melange exhibit MORB and within-plate characteristics. The data suggest that they most probably represent fragments of accreted oceanic lithosphere including MORB and intra-plate volcanic edifices.

6. Discussion

The various types and ages of rock groups that range from Paleozoic to Quaternary were observed in the Central Pontide Supercomplex (Okay et al., 2013; Marroni et al., 2014; Okay and Nikishin, 2015). Metamorphic basement rocks, belonging to the Kunduz Formation, are interpreted as a marginal basin complex located in the southern side of Eurasia before the Late Jurassic (Ustaömer and Robertson, 1997, 1999; Robertson, 2002) (Figure 14a).

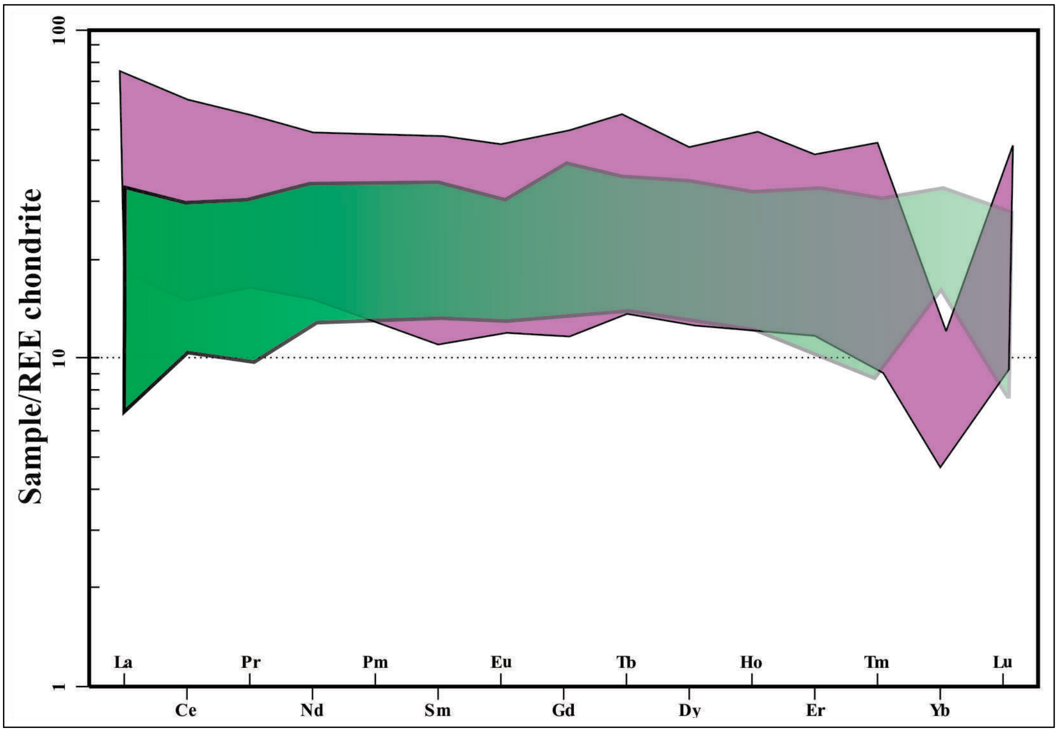


Figure 12- Chondrite-normalized REE diagrams (Sun and McDonough, 1989).

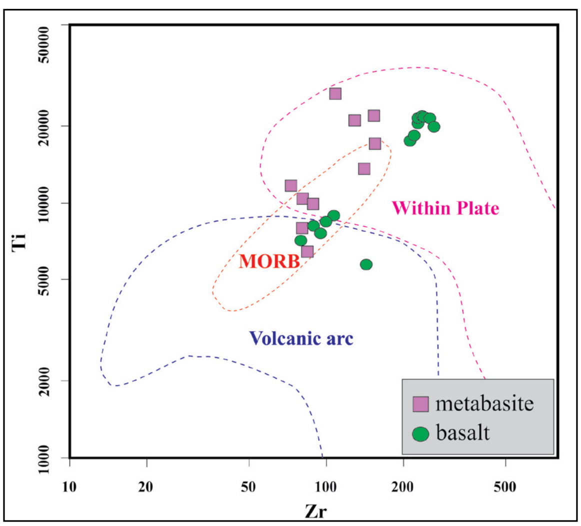


Figure 13- Ti-Zr diagram of metabasites (Pearce, 1982).

