Bulletin of the Mineral Research and Exploration

http://bulletin.mta.gov.tr

The internal structure of Beypazarı Blind Thrust Zone around Çayırhan

Anıl ARDAHANLIOĞLU[a*], Gürol SEYİTOĞLU[a] and Korhan ESAT[a]

[a]*Ankara University, Department of Geological Engineering, Tectonics Research Group, Gölbaşı, Ankara, Turkey*

Research Article

Keywords:
Central Anatolia, Neotectonics, Blind thrust fault, Earthquake, Fault-propagation fold.

Received Date: 15.09.2019
Accepted Date: 19.11.2019

ABSTRACT

The Beypazarı Blind Thrust Zone, which is surrounded by the North Anatolian, the Eskişehir, and the Kırıkkale-Erbaa fault zones, is a recently defined neotectonic structure developed in the NW central Anatolia together with the Eldivan-Elmadağ and the Abdüsselam Pinched Crustal Wedges. In this study, the internal structure of the Beypazarı Blind Thrust Zone has been examined in detail around Çayırhan region. It has been defined that it consists of the Karaköy, Sekli, Nalçabayırı, Uzunbayır blind thrusts, Davutoğlan Back Thrust, and Beypazarı Blind Thrust I-II from north to south, respectively with help of the fault-propagation folds in the study area. The existence of economically important and operational resources such as lignite and trona in the Neogene sequence affected by these faults in the region and earthquake generating potential of the faults determined in previous studies increase the importance of this study.

1. Introduction

The Neogene Beypazarı-Çayırhan basin located in the central Anatolia region contains important mineral deposits. The basin has been subjected to geochemical studies due to its potential for geothermal resources as well as lignite and trona deposits (Helvacı et al., 1981; Özpeker et al., 1991; Suner, 1993; Kavuşan, 1993*a*; Karadenizli, 1995; Orti et al., 2002; Özçelik, 2002; Özgüm et al., 2003; Özçelik and Altunsoy, 2005; Diker et al., 2006; Şener, 2007; Garcia-Veigas et al., 2013; Bechtel et al., 2014; Pehlivanlı et al., 2014). Although the researches are mainly concentrated on mineral deposits, there are also engineering geology studies (Aksoy et al., 2006; Apaydın, 2010). When all these engineering and mineral deposits studies are taken into consideration, some researchers indirectly have mentioned about the tectonics and structural geology of the region (Yağmurlu et al., 1988; İnci, 1991; Kavuşan, 1993*b*). The studies based on the structural geology and tectonics of the region are less when compared with other subjects (Demirci, 2000; Seyitoğlu et al., 2017*a*; Şahin et al., 2019).

Major geological structures in the basin were defined as the "Beypazarı flexure" (Randot, 1956; Kalafatçıoğlu and Uysallı, 1964; Kavuşan, 1993*b*) and the "Beypazarı monocline" (Yağmurlu et al., 1988; Demirci, 2000). The same structures were defined by Seyitoğlu et al. (2017*a*) as fault propagation folds due to blind thrust faults. It was stated that the region remained under the influence of extensional tectonic regime in the early Miocene and the contractional tectonic regime in NW-SE direction between the North Anatolian and the Eskişehir Fault Zones in the early Pliocene (Yağmurlu et al., 1988). Kavuşan (1993*b*) stated that the basin has been developed under the NW-SE contractional tectonic regime since the beginning of the formation of the basin. Demirci (2000) mentioned about three different tectonic phases (contraction in

Citation info: Ardahanlıoğlu, A., Seyitoğlu, G., Esat, K. 2020. The internal structure of Beypazarı Blind Thrust Zone around Çayırhan. Bulletin of the Mineral Research and Exploration 163,77-97. https://doi.org/10.19111/bulletinofmre.651712.

Corresponding author: Anıl ARDAHANLIOĞLU, a.ardahanli@gmail.com

E-W direction, contraction and extension phases in N-S direction) that were active in the region.

Seyitoğlu et al. (2017*a*) revealed that the structures observed in the region were fault propagation folds related to blind thrust faults using the Erenler Back Thrust observed at the surface in the study carried out around Beypazarı. They defined the main factor affecting the formation of all observed structures in the region as the Beypazarı Blind Thrust Zone (Figure 1). The seismic activity distribution and focal mechanism solutions of this zone show that the zone is active today (Seyitoğlu et al., 2017*a*). The reason why such a structure is observed in the Beypazarı-Çayırhan basin is the contraction developed in the inverse triangle shaped area defined as the Northwest Central Anatolia Contractional Region (Esat and Seyitoğlu, 2010; Esat, 2011). They also emphasized that the Beypazarı Blind Thrust Zone should be assessed as a neotectonic structure together with the Eldivan-Elmadağ Pinched Crustal (Seyitoğlu et al., 2009) and the Abdüsselam Pinched Crustal Wedge (Esat et al., 2017) (Figure 1). Şahin et al. (2019) stated that the deformation in the region was directly related to the closure of the Intra-Pontide and İzmir-Ankara oceans, and emphasized the importance of deformation in the area bounded by young faults such as the North Anatolian Fault Zone and the Eskişehir Fault Zone.

With this study, it is aimed to reveal the internal structure of the Beypazarı Blind Thrust Zone with detailed field observations in the Beypazarı-Çayırhan basin that contains important underground resources such as lignite and trona and to reach a general tectonic model, which would be tested by the mining activities, drilling data and geophysical methods.

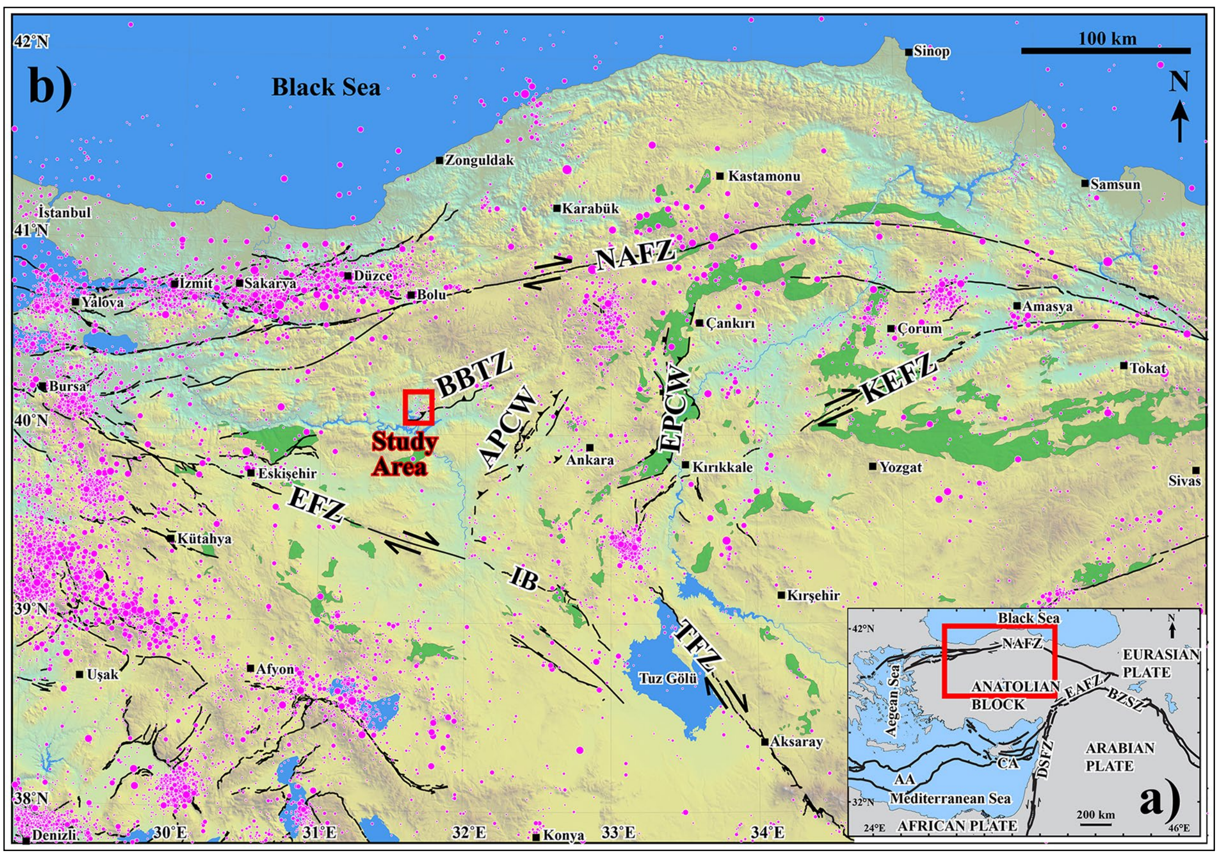

Figure 1- a) Neotectonic elements of the Eastern Mediterranean. DSFZ: Dead Sea Fault Zone; BZSZ: Bitlis-Zagros Suture Zone; EAFZ: Eastern Anatolia Fault Zone; NAFZ: North Anatolian Fault Zone; AA: Aegean Arc; CA: Cyprus Arc. b) The main neotectonic elements of the northwestern Central Anatolia and the location of the study area. KEFZ: Kırıkkale-Erbaa Fault Zone; TFZ: Tuzgölü Fault Zone; EFZ: Eskişehir Fault Zone; IB: Ilıca Branch; EPCW: Eldivan-Elmadağ Pinched Crustal Wedge; APCW: Abdüsselam Pinched Crustal Wedge; BBTZ: Beypazarı Blind Thrust Zone. Faults are taken from the following publications: Şaroğlu et al. (1992); Seyitoğlu et al. (2009; 2015; 2017*a*); Esat (2011); Emre et al. (2013); Esat et al. (2014; 2016; 2017). The distribution of the epicenters of earthquakes with magnitude 3 and above recorded in the instrumental period is shown in the UDİM catalog of Boğaziçi University Kandilli Observatory.

2. Stratigraphy of the Beypazarı-Çayırhan Basin

The stratigraphy of the basin has been studied by previous researchers (Siyako, 1983; Yağmurlu et al., 1988; Kavuşan, 1993*b*), and compiled and updated by Helvacı (2010). The basement rocks observed in the study area are metamorphic units consisting of mainly mica schists. The first sedimentary unit overlying the basement is the Kızılçay group. Paleocene age of the Kızılçay group (Helvacı, 2010) was updated by Şahin et al. (2019) as the middle-upper Eocene (Figure 2). The Kızılçay group consists of red, wine-colored conglomerate, sandstone, claystone and volcaniclastics. The unconformably overlying Çoraklar formation is composed of orange, red orange, yellowish red conglomerate, sandstone, siltstone and mudstone. This formation is economically important as it contains lower and upper lignite levels. The Hırka formation, which overlies the Çoraklar formation, contains white, dirty-white, beige mudstone, claystone, shale, siltstone and dolomitic limestones as well as trona. Radiometric dating studies from tuff levels yielded 21.5 ± 0.9 Ma (early Miocene) (Helvacı, 2010). The Akpınar formation transitionally overlies the Hırka formation. It consists of siliceous limestone, chert, claystone, tuff and mudstone alternations. The Bozbelen formation is composed of blue-green, dark green, reddish sandstone, conglomerate and mudstone. The Kirmir formation, which is the youngest Neogene unit, is composed of greenish gray, green colored claystones and gypsum levels (Figure 2).

The distinction of the Quaternary units of the region in this study is based on the classification proposed by Kazancı (2012). This makes it possible to create a more realistic mapping and interpretation of the geology of the region. For example, in all of the studies conducted in Uluköy and its vicinity in the study area (Yağmurlu et al., 1988; Kavuşan, 1993*b*; Helvacı, 2010), the area mapped as the Kızılçay formation was found to be covered by the alluvial fans (Figure 3).

