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A Late Pliocene - Quaternary Pinched Crustal Wedge in NW Central Anatolia, Turkey: A Neotectonic Structure Accommodating the Internal Deformation of the Anatolian Plate

KB Orta Anadolu'da Geç Pliyosen – Kuvaterner Kıstırılmış Kabuksal Tektonik Kama: Anadolu Levhasının iç Deformasyonunu Üstlenen Bir Neotektonik Yapı

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ABSTRACT

The Neo-Tethyan suture zone in the western margin of the Çankırı basin (NW central Anatolia, Turkey) has been reactivated as a pinched crustal wedge due to a NW – SE compression created by the right lateral North Anatolian Fault Zone and the Kırıkkale – Erbaa Fault Zone. This neotectonic structure, the Eldivan-Elmadağ pinched crustal wedge-(EPCW), having a thrusted eastern and normal faulted western margin, has accommodated a 2.8 km shortening since the Late Pliocene. This result accords with the model in which the Anatolian plate is squeezed from the east rather than pulled from the southwest. The EPCW, a recently active structure, should be regarded as a potential source in the earthquake risk assessment of central Anatolia, particularly for the capital city Ankara and for Çankırı.

Keywords: Neotectonics, Central Anatolia, GPS, Seismicity, Turkey

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ÖZ

Sağ yanal Kuzey Anadolu Fayı Zonu ve Kırıkkale-Erbaa Fay Zonu tarafından yaratılan KB-GD sıkışma sonucu Çankırı havzasının batı kenarında Neo-Tetis kenet zonu tektonik kama şeklinde yeniden hareketlenmiştir. Eldivan-Elmadağ Kıstırılmış Tektonik Kaması (EKTK) adı verilen bu neotektonik yapı, bindirme faylı doğu kenarına ve normal faylı batı kenarına sahip olup, Geç Pliyosen'den beri 2.8 km'lik kısalmayı karşılamaktadır. Bu sonuç Anadolu levhasının GB'dan çekilmesi modelinden ziyade doğudan itilmesi modeli ile uyumludur. Güncel olarak aktif bir yapı olan EKTK, Orta Anadolu'nun özellikle başkent Ankara ve Çankırı'nın deprem riski değerlendirilmesinde potansiyel kaynak olarak algılanmalıdır.

Anahtar Kelimeler: *Neotektonik, Orta Anadolu, Küresel Konumlama Sistemi, Depremsellik, Türkiy*

INTRODUCTION

There is agreement about the closure of the northern branch of the Neo-Tethys during Cretaceous and Eocene times along the north dipping subduction that produced the İzmir - Ankara- Erzincan suture zone in Anatolia, Turkey (Şengör and Yılmaz, 1981; Tüysüz et al., 1995; Erdoğan et al., 1996; Görür et al., 1998; Okay and Tüysüz, 1999). However, debate continues concerning the post-collisional tectonic evolution of central Anatolia. Following the classical "neotectonic ova regime" view of Şengör (1979; 1980), Görür et al. (1998) suggested that the neotectonic period in central Anatolia started at the middle to late Miocene with an intracratonic basin development. Koçyiğit et al. (1995) proposed another hypothesis, claiming that the intracontinental convergence related to the closure of the Neo-Tethys, i.e. "the Ankara Orogenic Phase", continuing until late Pliocene. Alternatively, Seyitoğlu et al. (1997) suggest that post-collisional intracontinental convergence gave way to the extensional tectonics at the beginning of the Miocene, probably due to orogenic collapse, and that the effect of the North Anatolian Fault Zone can be seen in the region following Pliocene times.

One of the key locations regarding the post-collisional tectonic evolution in central Anatolia is the western margin of the Çankırı basin which is surrounded by the Neo-Tethyan suture zone (Fig. 1). In this area, a Miocene-lower Pliocene extensional basin fill is fragmented by a NNE-trending east-vergent tectonic sliver. It has been proposed that this neotectonic structure was created after the late Pliocene by the movement of the North Anatolian Fault Zone and its splay the Kırıkkale – Erbaa Fault Zone (Seyitoğlu et al., 2000; 2004).