It is suggested that the age of metamorphism of the metabasites within Kunduz Formation is Late Jurassic (Aygül et al., 2016; Çelik et al., 2016) by the way of $^{40}Ar/^{39}Ar$ method which yield robust plateau ages. Geochemical data reveals that protoliths of the metabasites have tholeiitic composition and are characterized with the MORB and within plate tholeiites. High pressure and low temperature (HP-LT) metamorphism occurred in Albian (Okay et al., 2013) in the area which was thrusted into an accretionary prism area due to the northward subduction of the Tethys oceanic crust (Çelik et al., 2011; Topuz et al., 2012; Marroni et al., 2014; Okay et al., 2013). The geochemistry of basalts in the Kirazbaşı Melange show MORB to within plate-type settings (Rice et al., 2006). In this study, the basalts have tholeiite character and they coincide with the MORB and within plate areas as the geotectonic position as referred by Rice et al. (2006).

Permian limestone deposited on carbonate platforms in shallow areas located in the southern side of Eurasia (Yılmaz and Tüysüz, 1988) were thrust over Kunduz Metamorphites (Figure 14b) with the Domuzdağ-Saraycıkdağı Complex in the area from north to south in Upper Jurassic (Ustaömer and Robertson, 1999) with the closure of Tethys oceanic crust. With this thrusting, which has been related to the northwards subduction (Okay et al., 2013; Akbayram et al., 2013; Marroni et al., 2014; Tüysüz, 2017), regional metamorphism developed in the Albian (Okay et al., 2013). As a result of this thrusting, The Pelitözü tectonic slice, which presents a specific tectono-stratigraphical sequence from bottom to top was formed in the study area (Figure 14b). After the

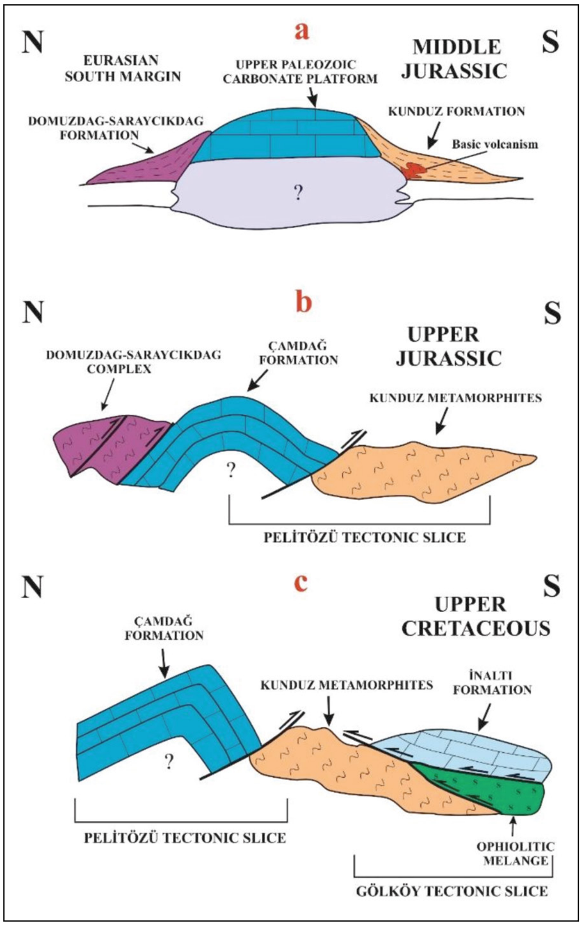


Figure 14- Structural evolution of the tectonic slices in the study area; a) Middle Jurassic period, b) Upper Jurassic period, and c) Upper Cretaceous period.