The river channels with narrow Quaternary beds cut all across the study area. There are also flood plains that developed at low elevations belonging to

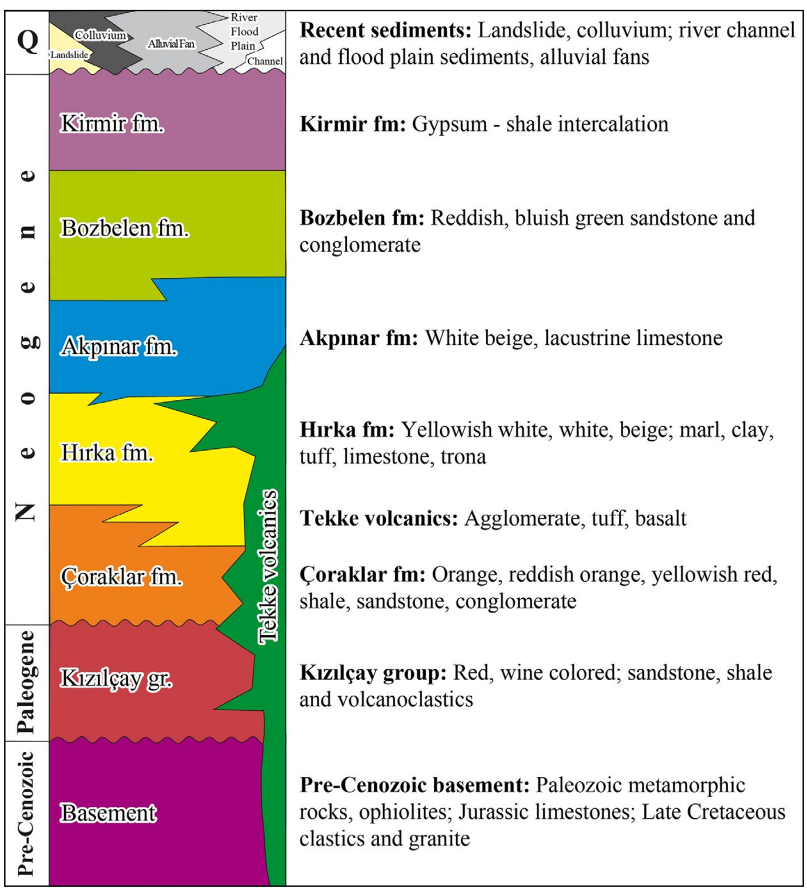

Figure 2- Stratigraphy of the study area (Helvacı, 2010).

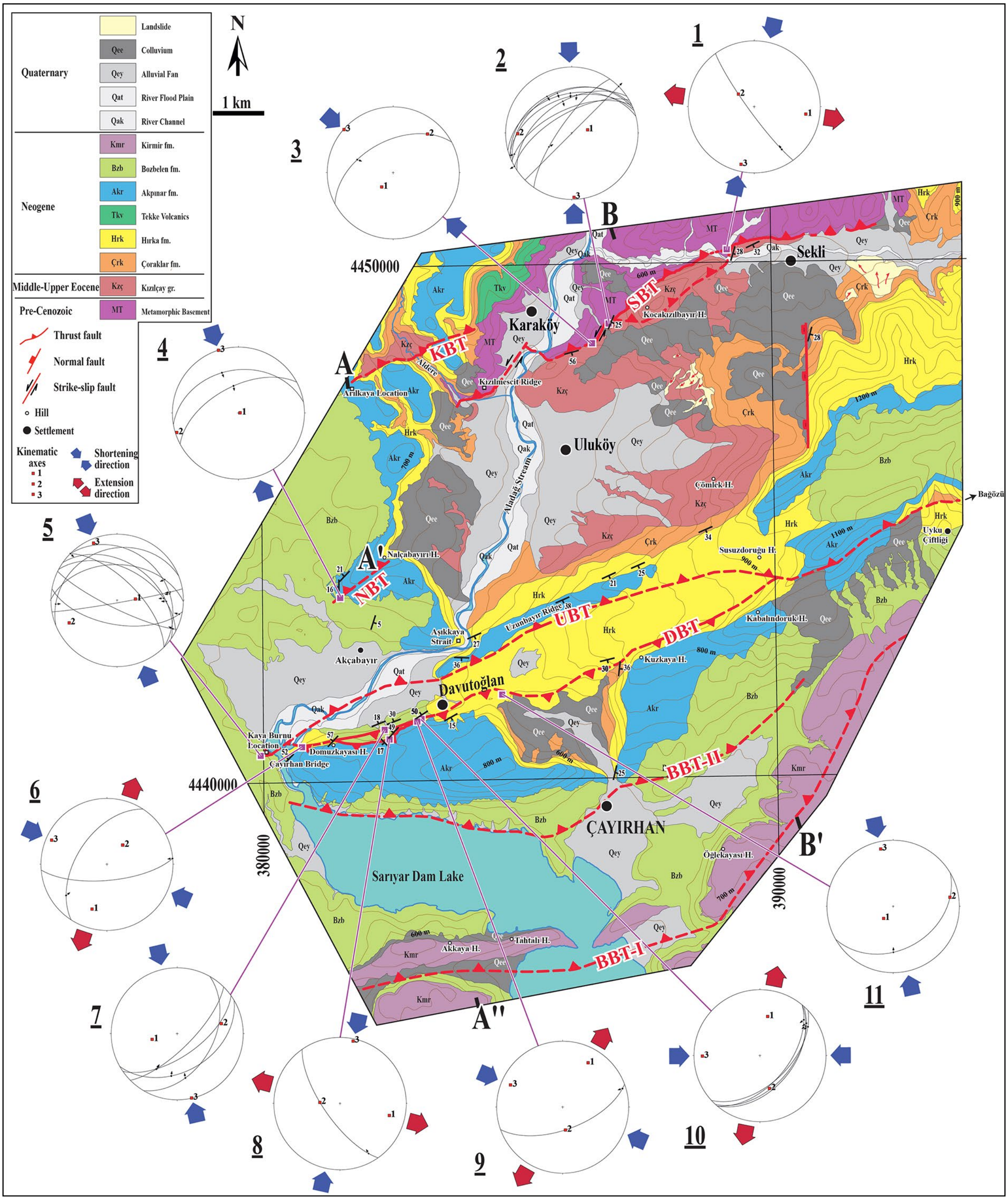

Figure 3- Geological map of the Çayırhan and surroundings. It was redrawn using the previous studies (Siyako, 1983; Kavuşan, 1993*b*; Helvacı, 2010). The circles around the map, the fault planes measured in the field and striations on them are the presentation of equal area lower hemisphere projection. This demonstration and kinematic analysis were performed using FaultKin (Marrett and Allmendinger, 1990; Allmendinger et al., 2012) software. See table 1 for kinematic data. BBT: Beypazarı Blind Thrust, DBT: Davutoğlan Back Thrust, KBT: Karaköy Blind Thrust, NBT: Nalçabayırı Blind Thrust, SBT: Sekli Blind Thrust, UBT: Uzunbayır Blind Thrust.

Table 1- Fault plane-striae data observed in the study area and orientations of the kinematic axes. See figure 3 for the spherical projection views of the data. "# on map" column refers to the spherical projection numbers on the figure 3.

Location (UTM-ED50)			Fault		Striae		Slip	Kinematic Axes					
								1		2		3	
# on Map	X (East)	Y (North)	Strike	Dip	Trend	Plunge		Trend	Plunge	Trend	Plunge	Trend	Plunge
1	389152	4450204	144	83	147	24	Reverse	98	22	309	65	193	12
2	386827	4448826	236	50	344	49	Reverse	78	70	269	19	178	4
			250	45	7	42	Reverse						
			244	36	340	36	Reverse						
			248	34	326	33	Reverse						
			255	40	358	39	Reverse						
			245	60	250	9	Normal						
			240	65	240	0	Normal						
			45	90	45	0	Normal						
			215	75	239	57	Reverse						
3	386532	4448438	242	50	290	42	Reverse	219	68	42	23	311	1
4	381541	4443574	260	35	338	34	Reverse	82	88	252	2	342	0
			242	57	350	56	Reverse						
5	379969	4440539	271	45	66	23	Reverse	86	68	245	21	338	7
			116	80	117	6	Reverse						
			100	60	103	4	Reverse						
			248	23	267	8	Reverse						
			315	26	83	21	Reverse						
			298	49	87	30	Reverse						
			305	42	91	27	Reverse						
			80	87	81	20	Reverse						
			315	65	315	0	Reverse						
6	380762	4440682	213	52	233	23	Reverse	198	29	40	59	294	9
			85	70	85	0	Reverse						
7	382352	4440981	55	62	210	39	Reverse	257	58	77	32	167	0
			30	44	169	32	Reverse						
			60	42	188	35	Reverse						
			45	72	210	38	Reverse						
8	382482	4440848	145	70	150	14	Reverse	104	24	273	65	12	4
9	383009	4441166	70	62	73	5	Reverse	30	23	173	61	293	16
10	383062	4441200	40	55	51	15	Reverse	11	40	164	47	269	14
			42	50	55	15	Reverse						
			47	54	59	16	Reverse						
			40	48	57	18	Reverse						
11	384608	4441680	60	35	180	31	Reverse	218	71	81	14	348	12

these channels. Alluvial fans that develop in the region also cover large areas. However, the slope debris and landslides in the Quaternary units, which are caused by not having sufficient strength of the older rocks, are also important. All of these Quaternary units are transitional with each other (Figure 2).

3. Structural Geology and Tectonics of the Beypazarı Çayırhan Basin

Geological mapping were done between the Çayırhan in the south, Sekli in the north, Çayırhan Bridge in the west, and Hırka in the east (Figure 3). Most of the thrust/blind thrust structures observed in the region are located just in the north of Çayırhan. The high angle limbs of asymmetrical anticlines were used following the criteria revealed by Seyitoğlu (2017*a, b*) when mapping the blind thrusts on to the geological map detected during field studies. During this, the indicators mentioned about blind thrusts and fault propagation folds and theoretical background were used. The structures identified as a result of field studies will be explained in a sequence from north to south.

3.1. Karaköy Blind Thrust

This structure, shown by Yağmurlu et al. (1988), Helvacı (2010) and Helvacı et al. (2014) as normal fault dipping southwest were mapped by Kavuşan (1993*b*) as thrust planes dipping northwest. The limestone layers belonging to the Akpınar formation inside the Aldere valley and near the Arılkaya location in the west of Karaköy acquire high dipping and thus the thrust line is encountered. This line carried conglomerate and volcaniclastics of the Kızılçay group to the same level with the units of the Akpınar formation elevating them in the axis of an asymmetrical anticline (Figure 3). The deformation on layers caused by the thrust line is clearly observed on Google Earth images and they were marked as blind thrust in front of the steeply dipping southern limb of the asymmetric anticline. The deformation caused by the thrust can no longer be traced to the west of Karaköy under the Hırka formation and younger formations (Figures 4a and b). According to field observations, it can be said that the Karaköy Blind Thrust were developed after the Akpınar formation, which is the youngest unit affected by deformation.

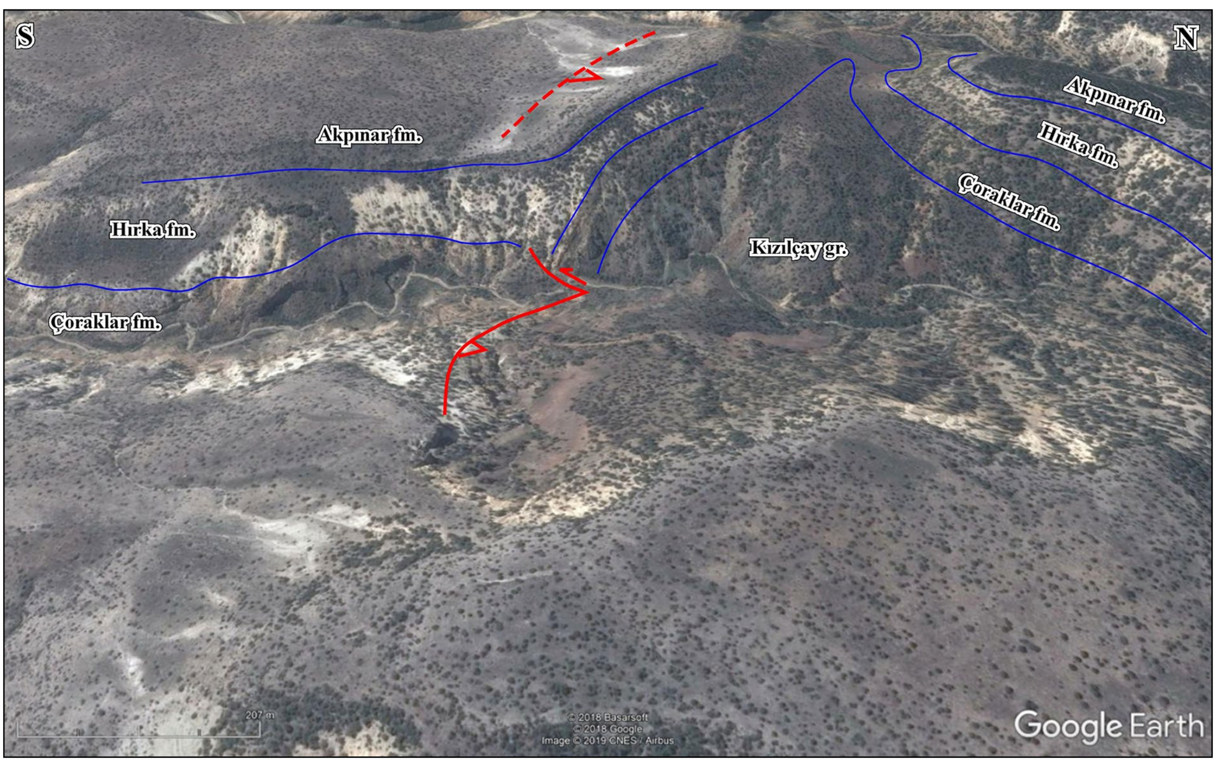

Figure 4- a) Karaköy Blind Thrust and south verging asymmetric anticline in the hanging wall. The boundaries of the units are marked on the inclined Google Earth image.