The aims of this paper are (a) to give a detailed description of the tectonic sliver named here as the Eldivan – Elmadağ pinched crustal wedge (EPCW) that is one of the rare structures in the geological literature to have sub-parallel normal and thrust faults in its western and eastern margins respectively, and (b) to discuss the internal deformation of NW central Anatolia by combining geological, seismological and GPS data and to contribute to the discussion concerning whether the westward translation of the Anatolian plate is created by squeezing from east (Şengör, 1980; Şengör et al., 1985; 2005) or by pulling from the west - southwest (Chorowicz et al., 1999; Adıyaman et al., 2001; Mart and Ryan, 2002; Mart et al., 2005; Reilinger et al., 2006).

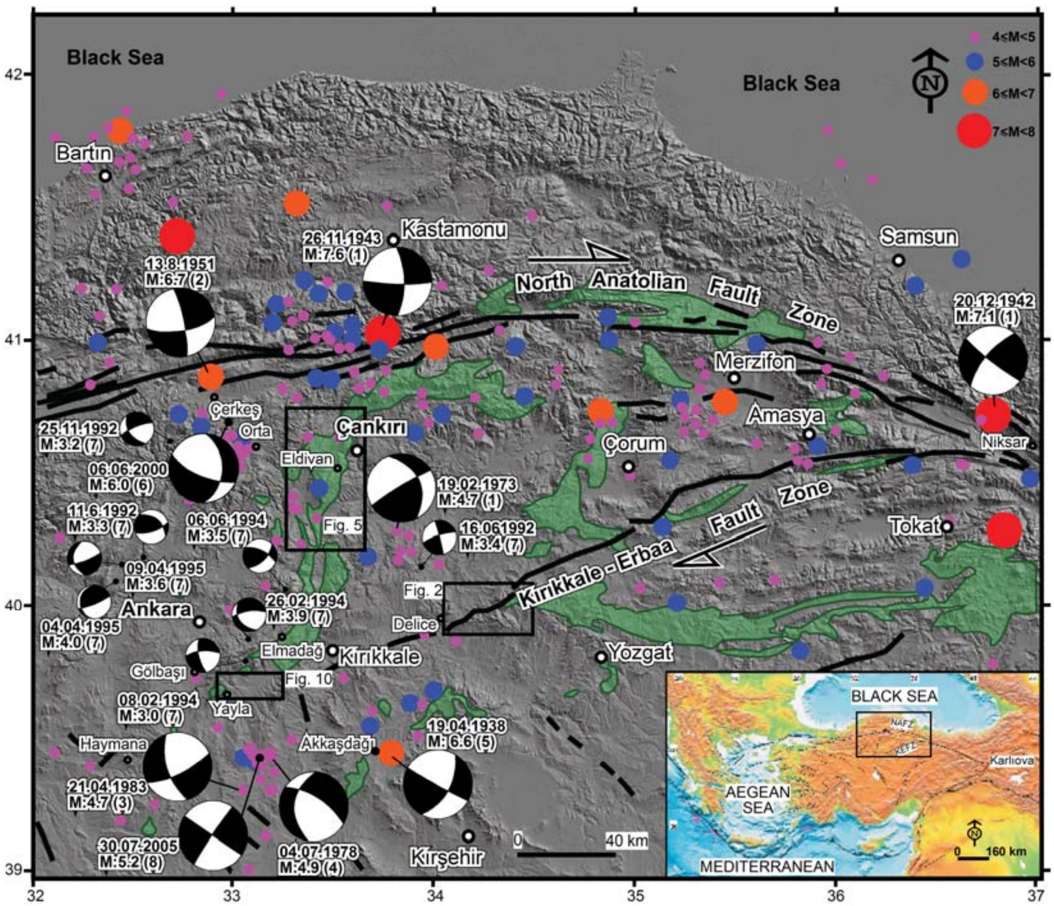


Figure 1. General location map of the studied areas. Green areas represent the Neo-Tethyan suture zone. Focal Mechanism Solutions are from (1) Canıtez and Büyükaşıkoğlu, 1984; (2) Mc Kenzie, 1972; (3) Kalafat, 1998; (4) Kocaefe, 1981; (5) Jackson and Mc Kenzie, 1984; (6) Taymaz et al., 2007; (7) Baran, 1996; (8) Harvard CMT solution (http://www.globalcmt.org/CMTsearch.html). The earthquake epicentres are provided by the Turkish Republic, General Directorate of Disaster Affairs, Earthquake Research Department.

Şekil 1. *Çalışma alanlarının genel yerbulduru haritası. Yeşil alanlar Neo-Tetis kenet zonunu göstermektedir. Odak Mekanizması çözümleri aşağıdaki referanslara aittir. (1) Canıtez and Büyükaşıkoğlu, 1984; (2) Mc Kenzie, 1972; (3) Kalafat, 1998; (4) Kocaefe, 1981; (5) Jackson and Mc Kenzie, 1984; (6) Taymaz et al., 2007; (7) Baran, 1996; (8) Harvard CMT solution (http://www.globalcmt.org/CMTsearch.html). Deprem dışmerkezleri Afet İşleri genel Müdürlüğü, Deprem Araştırma Bölümüne aittir.*