transgression that started in the Jurassic, a carbonate platform occurring in the Pontides (Ketin and Gümüş, 1963; Tüysüz, 1985) formed the İnaltı Formation. This unit thrust over both the Kirazbaşı ophiolitic Melange and metamorphic basement as a result of the subduction to the northwards and collision (Figure 14c). This tectono-stratigraphic sequence also formed the Gölköy tectonic zone. Rice et al. (2006) stated that in the Akkaya and Yuvasaray regions of the Central Pontides, there is a northward kinematic orientation within the Upper Cretaceous-Lower Cenozoic units, whereas the Kirazbaşı Ophiolitic Melange tends to thrust similar the north. As a result of the geological mapping studies, it was understood that the units belonging to ophiolitic melange in the study area have both north and south thrust planes (Figure 2), and they are compatible with the kinematic analysis proposed by Rice et al. (2006).

Middle Jurassic accretionary complex (Kunduz Metamorphites) formed with the continuation of subduction (Okay et al., 2013). The rocks located in this area had metamorphism under the conditions of high pressure and low temperature (HP, LT) in Albian (Okay et al., 2013). It has been reported that a similar structure exists in the southern part of the Kargı Massif (Yiğitbaş et al., 1990; Okay et al., 2006; Tüysüz and Tekin, 2007). A large part of the study area to the east of Kargı consists of rocks belonging to ophiolitic melange overlying the metamorphic basement with tectonic contact.

The Gölköy tectonic slice was formed by the northerly thrusting (Rice et al., 2006), related to the northward's subduction (Okay et al., 2013; Akbayram et al., 2013; Marroni et al., 2014; Tüysüz, 2017), of Kirazbaşı complex (ophiolitic melange) and Mesozoic carbonate rocks over the metamorphic rocks forming the basement of the area. The distance between the Pontides, Taurid-Anatolide and Kırşehir blocks probably decreased in the Paleocene and continued to exist until the Early-Middle Eocene (Okay et al., 2017). The thrust faults in Central Pontides started in the Late-Eocene and (Kaymakçı et al., 2009; Espurt et al., 2014; Hippolyte et al., 2016). Yılmaz and Tüysüz (1984) stated that during the subduction of oceanic lithosphere towards the north in Late Cretaceous, the slices in the Atlantic-type continental margin located in the north-end moved towards the south, and argued that later in the Paleocene-Early Eocene, the direction of the movement of retro-thrust was towards the north due to the compression in the south. However, in the study area, there is no evidence that carbonate rocks thrust after the Eocene. However, when the contact relations are examined, it is determined that the ophiolitic mélange is thrust over the Upper Cretaceous-Lower Eocene Beşpınar Formation (Figure 2). This situation hereby indicates that the thrusting postdates Early Eocene.

Uğuz and Sevin (2009) asserted that the allochthonous rocks in the area are formed of lower and upper tectonic slices and that the metamorphic rocks have autochthonous character.

7. Results

In the study area, not only ophiolite or ophiolitic melange tectonically exists on the metamorphic belt, it has been determined that carbonate units of different ages are also tectonically located on these imbrication zones. The tectonic slices formed in this study have been defined as PTS, GTS, and OMS for the first time.

The whole rock geochemistry studies explain that Kunduz metamorphites and basalts from the ophiolitic melange exhibit the tholeiitic character. Their chondrite-normalized trace element patterns show enrichment in LREE (La, Ce, Nd) for metabasites of the Kunduz Metamorphites relative to basalts belonging to the ophiolitic mélange. In addition, HREE (Er, Tm, Yb, Lu) exhibits almost flat trends for each unit.