Figure 4- b) Field view of the steeply dipping southern limb of the asymmetric anticline used to determine the location of the Karaköy Blind Thrust. Note that the dipping of the units gradually decreases upwards.

3.2. Sekli Blind Thrust

The Sekli thrust has been noticed and mapped in almost all previous studies (Yağmurlu et al., 1988; Kavuşan, 1993*b*). To the north of Sekli village, the gray metamorphic rocks clearly thrusted on maroon-colored Kızılçay group sedimentary units (Figures 3 and 5a). The thrust zone was subjected to extensive shearing (Figure 5b). The Sekli thrust disappears under the Quaternary alluvium in east-northeast direction and continues in the west-southwest direction as blind thrust and back thrust. This feature was most clearly observed on the southwestern slopes of the Kocakızılbayır Hill (Figure 5c). It is observed that an asymmetric anticline is formed on the up thrown block of the fault affecting the Kızılçay group and the fault does not reach the surface (fault-propagation fold) (Figure 5c). The Sekli thrust, which is observed as a high angle reverse fault on the Uluköy - Karaköy road, is clearly observed on the Kızılmescit ridge on the western edge of the Aladağ stream. Here, it has deformed the Kızılçay group by thrusting with Çoraklar formation which unconformably overlies the metamorphic basement (Figure 5d). To the west of Aldere, it is clearly observed that the up thrown block of this thrust rises along the Çoraklar formation above the metamorphic basement (Figure 5e). Although the Sekli Blind Thrust is observed on the surface in some sections due to abrasion, it is a blind thrust as it is observed on the Kocakızılbayır Hill, and according to the field observations it can be said that it was developed at least after the Çoraklar formation.

3.3. Nalçabayırı Blind Thrust

This thrust has not been identified in previous studies (Figure 3). Only, Şahin et al. (2019) showed the presence of an asymmetric fold in Nalçabayır Hill. Looking from the east of Nalçabayır Hill to the west, the presence of the asymmetric anticline is clearly observed. As a coal quarry is active in this area, it is understood that the Hırka formation overlies

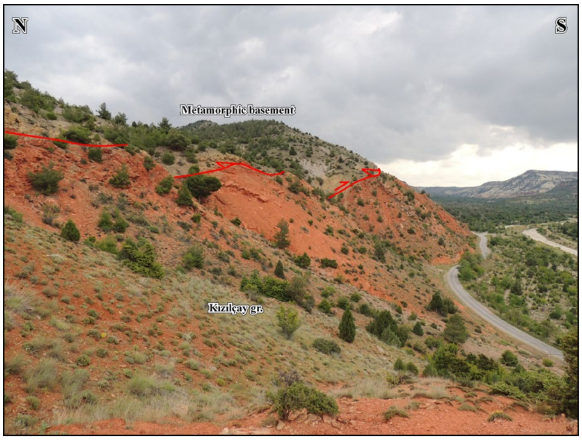

Figure 5- a) Field view of the Sekli Blind Thrust observed on the abraded surface. The north of Sekli village.

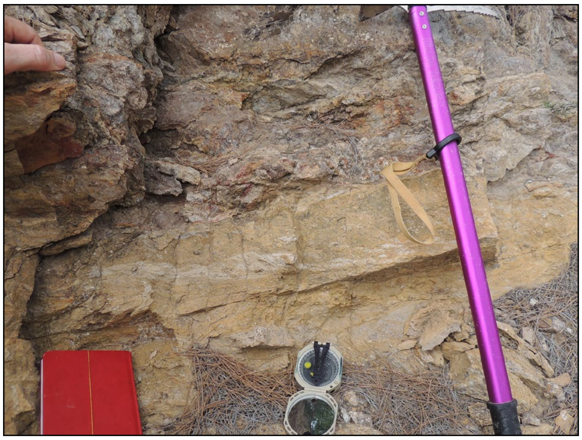

Figure 5- b) Intense shear zone belonging to the Sekli Blind Thrust. Looking north.

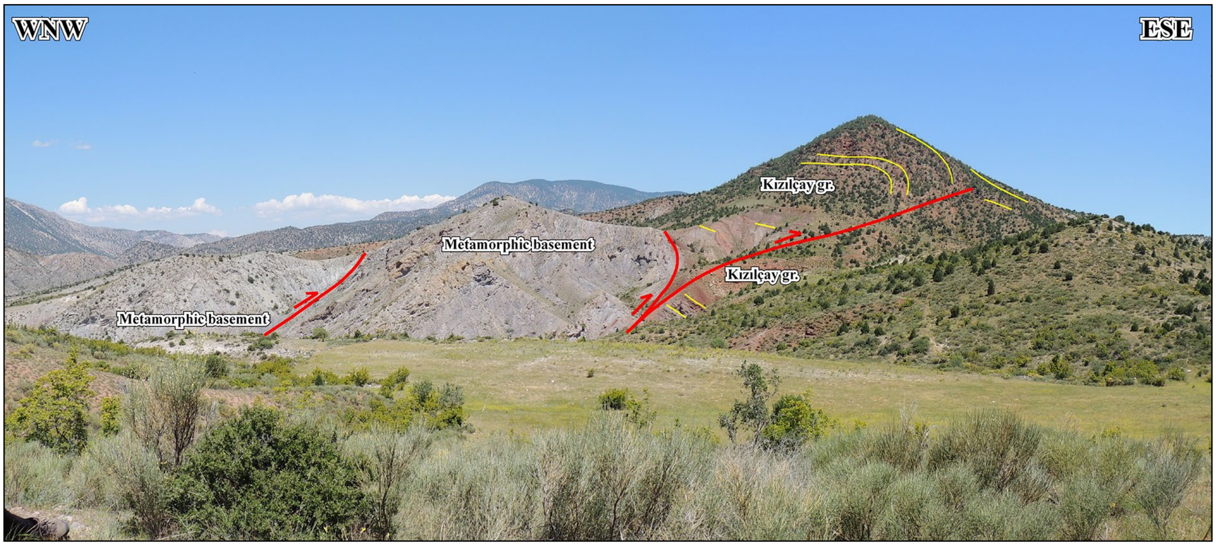

Figure 5- c) Field view of the Sekli Blind Thrust on the Kocakızılbayır Hill.

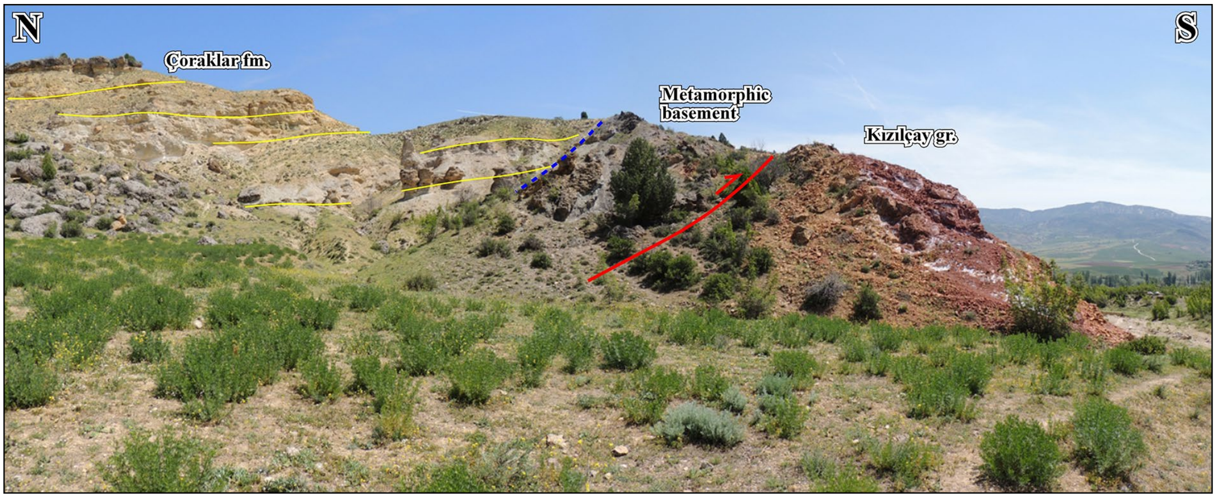

Figure 5- d) The tectonic contact between metamorphic basement together with overlying Çoraklar fm. and the Kızılçay group on the Kızılmescit ridge where the Sekli Blind Thrust can be observed on the surface.

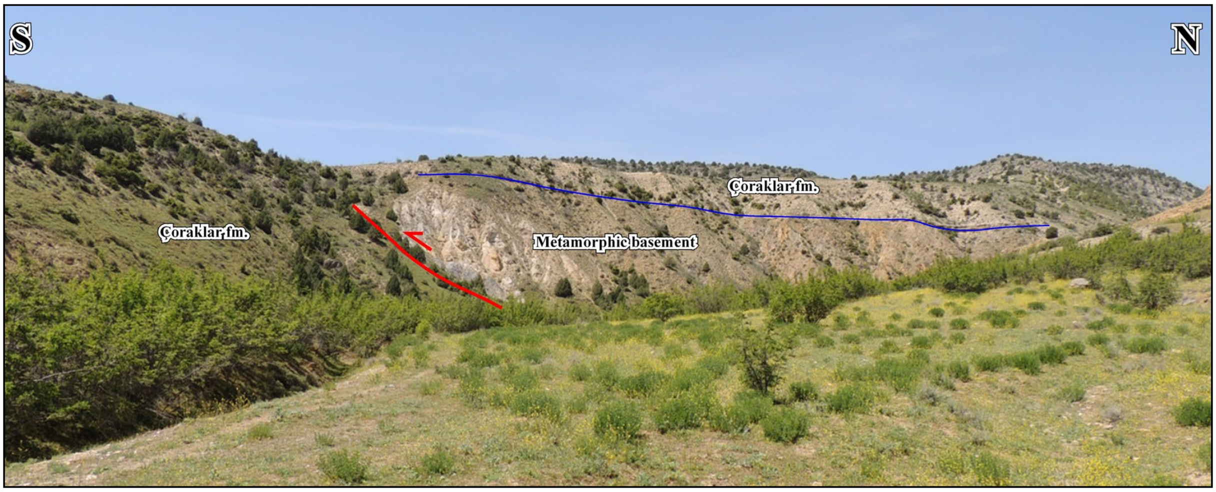

Figure 5- e) Sekli Blind Thrust in west of Aldere has brought the metamorphic basement over Çoraklar fm. To the west of this location, the thrust plane disappears under younger units.

the Çoraklar formation. The blind thrust can be hypothetically drawn just in front of the high angle southern limb of the asymmetric anticline (Figure 6a). The axis of the Nalçabayırı anticline is a structure plunging southwest. The asymmetric anticline also diminishes increasingly, as the movement on the blind thrust plane is most probably reduced laterally. It is possible to see the synthetic thrust planes and back thrust planes with hypothetical blind thrusts in the valley opening perpendicular to the axis in the area where the Nalçabayır anticline disappears (Figure 6b). They generally form a triangular zone (Figure 6c). The general position of the Nalçabayır asymmetrical anticline and the probable blind thrust were marked on the eastern slope of the valley opening perpendicular to the fold axis (Figure 6d). It is possible to say that the Nalçabayırı Blind Thrust was developed after the Akpınar formation.

3.4. Uzunbayır Blind Thrust

The north dipping Uzunbayır blind thrust passes through the Kaya Burnu locality to the southwest of the Akçabayır village and to the south of Aşıkkaya strait, and it extends to the north of the Uyku Çiftlik following the south of Uzunbayır ridge (Figure 3). In this area, the northwest dipping Çömlek Tepe normal Fault was defined by Yağmurlu et al. (1988) in previous studies. However, the Çoraklar formation overlies the Kızılçay group with an angular unconformity along the stated fault boundary, especially at the Çömlek Hill locality. On the other hand, when looking at the drainage lines on the southern and northern slopes of the Uzunbayır ridge, it is observed that the northward drainages are long and southward drainages are short. This shows that the Uzunbayır ridge is in fact an asymmetric fold. Its field evidence is located about 1.5 km northeast of

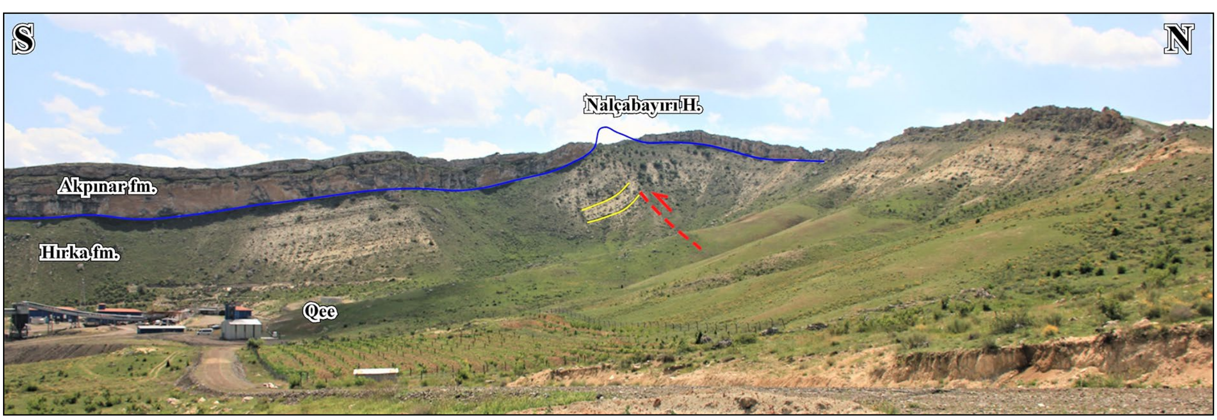

Figure 6- a) West plunging asymmetric anticline on the Nalçabayırı Tepe and the probable location of the Nalçabayırı Blind Thrust.