THE MAIN NEOTECTONIC ELEMENTS OF NW CENTRAL ANATOLIA, TURKEY

There are three main neotectonic elements in NW central Anatolia, namely the North Anatolian Fault Zone (NAFZ), the Kırıkkale-Erbaa Fault Zone (KEFZ) and the Eldivan-Elmadağ pinched crustal wedge (EPCW) (Fig.1).

The North Anatolian Fault Zone and the Kırıkkale-Erbaa Fault Zone

The North Anatolian Fault is a right lateral strike-slip fault (Ketin, 1948) extending from Karlıova in the east to the northern Aegean Sea in the west (Fig. 1 inset). The age range of the NAFZ is Late Miocene to Pliocene and the offset values range between 25 and 85 km (Şengör, 1979; Barka, 1992). The present day slip rate in this fault zone has been determined as 25-80 mm/yr by seismic data (Jackson and McKenzie, 1988) and as 17 - 26 mm/yr by GPS data (Barka and Reilinger, 1997; Mc Clusky et al., 2000; Provost et al., 2003; Reilinger et al., 2006). Fault mechanism solutions of the earthquakes show a typical right lateral strike-slip (Fig. 1). There are two main views of the evolution of the NAFZ. The most widely accepted is the tectonic escape model (Şengör, 1980; Şengör et al., 1985). It suggests that collision of the Arabian and Eurasian plates created the North and East Anatolian Fault Zones, and the Anatolian plate moves westward. This model implies that the NAFZ is younger towards the west, as documented by the evolution of shear distribution along the NAFZ (Şengör et al., 2005). On the other hand, Chorowicz et al. (1999) suggest that the escape wedges are moving from west to east and continue to the present day Karlıova (Fig. 1 inset). The backward retreat of the Hellenic slab is given as the cause of the west – southwest motion of the Anatolian plate that creates generally extensional deformation.