Acknowledgements

This study is a part of a Ph.D. thesis that was prepared in the Graduate School of Science and Engineering of İstanbul University was supported by TÜBİTAK project no: 113Y536.

References

Akbayram, K., Okay, A. I., Satır, M. 2013. Early Cretaceous closure of the Intra-Pontide Ocean in western Pontides (northwestern Turkey). Journal of Geodynamics 65, 38-55.

Akbulut, M., Oyman, T., Çiçek, M., Selby, D., Özgenç, I., Tokçaer, M. 2016. Petrography, mineral chemistry, fluid inclusion microthermometry and Re–Os geochronology of the Küre volcanogenic massive sulfide deposit (Central Pontides, Northern Turkey). Ore Geology Reviews 76, 1-18.

Altherr, R., Topuz, G., Marschall, H., Zack, T., Ludwig, T. 2020. Evolution of a tourmaline bearing lawsonite eclogite from the Elekdağ area (Central Pontides, N Turkey): Evidence for infiltration of slab-derived B-rich fluids during exhumation. Contributions to Mineralogy and Petrology 148, 409-425.

Altun, Y., Yılmaz, H., Siner, I., Yazar, F. 2015. The secrets of massive sulfide deposits on mid-ocean ridge and Küre-Magaradoruk copper deposit. Bulletin of the Mineral Research and Exploration 150, 51–65.

Aydın, M., Demir, O., Özçelik, Y., Terzioğlu, N., Satır, M. 1995. A geological revision of İnebolu, Devrekani Agülı and Küre areas: new observations in PaleoTethys–NeoTethys sedimentary successions. Erler, A., Ercan, T., Bingöl, E., Örçen, S. (Ed.). Geology of the Black Sea Region, General Directorate of Mineral Research and Exploration, 33–38.

Aygül, M., Okay, A. I., Oberhansli, R., Ziemann, M. A. 2015*a*. Thermal structure of lowgrade accreted Lower Cretaceous distal turbidites, the Central Pontides, Turkey: insights for tectonic thickening of an accretionary wedge. Turkish Journal of Earth Sciences 24, 461–474.

Aygül, M., Okay, A. I., Oberhansli, R., Schmidt, A., Sudo, M. 2015*b*. Late Cretaceous infant intra-oceanic arc volcanism, the Central Pontides, Turkey: petrogenetic and tectonic implications. Asian Journal of Earth Sciences 111, 312-327.

Aygül, M., Okay, A. I., Oberhänsli, R., Sudo, M. 2016. Pre-collisional accretionary growth of the southern Laurasian active margin, Central Pontides, Turkey. Tectonophysics 671, 218–234.

Çakır, Ü. 1995. Asıköy-Toykondu (Küre-Kastamonu) masif sülfid yataklarının jeolojik özellikleri. Bulletin of the Mineral Research and Exploration 117, 29–40.

Çelik, Ö. F., Chiaradia, M., Marzoli, A., Özkan, M., Billor, Z. 2016. Jurassic metabasic rocks in the Kızılırmak accretionary complex (Kargı region, Central Pontides, Northern Turkey). Tectonophysics 672–673, 34–49.

Çelik, Ö. F., Marzoli, A., Marschik, R., Chiaradia, M., Neubauer, F. 2011. Early–Middle Jurassic intra-oceanic subduction in the İzmir-Ankara-Erzincan Ocean, Northern Turkey. Tectonophysics 509, 120–134.

Çelik, Ö. F., Marzoli, A., Marschik, R., Chiaradia, M., Mathur, R. 2018. Geochemical, mineralogical and Re-Os isotopic constraints on the origin of Tethyan oceanic mantle and crustal rocks from the Central Pontides, northern Turkey. Mineralogy and Petrology 112, 25–44.

Çimen, O., Göncüoğlu, M. C., Sayit, K. 2016. Geochemistry of the metavolcanic rocks from the Çangaldağ Complex in the Central Pontides: implications for the Middle Jurassic arc-back-arc system in the Neotethyan Intra-Pontide Ocean. Turkish Journal of Earth Sciences 25, 491–512.