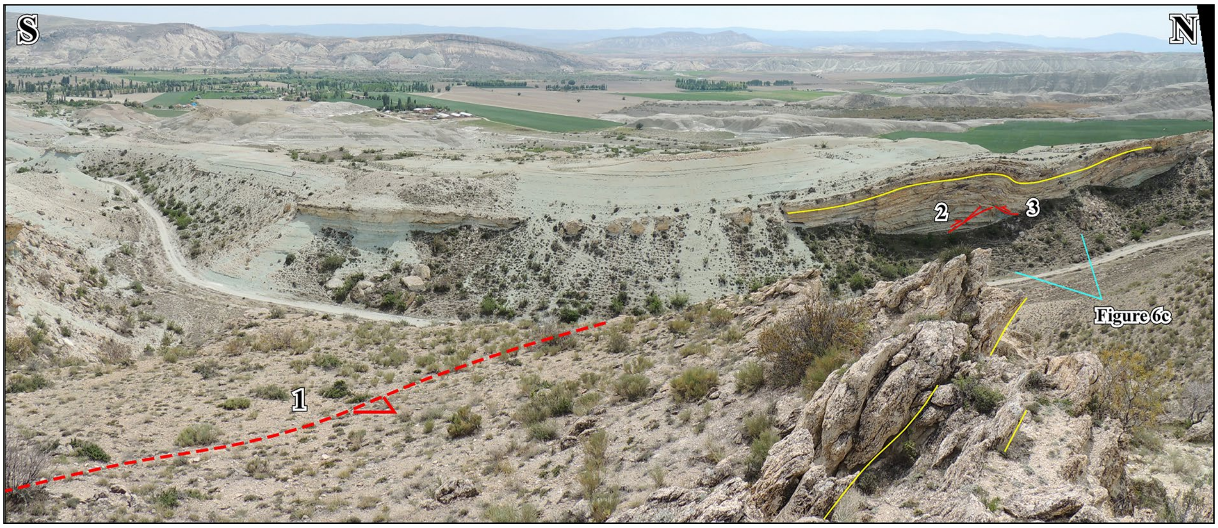

Figure 6- b) Triangle zone among (1) The Nalçabayırı Blind Thrust, (2) Back Thrust and (3) Synthetic Thrust. The position of the Nalçabayırı Blind Thrust was drawn in front of the steeply dipping limb of the asymmetric anticline.

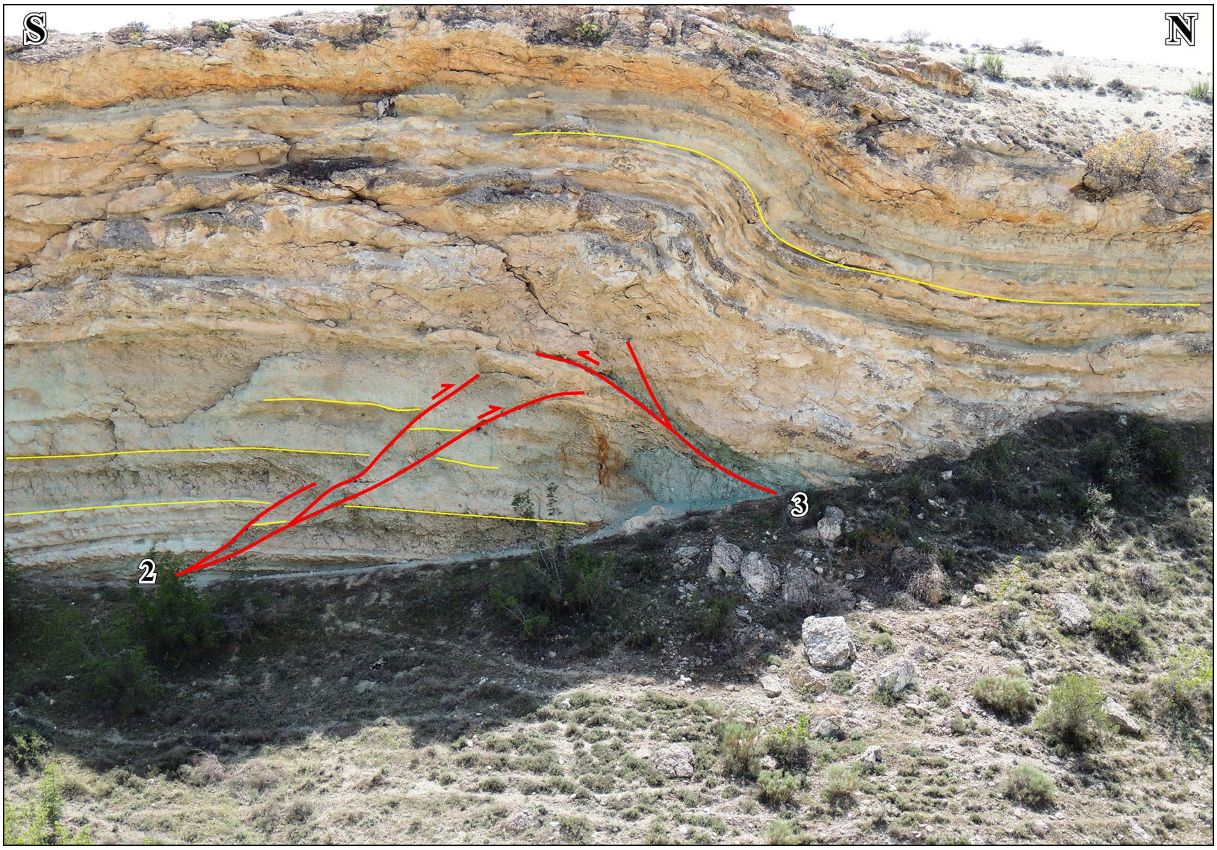

Figure 6- c) Close up view of; (2) the back thrust plane and (3) the synthetic thrust plane of the Nalçabayırı Blind Thrust.

the Davutoğlan in the Aşıkkaya strait opened by the Aladağ stream. The dipping increasing towards south can be easily observed in the layers (Figure 7a). The fault is named in this study as the Uzunbayır Blind Thrust, due to the name of the ridge.

Field observations related to the presence of Uzunbayır Blind Thrust are located at western and eastern ends of this fault in the study area. The shear zone observed in the west after passing the Çayırhan Bridge, 250 meters northwest in the direction of

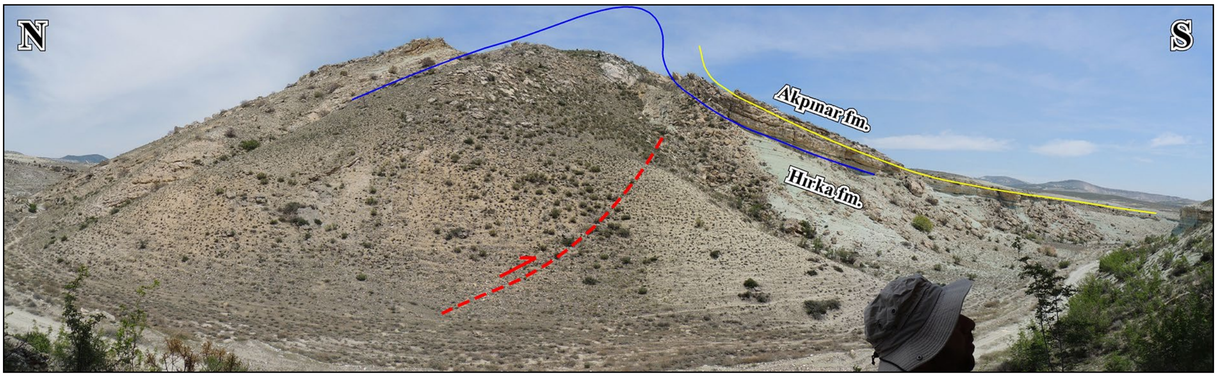

Figure 6- d) The probable position of the asymmetrical anticline and Nalçabayırı Blind Thrust on the Nalçabayırı Hill. This panoramic view shows the opposite slope of the figure 6c.

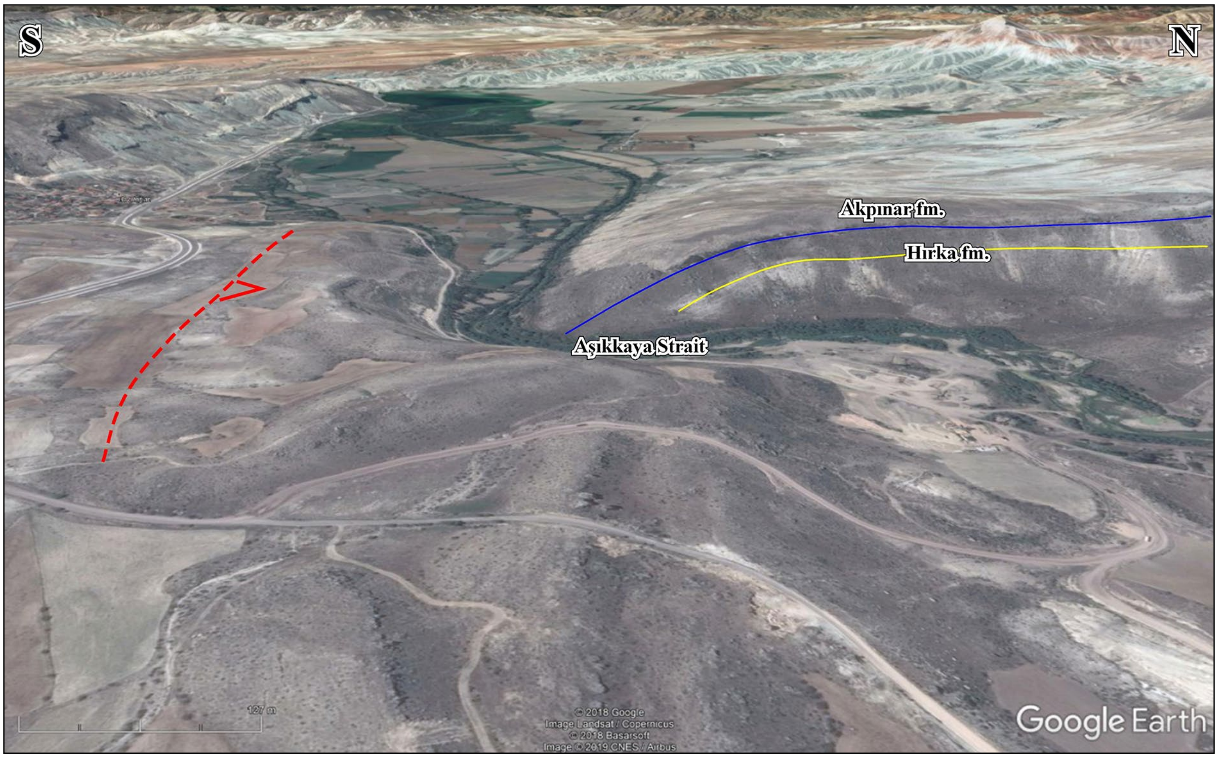

Figure 7- a) Inclined Google Earth image of the asymmetric anticline formed by the layers of the Akpınar and Hırka formations in the Aşıkkaya strait. The probable position of the Uzunbayır Blind Thrust in front of the 30° dipping limb is indicated by a dashed red line. The thrust planes can be traced on the surface at eastern and western edges of the study area. See figures 7b and c.

Nallıhan, belongs to the Uzunbayır Blind Thrust (Figure 7b).