The NAFZ has several NE- SW trending splays (Bozkurt and Koçyiğit, 1995; 1996; Koçyiğit and Beyhan, 1998; Westaway and Arger, 2001), and the Kırıkkale- Erbaa Fault (Şengör et al., 1985; 1989; Polat, 1988) is one of its important splays (Fig. 1). This fault is also known as the Ezinepazarı Fault (Şaroğlu et al., 1992), the Ezinepazarı – Sungurlu Fault (Koçbulut et al., 2003) and the Sungurlu Fault (Kaymakçı et al., 2003; Şengör et al., 2005). Its eastern end was activated by the 1939 Erzincan earthquake (Ketin, 1948; 1957; Ambraseys 1970; Barka and Kadinsky-Cade, 1988; Tatar et al., 1995) and connected to the NAFZ by a 15 degree restraining bend to the southwest of the Niksar basin (Barka and Kadinsky-Cade, 1988). Its southwestern end reaches south of Kırıkkale via the northern part of Keskin pluton. In detail, this fault zone shows an anastomosing structure to the east of Delice (Figs. 1 and 2). Although statistically insignificant, GPS measurements (Reilinger et al., 2006; KKIR and YOZG stations) indicate a 1.35 mm/yr right lateral displacement; that KEFZ is an active neotectonic element evidenced by recent seismic activities (Fig. 1).

The Eldivan-Elmadağ pinched crustal wedge (EPCW)

The İzmir – Ankara - Erzincan suture zone, a remnant of the Neo-Tethyan oceanic crust, has an omega shape between Ankara and Sungurlu (Çorum) and limits the Çankırı basin from the west, north and east (Fig. 1). Neogene stratigraphy in the Çankırı basin starts with a lower Miocene Kılçak formation (Şen et al., 1998; Kaymakçı, 2000; Özcan et al., 2007) having fluvio-lacustrine conglomerates sandstones and mudstones with lignite layers (Fig. 3). It is conformably overlain (Özcan, 2003) by the Lower- Middle Miocene alluvial fan and fluviatile red conglomerates and sandstones of the Kumartaş formation (Şen et al., 1998; Karadenizli et al., 2003; 2004; Esat, 2004). The Kumartaş formation passes laterally and vertically into the yellowish conglomerates, sandstones and dominantly marl and mudstones of the lacustrine Hançili formation (Karadenizli et al., 2003; Savaşçı and Seyitoğlu, 2004). The Çankırı member of the Kumartaş formation is covered by the Upper Miocene evaporitic Bayındır formation and its red mudstones of the Süleymanlı member, which represents flood plain deposits (Karadenizli et al., 2004). It is overlain by the Pliocene evaporitic Bozkır formation (Varol et al., 2002). Late Pliocene to Pleistocene alluvial fan deposits of the Deyim formation (Aziz, 1975; Kaymakçı, 2000) cover the earlier units with an angular unconformity (Fig. 3).