Çimen, O., Göncüoğlu, M. C., Simonetti, A., Sayit, K. 2017. Whole-rock geochemistry, zircon U-Pb and Hf isotope systematics of the Çangaldag pluton: evidences for middle Jurassic Continental

Arc magmatism in the central Pontides, Turkey. Lithos 290, 136–158.

Çimen, O., Göncüoğlu, M.C., Simonetti, A., Sayit, K. 2018. New zircon U-Pb LA-ICP-MS ages and Hf isotope data from the Central Pontides (Turkey): geological and geodynamic constraints. Journal of Geodynamics 116, 23–36.

Derman, A. S., Sayılı, A. 1995. İnaltı Formation: a key unit for regional geology. In: Erler, A., Ercan, T., Bingöl, E., Örçen, S. (Eds.). Geology of the Black Sea Region, General Directorate of Mineral Research and Exploration, 104–108.

Dönmez, C., Günay, K., Yıldız, H., Şahin, Ş. 2013. Gökırmak ve Devrettepe-Hanönü (Kastamonu) Cu cevherleşmesi. MTA Doğal Kaynaklar ve Ekonomi Bülteni 127, 16.

Espurt, N., Hippolyte, J. C., Kaymakçı, N., Sangu, E. 2014. Lithospheric structural control on inversion of the southern margin of the Black Sea Basin, Central Pontides, Turkey. Lithosphere 6(1), 26-34.

Eyüboğlu, Y., Santosh, M., Keewook, Yi., Tüysüz, N., Korkmaz, S. 2014. The Eastern Black Sea-type volcanogenic massive sulfide deposits: geochemistry, zircon U-Pb geochronology and an overview of the geodynamics of ore genesis. Ore Geology Reviews 59, 29-54.

Finetti, I., Bricchi, G., Del Ben, A., Pipan, M., Xuan, Z. 1988. Geophysical study of the Black Sea. Bolletino di Geofisica ed Applicata 30, 197–324.

Genç, Ş., Kurt, Z., Küçükmen, Ö., Cevher, F., Saraç, G. 1991. Merzifon (Amasya) dolayının jeolojisi, General Directorate of Mineral Research and Exploration, Report No: 9527, Ankara (unpublished).

Göncüoğlu, M. C. 2010. Introduction to the geology of Turkey: geodynamic evolution of the Pre-Alpine and Alpine Terranes. Bulletin of the Mineral Research and Exploration 1–69.

Görür, N. 1988. Timing of opening of the Black Sea Basin. Tectonophysics 147, 247–262.

Gücer, M. A, Arslan, M., Sherlock, S., Heaman, L. M. 2016. Permo-Carboniferous granitoids with Jurassic high- temperature metamorphism in Central Pontides, Northern Turkey. Mineralogy and Petrology 110, 943-964.

Gümüşsu, M. 1980. Amasya ili, Merzifon ve Suluova İlçeleri kömür jeolojisi. General Directorate of Mineral Research and Exploration, Report No. 7063, Ankara.

Günay, K., Dönmez, C., Oyan, V., Yıldırım, N., Çiftçi, E. 2018. Geology and geochemistry of sediment-hosted hanönü massive sulfide deposit (Kastamonu – Turkey). Ore Geology Reviews 101, 652–674.

Günay, K., Dönmez, C., Oyan, V., Baran, C., Çiftçi, E., Parlak, O., Yıldırım, N., Deng., XH, Li C., Yıldırım, E., Özkümüş, S. 2019. Geology, geochemistry and Re-Os geochronology of the Jurassic Zeybek volcanogenic massive sulfde deposit (Central Pontides, Turkey). Ore Geology Reviews 111, 102994.