It is interpreted that the Uzunbayır Blind Thrust and the Davutoğlan Back Thrust connect between the Kabalındoruk Tepe and Susuzdoruğu Tepe, which is located about 5 km northeast of Çayırhan and that the Uzunbayır Blind Thrust continues eastward towards the Bağözü (Figure 3). The observation point in east of the Uzunbayır Blind Thrust is in the valley opened by the Uyku Çiftlik creek, at 500 meters north of the Uyku Çiftlik, which is approximately 7 km northwest of Kuzkaya Hill (Figure 7c). In this position, which can be easily viewed on satellite images, the Uzunbayır Blind Thrust is observed on the surface, and the Çoraklar formation is placed over the younger Akpınar formation and disappears between the layers of the Akpınar formation (Figure 7d).

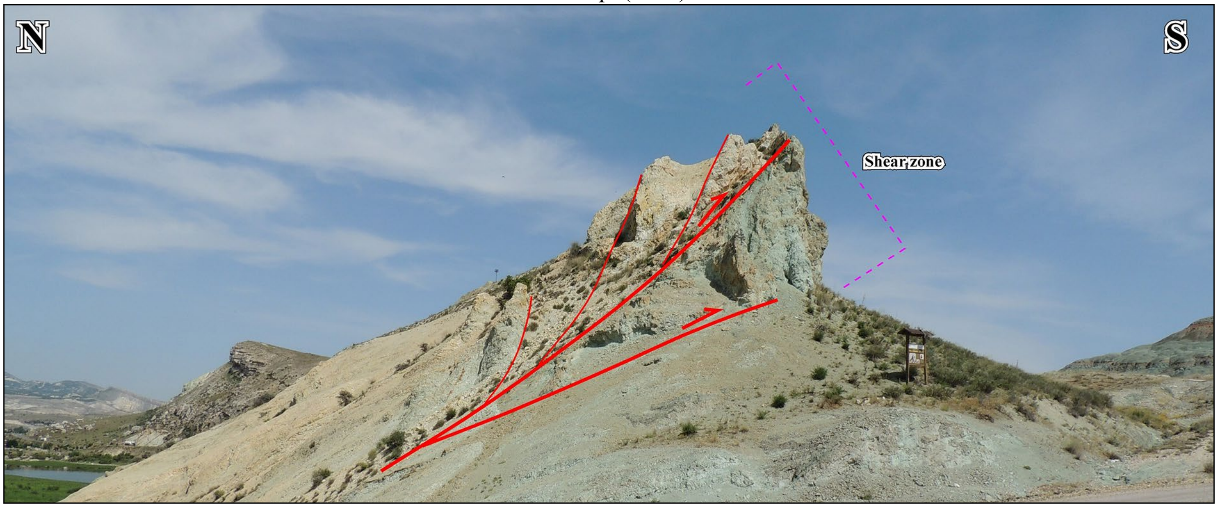

Figure 7- b) North dipping shear zone which can be traced on the surface as a continuation of the Uzunbayır Blind Thrust in the west of the study area. The west of the Çayırhan Bridge.

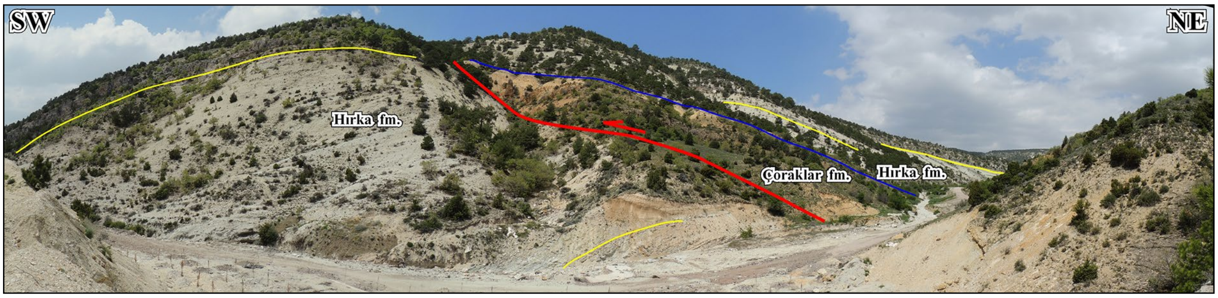

Figure 7-c) Panoramic view of the surface track of the Uzunbayır Blind Thrust in the Uyku Çiftlik creek in east of the study area. The Çoraklar fm. has been thrusted on the Hırka fm.

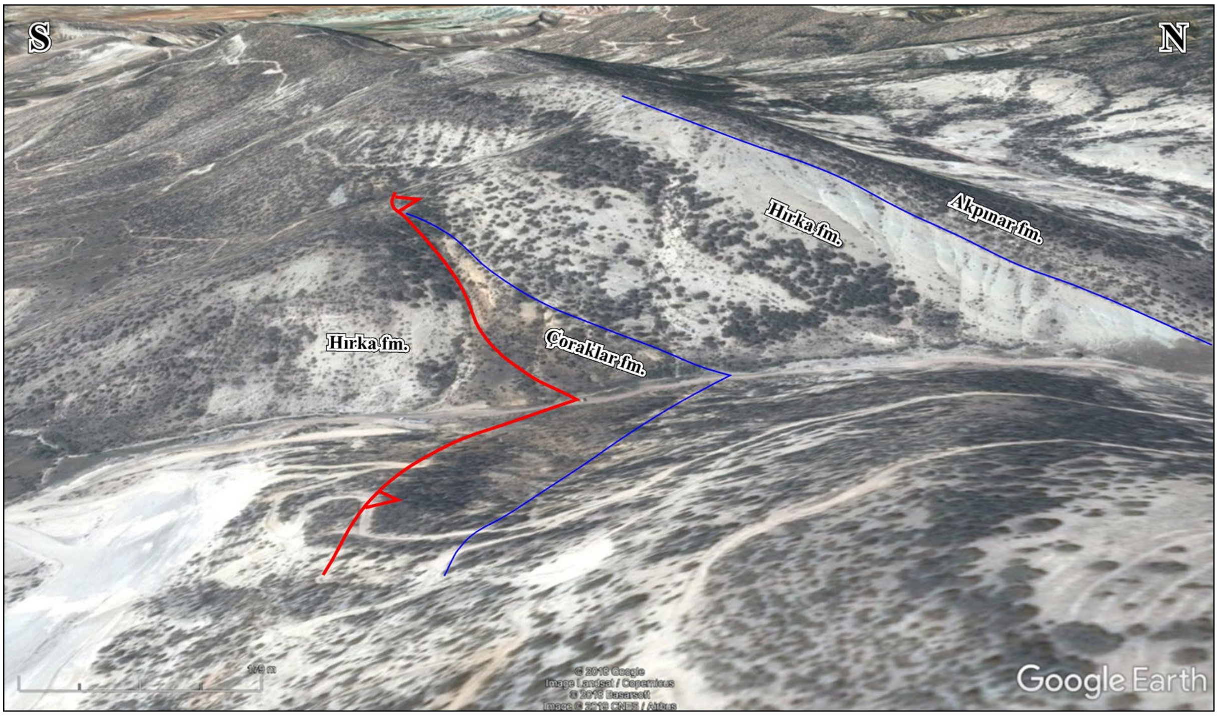

Figure 7-d) Inclined Google Earth image of the Uzunbayır Blind Thrust on the surface of the Uyku Çiftlik creek in the east of the study area.

3.5. Davutoğlan Back Thrust

It was named as the Davutoğlan Fault by previous investigators and defined as the northwest dipping normal fault by Yağmurlu et al. (1988) and Helvacı (2010), as northwest dipping reverse fault by Kavuşan (1993*b*) and as south dipping thrust fault by Şahin et al. (2019).

Helvacı (2010) starts the Davutoğlan Fault from the northwest of Beypazarı (near Zaviye) in the geological map and advances it towards west in reverse fault character. However, it is cut by the strike-slip fault near the Uyku Çiftlik, which is approximately 8 km northwest of Çayırhan, and continues from this point to the west as a normal fault character. On the other hand, Kavuşan (1993*b*) drew it as continuous, north dipping reverse fault. Lisenbee et al. (2010) defines the Davutoğlan Fault as a right-lateral strike-slip fault and explains folding around it by strike-slip faulting. According to this study, the fault passes to an anticline in the east and the offset becomes zero in the west. The recent study was carried out in the region by Şahin et al. (2019). They stated that the Davutoğlan Fault had gained the character of blind thrust in western end and dipped southward.

Our detailed field observations on the Davutoğlan Fault, which were evaluated in different ways in terms of both the fault character and the dip direction of the fault plane, are listed below.

The asymmetric anticline observed at the Kuzkaya Hill (Figure 3), approximately 2.5 km northeast of Çayırhan, indicates the presence of a south dipping blind thrust (Figure 8a). The kinematic indicators on the fault plane of the south dipping thrust are clearly observed in the road cut on the hill at 1 km east of the Davutoğlan Village (Figure 8b). Here, both the south dipping thrust plane and northward movement of the thrust were precisely determined by the position of the drag folds, and contrary to the southward thrusts dominantly observed in the region, it was named as the Davutoğlan Back Thrust (Figure 8b).

The northern slope of the Domuzkayası Hill located to the west of the Davutoğlan Village is another key location where all structural elements of the Davutoğlan Thrust are observed (Figure 8c). The Davutoğlan Back Thrust consists of the southern and northern branches. The southern branch is characterized by a well-developed ramp anticline, where the underlying Akpınar formation is uplifted and thrusted over the Bozbelen formation (Figure 8c). The northward movement on the southern branch of the Davutoğlan Thrust was clearly determined by the position of drag folds on the up thrown and down thrown blocks of the fault (Figure 8d). The northern branch of the Davutoğlan Thrust shows intense shearing, and the south dipping geometry of the shear plane is remarkable when looked at a closer distance (Figure 8e). The shear zone, which is more resistant to abrasion than its surroundings, forms an immediately noticeable elevation like a wall to the south of the Çayırhan - Nallıhan road (Figure 8f).

The northern branch of the Davutoğlan Back Thrust is also clearly observed between the Domuzkayası Hill and Davutoğlan village as a shear plane dipping

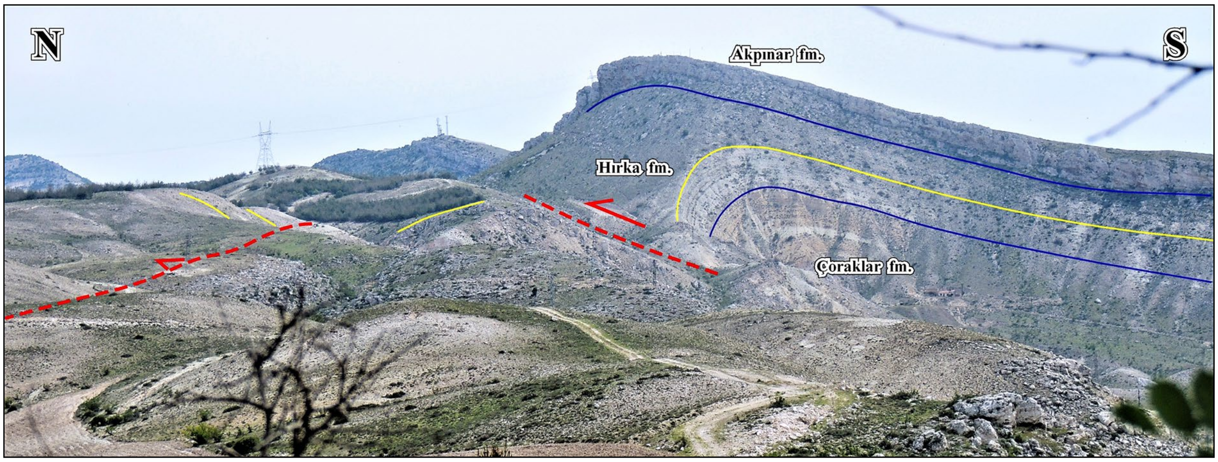

Figure 8- a) The location of the north verging asymmetric anticline on the Kuzkaya Hill and associated Davutoğlan Back Thrust. In the north, the traces of the Uzunbayır Blind Thrust on the surface are shown.