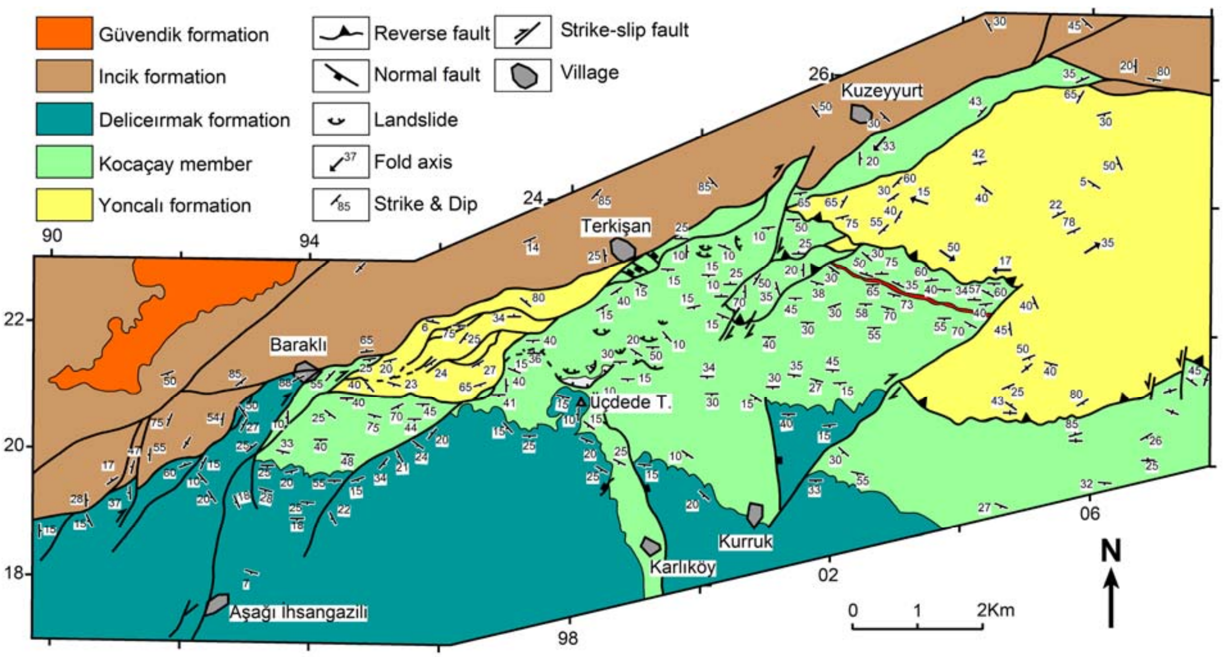


Figure 2. The anastomosing structure along the KEFZ (Seyitoğlu unpublished data-1987, Lithostratigraphy is adapted from Erdoğan et al. 1996, Karadenizli 1999, Karadenizli et al. 2004).

Şekil 2. *Kırıkkale-Erbaa Fay Zonu boyunca dallanmalı-örgülü yapı (Seyitoğlu 1987 – yayınlanmamış veri. Litostratigrafi Erdoğan vd. 1996, Karadenizli 1999, Karadenizli vd. 2004'den uyarlanmıştır).*