Hakyemez, Y., Barkurt, M. Y., Bilginer, E., Pehlivan, Ş., Can, B. 1986. Yapraklı-llgaz-Çankırı-Çandır dolayının jeolojisi, General Directorate of Mineral Research and Exploration, Report No: 7966, Ankara.

Hippolyte, J. C., Müller, C., Kaymakçı, N., Sangu, E. 2010. Dating of the Black Sea Basin: new nannoplankton ages from its inverted margin in the Central Pontides (Turkey). In: Sosson, M., Kaymakçı, N., Stephenson, R., Bergerat, F., Starostenko, V. (Ed.). Sedimentary Basin Tectonics from the Black Sea and Caucasus to the Arabian Platform. Geological Society of London, Special Publications 340, 113–136.

Hippolyte, J. C., Espurt, N., Kaymakçı, N., Sangu, E., Müller, C. 2016. Cross-sectional anatomy and geodynamic evolution of the Central Pontide orogenic belt (northern Turkey). International Journal of Earth Sciences 105, 81–106.

Kaymakçı, N., Özçelik, Y., White, S. H., Van Dijk, P. M. 2009. Tectono-stratigraphy of the Çankırı Basin: late Cretaceous to early Miocene evolution of the Neotethyan suture zone in Turkey. Geological Society of London, Special Publications 311(1), 67-106.

Ketin, İ. 1966. Tectonic units of Anatolia (Asia Minor). Bulletin of the Mineral Research and Exploration 66, 23–34.

Ketin, İ., Gümüş, A. 1963. Sinop-Ayancık arasında III. Bölgeye dahil sahaların jeolojisi. Turkish Petroleum Corporation, Report No: 288, Ankara.

Koç, Ş., Ünsal, A., Kadıoğlu, Y. 1995. Küre (Kastamonu) cevherleşmelerini içeren volkanitlerin jeolojisi, jeokimyası ve jeotektonik konumu. Bulletin of the Mineral Research and Exploration 117, 41-54.

Lefebvre, C., Meijers, M. J. M., Kaymakçı, N., Peynircioğlu, A., Langereis, C. G. 2013. Reconstructing the geometry of central Anatolia during the late Cretaceous: large-scale Cenozoic rotations and deformation between the Pontides and Taurides. Earth and Planetary Science Letters 366, 83-98.

Marroni, M., Frassi, C., Göncüoğlu, M. C., Di Vincenzo, G., Pandolfi, L. 2014. Late Jurassic amphibolite facies metamorphism in the Intra- Pontide Suture Zone (Turkey): an eastward extension of the Vardar Ocean from the Balkans into Anatolia?. Journal of the Geological Society of London 171, 605–608.

Nikishin, A. M., Okay, A., Tüysüz, O., Demirer, A., Wannier, M. 2015. The Black Sea basins structure and history: new model based on new deep penetration regional seismic data. Part 2: Tectonic history and paleogeography. Marine Petroleum Geology 59, 656–670.

Okay, A. I., Göncüoğlu, M. C. 2004. Karakaya Complex: a review of data and concepts. Turkish Journal of Earth Sciences 13, 77–95.

Okay, A. I., Nikishin, A. M. 2015. Tectonic evolution of the southern margin of Laurasia in the Black Sea region. International Geology Reviews 57, 1051-1076.

Okay, A. I., Altıner, D., Sunal, G., Aygül, M., Akdoğan, R. 2017. Geological evolution of the central Pontides. Simmons, M. D., Tari, G., Okay, A. I. (Ed.). Petroleum Geology of the Black Sea. Geological Society of London, Special Publications 464(1), 33.

Okay, A. I., Gürsel, S., Sherlock, S., Altıner, D., Tüysüz, O. 2013. Early Cretaceous sedimentation and orogeny on the active margin of Eurasia: Southern Central Pontides, Turkey. Tectonics 32, 1247–1271.

Okay, A. I., Gürsel, S., Tüysüz, O., Sherlock, S., Keskin, M. 2014. Low-pressure-high-temperature metamorphism during extension in a Jurassic magmatic arc, Central Pontides, Turkey. Journal of Metamorphic Geology 32, 49-69.