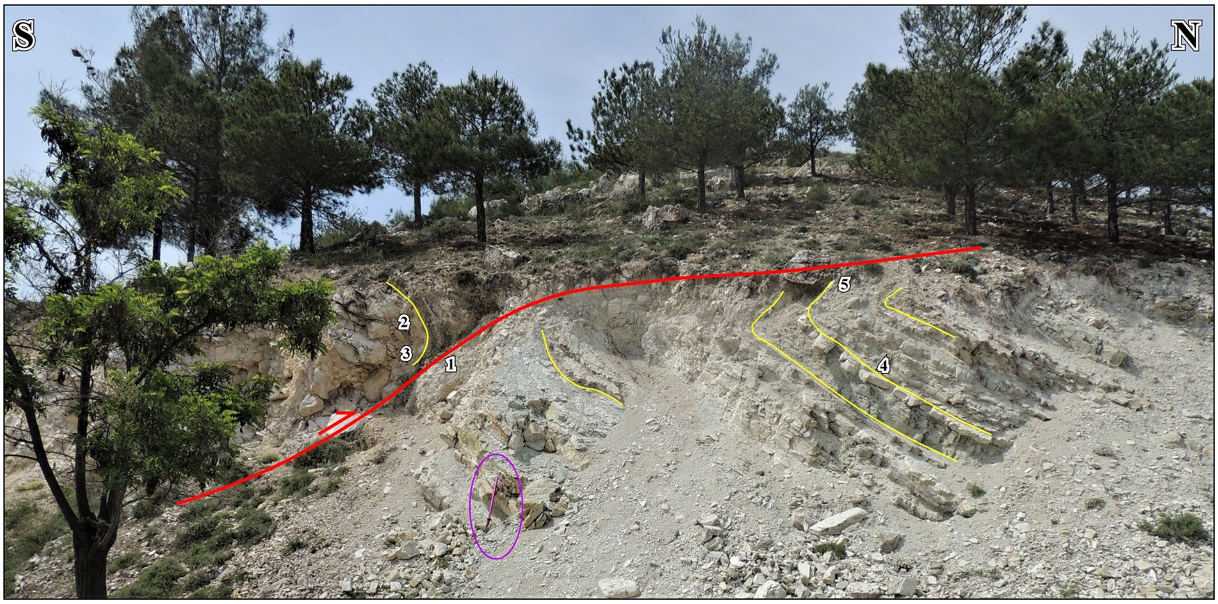

Figure 8-b) The Davutoğlan Back Thrust. The hanging wall has moved northward as drag folds show. The horizontal fold axis has E-W direction. (1) Fault plane: N 60 E, 35 SE; (2) Bedding: N 65 E, 65 NW; (3) Overturned bedding: N 30 E, 65 SE; (4) Bedding: E-W, 40N; (5) Overturned bedding: E-W, 55S.

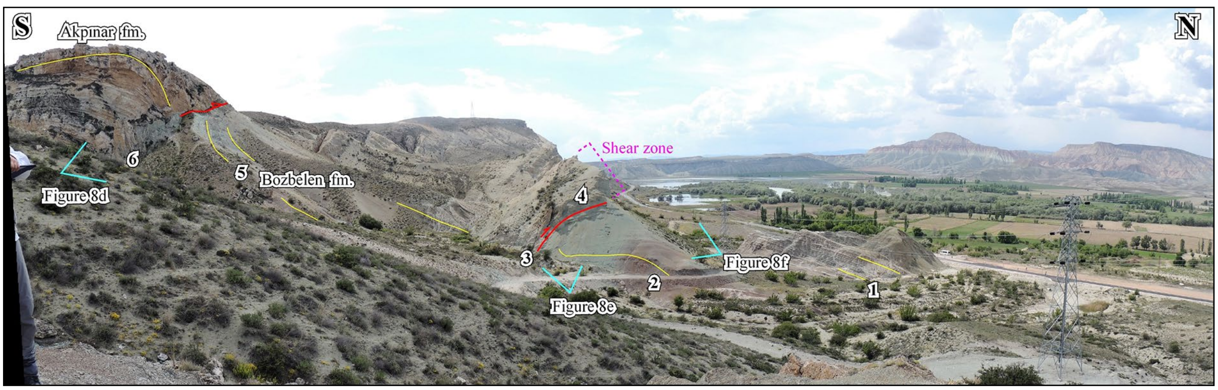

Figure 8- c) Panoramic photograph showing the position of the northern and southern branches of the Davutoğlan Back Thrust. The Akpınar fm. forming the north verging asymmetrical anticline on the up thrown block of the southern branch has been thrusted on the Bozbelen fm. The northern branch cuts the Bozbelen fm. (1) Bedding: N70E, 18NW; (2) Bedding: N60E, 30NW; (3) The fault plane of the northern branch: N70E, 55SE; (4) The location where the structural data is collected; (5) Bedding: N18E 55NW; (6) Bedding: N35E, 67NW.

south (Figure 3). Here, the asymmetric anticline created by the southern branch is clearly cut (Figure 8g). This relationship shows that the southern branch of the Davutoğlan Thrust was developed earlier than the northern branch and that an in-sequence thrust had taken place.

3.6. Beypazarı Blind Thrust

In previous studies, there has not been mentioned about main thrust passing through the south of Çayırhan except Seyitoğlu et al. (2017*a*), but the asymmetric fold axis has been shown in published geological maps (Yağmurlu et al., 1988; Kavuşan, 1993*b*; Helvacı, 2010; Şahin et al., 2019). Therefore, the structural relationship between the Beypazarı Blind Thrust and Davutoğlan Back Thrust has not been solved so far.

The criterion used for mapping of blind thrusts in the Southeastern Anatolia in Seyitoğlu et al. (2017*b*) was also applied to the Beypazarı blind thrust

Figure 8- d) Close-up view of the southern branch of the Davutoğlan Back Thrust. The northward movement of the fault is clearly observed from drag folds of up thrown and down thrown blocks. The photo was taken from the location (6) in figure 8c.

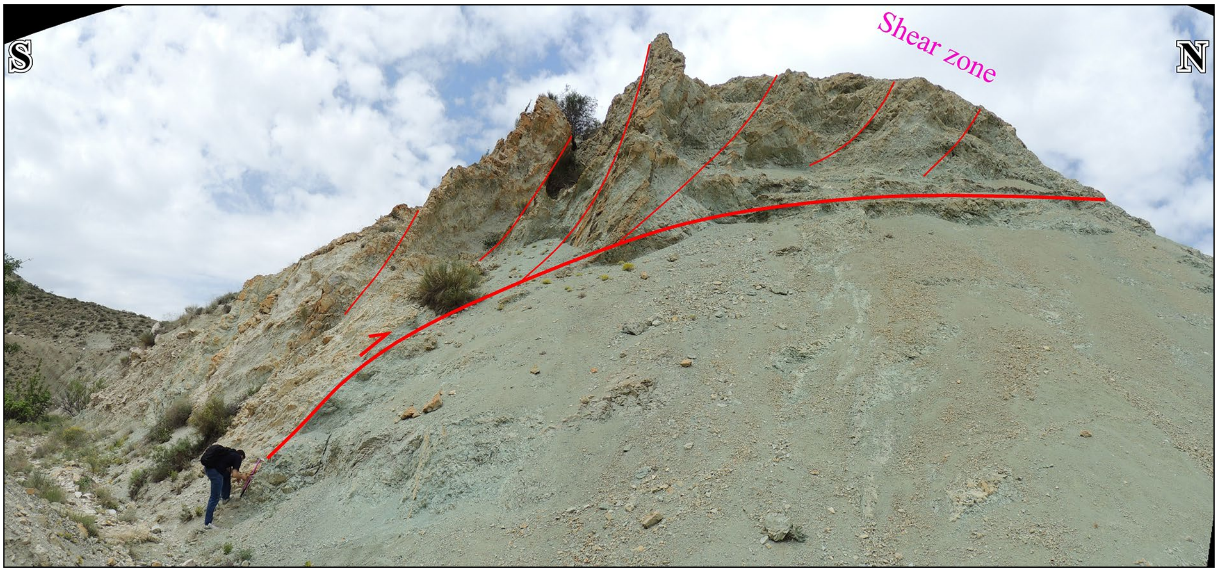

Figure 8- e) Close-up panoramic view of the northern branch of the Davutoğlan Back Thrust. The majority of the structural data of the fault was obtained from this location. The photo was taken from the location (3) in figure 8c.

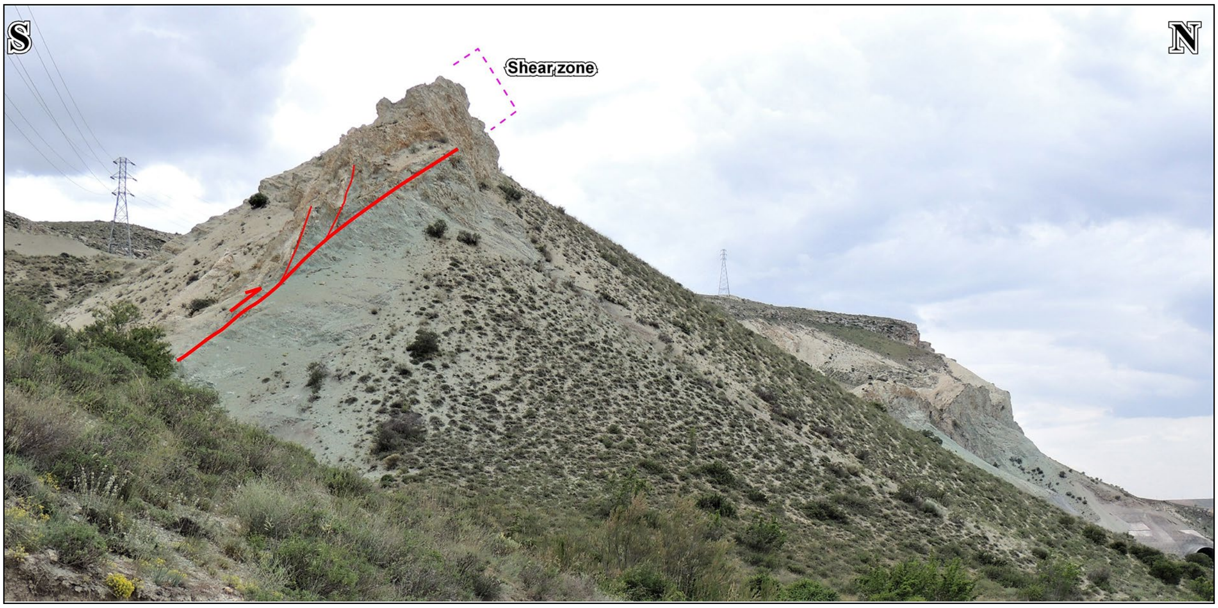

Figure 8- f) General view of the wall-like shear zone formed by the northern branch of the Davutoğlan Back Thrust in the Kuş Cenneti natural reserve area, south of the Çayırhan-Nallıhan highway.

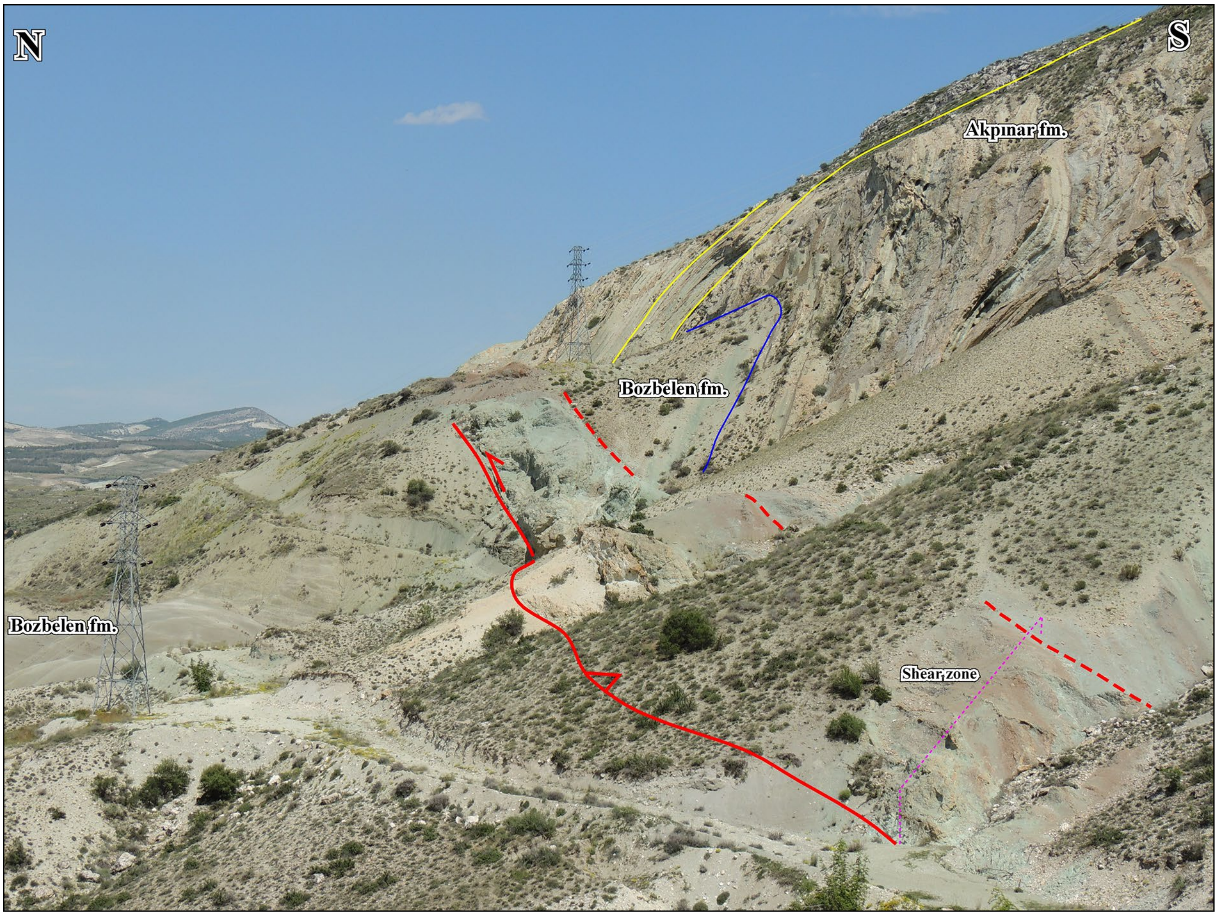

Figure 8- g) In the west of Davutoğlan village, photo showing the highly dipping limb of the asymmetric anticline formed by the southern branch of the Davutoğlan Back Thrust is cut by the northern branch. According to this observation, the Davutoğlan Back Thrust was evaluated as an in-sequence thrust.

(Seyitoğlu, 2017*a*) and a blind thrust line was drawn in front of the steeply dipping limb of the asymmetric anticline. Using the same criterion, it is observed that the Beypazarı blind thrust is divided into two branches when its continuity is observed by means of Google Earth images in the vicinity of Çayırhan to the southwest. The southernmost branch, Beypazarı Blind Thrust-I reaches Beypazarı passing from the south of 35° southeast dipping layers on the hills of Akkaya, Tahtalı and Öğlekayası. The northern branch, the Beypazarı Blind Thrust-II, on the other hand merges with the southern branch from Çayırhan following the northern coast of the Sarıyar Dam Lake.

The relationships of the faults and folds described above are shown on two geological cross-sections prepared from the geological map of the study area (Figure 3) (Figure 9a, b).

When all these observations are combined, it can be easily understood that the structures observed in the region between the Çayırhan-Davutoğlan and Sekli villages are the fault propagation folds of blind thrust systems.

4. Assessment of Structural Data

The fault plane and fault striation data collected from the field are shown on the map using the equal area lower hemisphere stereographic projection (Figure 3) and given as a table (Table 1). The FaultKin (Marrett and Allmendinger, 1990; Allmendinger et al., 2012) software was used for the kinematic analysis of fault data. Thus, the locations of the kinematic axes and the contraction and extension directions in relation to the faults were determined (Figure 3). Then, the fault plane solutions were generated utilizing the same software (Figure 10) and their compatibility with the structures in the field was evaluated in general.

The structural data obtained from thrust/reverse fault planes in the Kızılçay group, which are very close to the surface sections of the Sekli Blind Thrust and the data acquired from tear faults were shown on the stereonet plots 1, 2 and 3 in Figure 3. The combined assessment of these data shows that the Sekli Blind Thrust is NW dipping thrust with left lateral component which compensates NNW-SSE directing contraction (Figure 10a).

Striations obtained from the synthetic fault planes of the Nalçabayırı Blind Thrust (Figure 3; stereonet no: 4) show that NW-SE directing contraction is compensated by this fault (Figure 10b).

When data obtained from the location, which is considered as the section observed on the surface of the Uzunbayır Blind Thrust (Figure 3, stereonet no: 5)

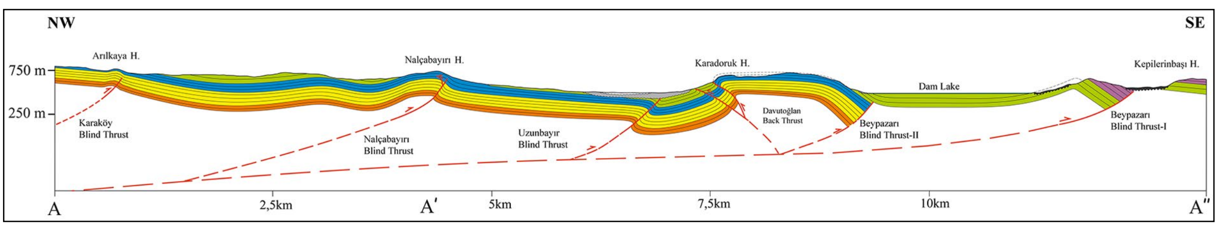

Figure 9- a) Geological cross section passing from the west of the study area that shows the internal structure of the Beypazarı Blind Thrust Zone. See figure 3 for location.

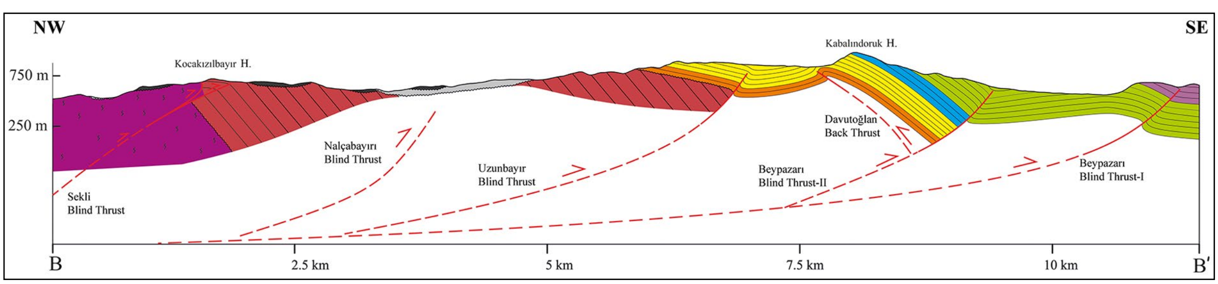

Figure 9- b) Geological cross section passing from the east of the study area that shows the internal structure of the Beypazarı Blind Thrust Zone. See figure 3 for location.

is assessed together, it shows that the Uzunbayır Blind Thrust, NW dipping thrust with left lateral component corresponds to the NW-SE contraction (Figure 10c).

The Davutoğlan Back Thrust is the structure in which the most kinematic data were collected in the study area (Figure 3; stereonet no: 6, 7, 8, 9, 10 and 11), and the combined assessment of the structural data shows that it is the thrust that has SW dipping, right lateral component meeting the NW-SE contraction (Figure 10d).

The overall evaluation of all data reveals the presence of a NW-SE-directed contraction in the region, such as individual thrusts (Figures 3 and 10 e), and this result is highly consistent with the overall assessment of data obtained from the focal mechanism solutions (Seyitoğlu et al., 2017*a*) (Figure 10f).

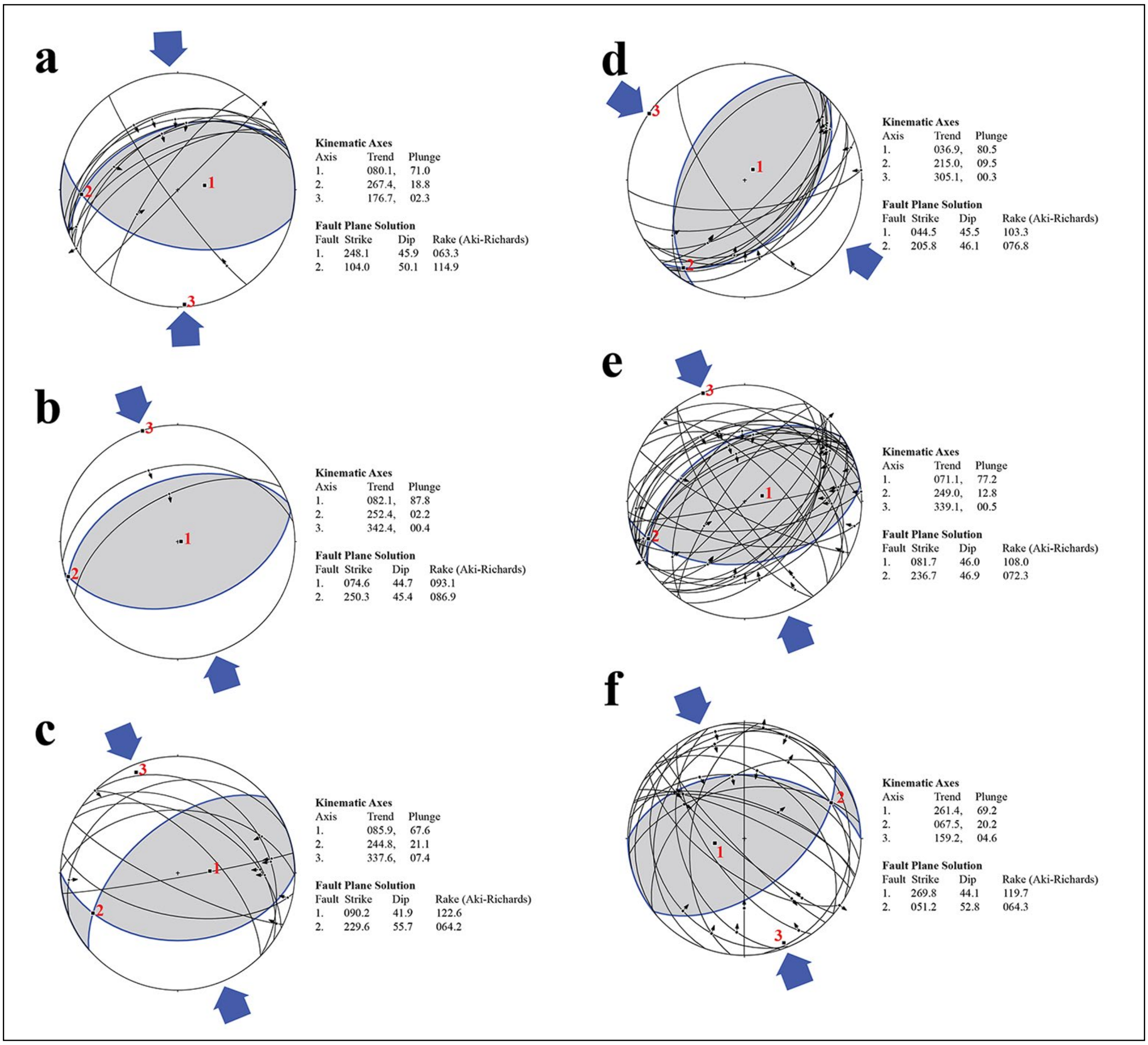

Figure 10- The analysis of kinematic data obtained from the faults in the study area. The gray area and the associated fault planes indicated by blue represent the fault plane solution. Accordingly, the blue arrows indicate the direction of contraction. This analysis was performed by FaultKin (Marrett and Allmendinger, 1990; Allmendinger et al., 2012) software. a) Fault planes of the Sekli Blind Thrust (Figure 3; measurements at locations 1, 2 and 3), b) Fault planes of the Nalçabayırı Blind Thrust (Figure 3; measurements at location 4), c) Fault planes of the Uzunbayır Blind Thrust (Figure 3; measurements at location 5), d) Fault planes of the Davutoğlan Back Thrust (Figure 3; measurements at locations 6, 7, 8, 9, 10 and 11), e) All fault planes measured in the region. See table 1 for kinematic data, f) The kinematic analysis of the fault data obtained from the focal mechanism solutions in the eastern part of the Beypazarı Blind Thrust Zone (Seyitoğlu et al., 2017*a*).

5. Discussion

In a recent study carried out in east-northeast of the study area (Seyitoğlu et al., 2017*a*), the Beypazarı Blind Thrust Zone has been defined and shown that this thrust has been formed by Başören and Kilci blind thrusts and the Erenler Back Thrust which can be traced on the surface. In this study, which was performed in the Çayırhan northern continuity of the Beypazarı Blind Thrust Zone, both the presence of blind thrusts from the outcrops in deep incised valleys and the sections that can be observed on the surface due to the erosion were proved. Besides, the structural data showing the movement directions of the faults were collected (presence of striations and drag folds). With the help of these data, the systematic relationships of the faults interpreted by different researchers in different ways in the study area were revealed and evaluated. Accordingly, the Beypazarı Blind Thrust Zone around Çayırhan consists of blind thrusts and back thrusts observed over a wide area. To order them from north to south, the Karaköy Blind Thrust was only noticed by the presence of the asymmetric anticline with a vergence to the south (Figure 4a, b). The Sekli Blind Thrust has been identified in previous studies and is clearly observed on the abraded surface (Siyako, 1983; Yağmurlu et al., 1988; Kavuşan, 1993*b*; Helvacı, 2010). However, the presence of fault propagation folds observed on the Kocakızılbayır Tepe in this study (Figure 5c) shows that this fault developed as a blind thrust. The Nalçabayırı Blind Thrust was also determined by the development of the asymmetric anticline and it was clearly observed that the back thrust and synthetic thrust planes formed a triangular zone (Figures 6b, c). The Uzunbayır Blind thrust was noticed by an asymmetric anticline in Aşıkkaya Boğazı and its presence was proved by the abrasion zone observed on the surface (Figure 7b) in the west and the thrust plane (Figure 7c) in the deep excavated valley in the east. The Davutoğlan Fault, which was the most emphasized by the previous studies in the study area and made different interpretations, was considered to be the Davutoğlan Back Thrust. When folding and faulting relations and structural data collected from the fault zone were evaluated together, it was understood that the character of the fault was thrust. However, it is also possible that this zone of weakness is used by a strike-slip fault. However, as Lisenbee et al. (2010) pointed out in their study that the Davutoğlan Fault disappeared within a relatively short distance for strike-slip faults on the surface. As a result, unlike all the thrusts in the region, the structure called the Davutoğlan Back Thrust, is south dipping and created north verging asymmetric folding (Figure 8c). It is considered that the Beypazarı Blind Thrust, the end most member of the Beypazarı Blind Thrust Zone, was developed as two separate branches (I and II) in the study area and that all the thrusts in deep were connected to a single shear zone (Figures 9a, b).