Okay, A. I., Şengör, A. M. C., Görür, N. 1994. Kinematic history of the opening of the Black Sea and its effect on the surrounding regions. Geology 22 (3), 267-270.

Okay, A. I., Tüysüz, O., Satır, M., Özkan-Altıner, S., Altıner, D. 2006. Cretaceous and Triassic subduction-accretion, HP/ LT metamorphism and continental growth in the Central Pontides, Turkey. Geological Society of America Bulletin 118, 1247–1269.

Özgül, N., Turşucu, A., Özyardımcı, N., Şenol, M., Bingöl, İ. 1981. Munzur dağlarının jeolojisi. General Directorate of Mineral Research and Exploration, Report No: 6995, 136, Ankara (unpublished).

Pearce, J. A. 1982. Trace element characteristics of lavas from destructive plate boundaries, andesites: orogenic andesites and related rocks. Thorpe R. S. (Ed.). John Wiley and Sons, Chichester, 525-548.

Pearce, J. A. 1996. A user's guide to basalt discrimination diagrams, Trace Element Geochemistry of Volcanic Rocks: Applications for Massive Sulphide Exploration. Wyman, D. A. (Ed.). Geological Association of Canada, Short Course Notes 12, 79–113.

Pearce, J. A. 2008. Geochemical fingerprinting of oceanic basalts with applications to ophiolite classification and the search for Archean oceanic crust. Lithos 100, 14–48.

Rice, S. P., Robertson, A. H. F., Ustaömer, T. 2006. Late Cretaceous–Early Cenozoic tectonic evolution of the Eurasian active margin in the Central and Eastern Pontides, northern Turkey. Robertson, A. H. F., Mountrakis, D. (Ed.). Tectonic Development of The Eastern Mediterranean Region. Geological Society of London, Special Publication 260, 413-445.

Robertson, A. H. F. 2002. Overview of the genesis and emplacement of Mesozoic ophiolites in the Eastern Mediterranean Tethyan Region. Lithos 65, 1-67.

Robertson, A. H., Ustaömer, T. 2004. Tectonic Evolution of The Intra-Pontide Suture Zone in The Armutlu Peninsula, NW Turkey. Tectonophysics 381, 175–209.

Robertson, A. H. F., Ustaömer, T., Parlak, O., Ünlügenç, Ü. C., Taşlı, K. 2006. The Berit transect of the Tauride thrust belt, S Turkey: Late Cretaceous-Early Cenozoic accretionary/collisional processes related to closure of the Southern Neotethys. Journal of Asian Earth Sciences 27, 108-145.

Robinson, A., Rudat, J. H., Banks, C. J., Wiles, R. L. F. 1996. Petroleum geology of the Black Sea. Marine and Petroleum Geology 13, 195–223.

Sun, S. S., McDonough, W. F. 1989. Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. Geological Society of London, Special Publication 42, 313-345.

Sütçü, Y. F., Barkurt, M. Y., Bilginer, E., Kurt, Z., Pehlivan, Ş. 1994. Boyabat-Vezirköprü arasının jeolojisi. General Directorate of Mineral Research and Exploration, Report No, 9884, Ankara.

Şengör, A. M. C., Yılmaz, Y. 1981. Tethyan evolution of Turkey: a plate tectonic approach. Tectonophysics 75, 181-241.

Şengör, A. M. C., Yılmaz, Y., Ketin, İ. 1982. Remnants of a pre-late Jurassic ocean in northern Turkey: fragments of Permian-Triassic Paleo-Tethys?. Geological Society of America Bulletin 93, 932-936.

Tekin, U. K., Göncüoğlu, M. C., Pandolfi, L., Marroni, M. 2012. Middle Late Triassic radiolarian cherts from the Arkotdag melange in northern Turkey: implications for the life span of the northern Neotethyan branch. Geodinamica Acta 25, 305–319.