6. Results

The Beypazarı Blind Thrust Zone consists of Karaköy, Sekli, Nalçabayırı, Uzunbayır blind thrusts and the Davutoğlan Back Thrust and Beypazarı Blind Thrust I-II faults around Çayırhan. All of the asymmetric anticlines developed with blind thrusts show vergence to the south, except for those associated with the Davutoğlan Back Thrust. An anticline called the Çayırhan dome (Kavuşan, 1993*b*) in the literature developed between the Davutoğlan Back Thrust and Beypazarı Blind Thrust-II. The Beypazarı Blind Thrust Zone is seismically active and it is one of the neotectonic structures developed between the North Anatolian Fault Zone, Eskişehir Fault Zone and Kırıkkale-Erbaa Fault Zone (Seyitoğlu et al., 2017*a*).

Acknowledgements

This article is a part of the MSc thesis of the first author who is about to complete it in the Tectonics Research Group of Ankara University. It was benefited from the field support given by the Faculty of Engineering of Ankara University to the “Advanced Geological Mapping” courses. We appreciate a lot for this opportunity. In addition, we would like to thank to Efe Demirci, the member of the Tectonics Research Group, for his contributions during field studies and to referees Prof. Dr. Yaşar Eren and Assoc. Prof. Dr. Volkan Özaksoy for their constructive contributions.

References

Aksoy, C.O., Onargan, T., Yenice, H., Küçük, K., Köse, H. 2006. Determining the stress and convergence at Beypazarı trona field by three-dimensional elastic-plastic finite element analysis: A case study. International Journal of Rock Mechanics and Mining Sciences 43, 166-178.

Allmendinger, R.W., Cardozo, N.C., Fisher, D. 2012. Structural Geology Algorithms: Vectors and Tensors. Cambridge University Press, 289 p.

Apaydın, A. 2010. Relation of tectonic structure to groundwater flow in the Beypazarı region, NW Anatolia, Turkey. Hydrogeology Journal 18, 1343- 1356.

Bechtel, A., Karayiğit, A.İ., Sachsenhofer, R.F., İnaner, H., Christanis, K., Gratzer, R. 2014. Spatial and temporal variability in vegetation and coal facies as reflected by organic petrological and geochemical data in the Middle Miocene Çayırhan coal field (Turkey). International Journal of Coal Geology 134/135, 46-60.

Demirci, C.Y. 2000. Structural Analysis in Beypazarı-Ayaş-Kazan-Peçenek Area, NW of Ankara (Turkey). Doktora Tezi, Orta Doğu Teknik Üniversitesi Fen Bilimleri Enstitüsü, 178 s, Ankara.

Diker, S., Çelik, M., Kadıoğlu, Y.K. 2006. Fingerprints of the formation of geothermal springs on the granitoids: Beypazarı-Ankara, Turkey. Environmental Geology 51, 365-375.

Emre, Ö., Duman, T.Y., Özalp, S., Elmacı, H., Olgun, Ş., Şaroğlu, F. 2013. Türkiye Diri Fay Haritası. Maden Tetkik ve Arama Genel Müdürlüğü, Özel Yayın Serisi 30, Ankara.

Esat, K. 2011. Ankara çevresinde Orta Anadolu'nun neotektoniği ve depremselliği. Doktora Tezi, Ankara Üniversitesi Fen Bilimleri Enstitüsü, 144 s, Ankara.

Esat, K., Seyitoğlu, G. 2010. Neotectonics of North Central Anatolia: A strike-slip induced compressional regime. Tectonic Crossroads: Evolving Orogens of Eurasia-Africa-Arabia, 4-8 October 2010, Ankara, p.38.

Esat, K., Çıvgın, B., Kaypak, B., Işık, V., Ecevitoğlu, B., Seyitoğlu, G. 2014. The 2005-2007 Bala (Ankara, Central Turkey) earthquakes: a case study for strike-slip fault terminations. Geologica Acta 12(1), 71-85.

Esat, K., Kaypak, B., Işık, V., Ecevitoğlu, B., Seyitoğlu, G. 2016. The Ilıca branch of the southeastern Eskişehir Fault Zone: an active right-lateral strike-slip structure in central Anatolia, Turkey. Bulletin of the Mineral Research and Exploration 152, 25-37.

Esat, K., Seyitoğlu, G., Ecevitoğlu, B., Kaypak, B. 2017. Abdüsselam Kıstırılmış Tektonik Kaması: KB Orta Anadolu'da daralma rejimiyle ilişkili bir Geç Senozoyik yapısı. Yerbilimleri 38, 33-56.

Garcia-Veigas, J., Gündoğan, İ., Helvacı, C., Prats, E. 2013. A genetic model for Na-carbonate mineral precipitation in the Miocene Beypazarı trona deposits, Ankara province, Turkey. Sedimentary Geology 294, 315-327.

Helvacı, C. 2010. Geology of the Beypazarı trona field, Ankara, Turkey. Tectonic Crossroads: Evolving Orogens of Eurasia-Africa-Arabia, Ankara, Turkey. Mid-congress field exursions guide book, 1-33.

Helvacı, C., Yılmaz, H., İnci, U. 1981. Beypazarı (Ankara) yöresi Neojen tortullarının kil mineralleri ve bunların dikey ve yanal dağılımı. Jeoloji Mühendisliği Dergisi 32/33, 33-42.

Helvacı, C., Öztürk, Y.Y., Satır, M., Shang, K.C. 2014. U-Pb zircon and KAr geochronology reveal the emplacement and cooling history of the Late Cretaceous Beypazarı granitoid, central Anatolia, Turkey. International Geology Review 56(9), 1138-1155. DOI: 10.1080/00206814.2014.921795

İnci, U. 1991. Miocene alluvial fan-alkaline playa lignitetrona bearing deposits from an inverted basin in Anatolia: sedimentology and tectonic controls on deposition. Sedimentary Geology 71, 73-97.

Kalafatçıoğlu, A., Uysallı, H. 1964. Geology of The Beypazarı - Nallıhan - Seben Region. Bulletin of the Mineral Research and Exploration 62, 1-11.

Karadenizli, L. 1995. Beypazarı havzası (Ankara batısı) üst Miyosen-Pliyosen jipsli serilerinin sedimantolojisi. Türkiye Jeoloji Bülteni 38, 63-74.

Kavuşan, G. 1993*a*. Beypazarı-Çayırhan linyitleri hümik asitlerin IR-Spektrofotometrik incelenmesi. Bulletin of the Mineral Research and Exploration 115, 91-98.

Kavuşan, G. 1993*b*. Beypazarı-Çayırhan kömür havzası linyitlerinin yataklanmasında tektonizmanın önemi. Doğa-Türk Yerbilimleri Dergisi / Turkish Journal of Earth Sciences 2, 135-145.

Kazancı, N. 2012. Kuvaterner birimlerinin haritalanması. Kazancı, N., Gürbüz, A. (Ed.), Kuvaterner Bilimi. Ankara Üniversitesi Yayını 350, 463-470.

Lisenbee, A.L., Uzunlar, N., Terry, M. 2010. The Davutoglan Wrench Fault: Intra-Anatolian Plate, Neogene Deformation, Ankara Province, Turkiye. Tectonic Crossroads: Evolving Orogens of Eurasia-Africa-Arabia, 4-8 October 2010, Ankara, p.38.

Marrett, R., Allmendinger, R.W. 1990. Kinematic analysis of fault-slip data. Journal of Structural Geology 12(8), 973-986.

Orti, F., Gündoğan, İ., Helvacı, C. 2002. Sodium sulphate deposits of Neogene age: the Kirmir Formation, Beypazarı basin, Turkey. Sedimentary Geology 146, 305-333.

Özçelik, O. 2002. Beypazarı (Ankara) kuzeyinde Miyosen yaşlı bitümlü birimlerin organik jeokimyasal özellikleri. Türkiye Jeoloji Bülteni 45, 1-17.

Özçelik, O., Altunsoy, M. 2005. Organic geochemical characteristics of Miocene bituminous units in the Beypazarı basin, central Anatolia, Turkey. The Arabian Journal for Science and Engineering 30, 181-194.

Özgüm, C., Gökmenoğlu, O., Erduran, B. 2003. Ankara, Beypazarı doğal soda (trona) sahası izotop hidrolojisi çalışmaları. Jeoloji Mühendisliği Dergisi 27, 3-16.

Özpeker, I., Çoban, F., Esenli, F., Eren, R.H. 1991. Miyosen yaşlı Hırka formasyonundaki (Beypazarı-Ankara) dolomitlerin mineralojik özellikleri. Türkiye Jeoloji Bülteni 34, 23-26.

Pehlivanlı, B.Y., Koç, Ş., Sarı, A., Engin, H. 2014. Factors controlling low Uranium and Thorium concentrations in the Çayırhan Bituminous shales in the Beypazarı (Ankara) area, Turkey. Acta Geologica Sinica 88, 248-259.

Randot, J. 1956. 1/100.000 lik 39/2 (Güney kısmı) ve 39/4 nolu paftaların jeolojisi. Seben-Nallıhan-Beypazarı ilçeleri. Maden Tetkik ve Arama Genel Müdürlüğü, Rapor No: 2517, Ankara (unpublished).

Seyitoğlu, G., Aktuğ, B., Karadenizli, L., Kaypak, B., Şen, Ş., Kazancı, N., Işık, V., Esat, K., Parlak, O., Varol, B., Saraç, G., İleri, İ. 2009. A late Pliocene - Quaternary pinched crustal wedge in NW Central Anatolia, Turkey: a neotectonic structure accommodating the internal deformation of the Anatolian Plate. Geological Bulletin of Turkey 52(1), 121-154.

Seyitoğlu, G., Ecevitoğlu, B., Kaypak, B., Güney, Y., Tün, M., Esat, K., Avdan, U., Temel, A., Çabuk, A., Telsiz, S., Uyar Aldaş, G. 2015. Determining the main strand of the Eskişehir strike-slip fault zone using subsidiary structures and seismicity: a hypothesis tested by seismic reflection studies. Turkish Journal of Earth Sciences 24, 1-20

Seyitoğlu, G., Esat, K., Kaypak, B. 2017*a*. One of the main neotectonic structures in the NW central Anatolia: Beypazarı Blind Thrust Zone and related fault-propagation folds. Bulletin of the Mineral Research and Exploration 154, 1-14.

Seyitoğlu, G., Esat, K., Kaypak, B. 2017*b*. The neotectonics of southeast Turkey, northern Syria and Iraq: the internal structure of the South East Anatolian Wedge and its relationship with the recent earthquakes. Turkish Journal of Earth Sciences 26, 105-126.

Siyako, F. 1983. Beypazarı (Ankara) linyitli Neojen havzası ve çevresinin jeoloji raporu. Maden Tetkik ve Arama Genel Müdürlüğü, Rapor No: 7431, 46 s., Ankara (unpublished).

Suner, M.F. 1993. The Beypazarı trona deposits. Földtani Közlöny 123(3), 271-282.

Şahin, M., Yaltırak, C., Karacık, Z. 2019. A case study of compression to escape tectonic transition: Tectonic evolution of the Nallıhan Wedge and comparison with the Tercan Wedge (Eastern Mediterranean, Turkey). Journal of Asian Earth Sciences 174, 311-331.

Şaroğlu, F., Emre, Ö., Kuşçu, İ. 1992. 1/1.000 ölçekli Türkiye diri fay haritası. Maden Tetkik ve Arama Genel Müdürlüğü, Ankara.

Şener, M. 2007. Depositional conditions of the coal-bearing Hırka Formation beneath Late Miocene explosive volcanic products in NW central Anatolia, Turkey. Journal of Earth System Science 116, 125-135.

Yağmurlu, F., Helvacı, C., İnci, U., Önal, M. 1988. Tectonic characteristics and structural evolution of the Beypazarı and Nallıhan Neogene basin, central Anatolia. METU Journal of Pure and Applied Sciences 21, 127-143.