Topuz, G., Göçmengil, G., Rolland, Y., Çelik, Ö. F., Zack, T. 2012. Jurassic accretionary complex and ophiolite from northeast Turkey: no evidence for the Cimmerian continental ribbon. Geology 41, 255–258.

Türkecan, A., Hepşen, N., Papak, I., Akbaş, B., Dinçel, A. 1991. Seben-Gerede (Bolu)-Güdül-Beypazarı (Ankara) ve Çerkeş-Orta-Kurşunlu (Çankırı) yörelerinin (Köroğlu dağları) jeolojisi ve volkanik kayaçların petrolojisi, General Directorate of Mineral Research and Exploration, Report No: 9193, Ankara (unpublished).

Tüysüz, O. 1985. Kargı Masifi ve dolayındaki tektonik birliklerin ayırdı ve araştırılması (petrolojik inceleme), PhD Thesis, İstanbul University, Institute of Science and Technology, 431.

Tüysüz, O. 1990. Tectonic evolution of a part of the Tethyside orogenic collage: the Kargı Massif, northern Turkey. Tectonics 9, 141–160.

Tüysüz, O. 1999. Geology of the cretaceous sedimentary basins of the western Pontides. Geological Journal 34, 75–93.

Tüysüz, O. 2017. Cretaceous geological evolution of the Pontides, Geological Society of London, Special Publications 464(1), 69.

Tüysüz, O., Tekin, U. K. 2007. Timing of imbrication of an active continentalmargin facing the northern branch of Neotethys, Kargı Massif, Northern Turkey. Cretaceous Research 28, 754–764.

Uğuz, M. F., Sevin, M. 2009. 1/100.000 Ölçekli Türkiye Jeoloji Haritaları, No:115, General Directorate of Mineral Research and Exploration, Ankara (in Turkish).

Ustaömer, T., Robertson, A. H. F. 1997. Tectonic-sedimentary evolution of the northtethyan margin in the central Pontides of northern Turkey. Robinson, A. G. (Ed.). Regional and Petroleum Geology of the Black Sea and Surrounding Region. American Association of Petroleum Geologists Memoir 68, 255–290.

Ustaömer, T., Robertson, A. H. F. 1999. Geochemical evidence used to test alternative plate tectonic models for the pre-Upper Jurassic (Palaeotethyan) units in the Central Pontides, N Turkey. Geological Journal 34, 25–53.

Yalçın, C. 2018. Geology and formation of the Gökçedoğan (Kargı-Çorum) Cu±Zn mineralisation. PhD Thesis, İstanbul University, Institute of Graduate Studies in Science and Engineering, 301 (in Turkish).

Yılmaz, Y., Tüysüz, O. 1984. Kastamonu-Boyabat-Vezirköprü-Tosya arasındaki bölgenin jeolojisi (Ilgaz-Kargı masiflerinin etüdü). Maden Tetkik ve Arama Genel Müdürlüğü Yayınları, Ankara (in Turkish).

Yılmaz, Y., Tüysüz, O. 1988. Kargı masifi ve dolaylarında Mesozoyik tektonik birliklerin düzenlemeleri sorununa bir yaklaşım. Turkish Association of Petroleum Geologist Bulletin 1(1), 73-86 (in Turkish).

Yılmaz, Y., Tüysüz, O., Yiğitbaş, E., Genç, S. C., Şengör, A. M. C. 1997. Geology and tectonic evolution of the Pontides. Robinson, A. G. (Ed.). Regional and Petroleum Geology of the Black Sea and Surrounding Region. Bullettin of American Association Petroleum Geology 68, 183–226.

Yiğitbaş, E., Tüysüz, O., Serdar, H. S. 1990. Yığışım prizması ve melanj gelişimine bir örnek: Orta Pontidler. Türkiye 8. Petrol Kongresi, Ankara, Türkiye, 25-26 (in Turkish).