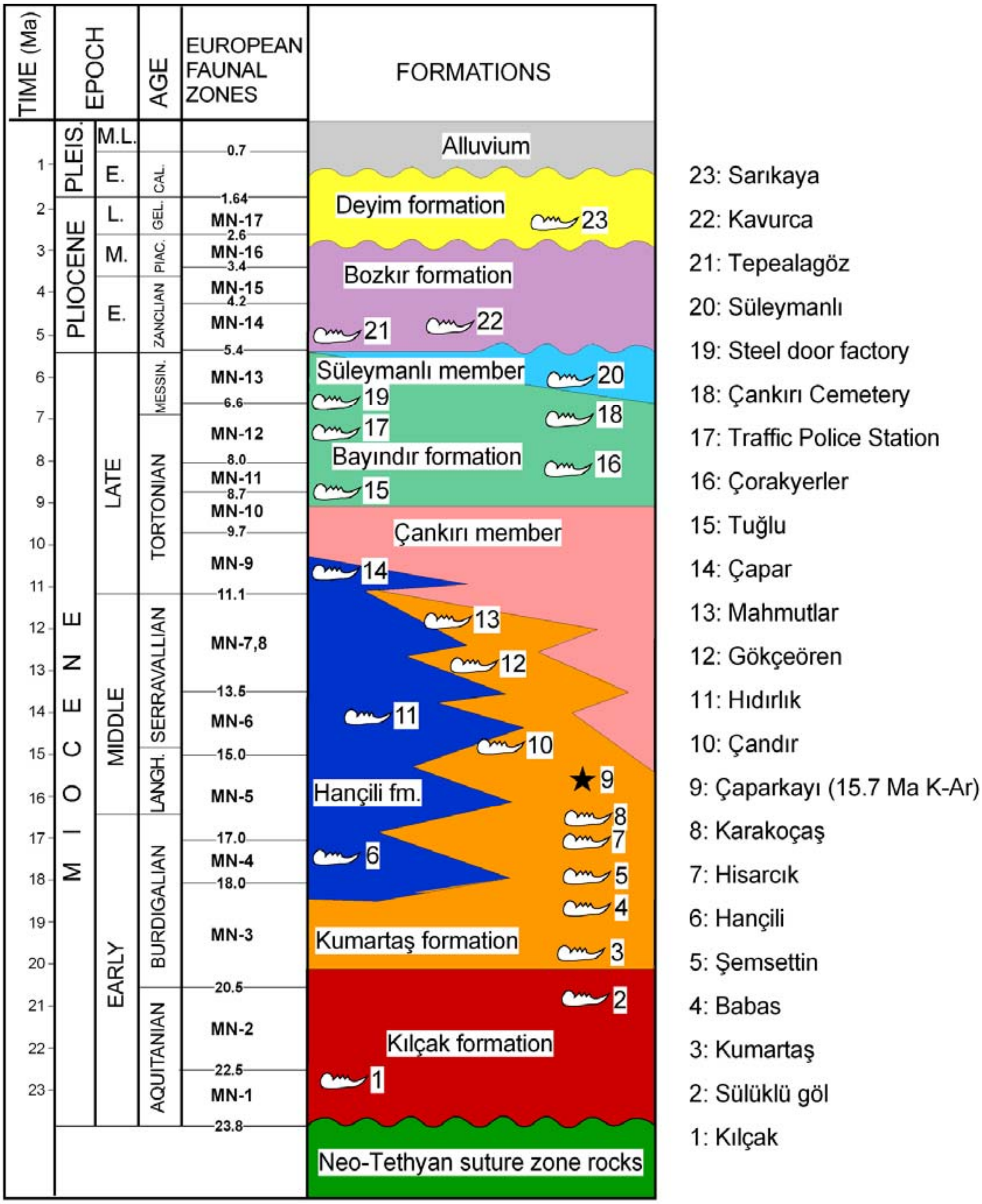


Figure 3. Generalized Neogene stratigraphy of western Çankırı basin. The numbers indicate micromammalian fossil locations (after Karadenizli et al., 2004).

Şekil 3. *Çankırı havzası batısının genelleştirilmiş Neojen stratigrafisi. Numaralar mikromemeli fosil lokasyonlarını göstermektedir (Karadenizli vd. 2004'den alınmıştır).*

The lower Miocene - lower Pliocene basin fill, on the western side of the Çankırı basin, is fragmented by an east-vergent tectonic sliver. The western side of this NNE-trending tectonic sliver shows a normal fault character, but its eastern side has acted as a thrust. It has been proposed that this east vergent tectonic sliver was created by the movement of the NAFZ and its splay the Kırıkkale-Erbaa Fault Zone after the late Pliocene, accommodating the internal deformation of the Anatolian Plate (Seyitoğlu et al., 2000; 2004) (Fig. 4). This tectonic sliver, named as the Eldivan-Elmadag pinched crustal wedge (EPCW), is mapped in detail from Çankırı to Kalecik (Fig. 5).

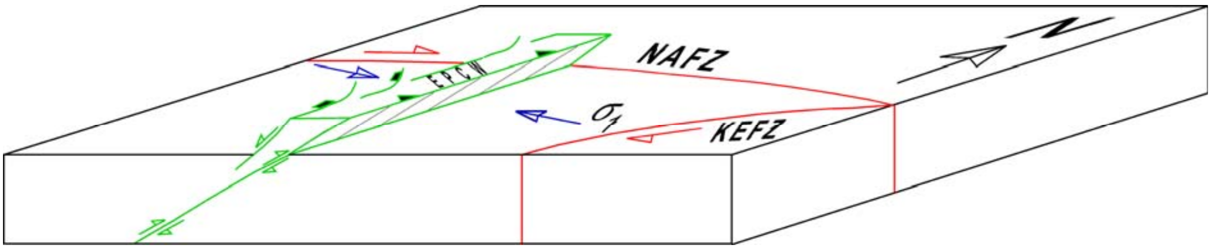


Figure 4. A simplified block diagram showing the position of the Eldivan-Elmadağ pinched crustal wedge (EPCW) between the North Anatolian Fault Zone (NAFZ) and the Kırıkkale-Erbaa Fault Zone (KEFZ).

Şekil 4. *Kuzey Anadolu Fay Zonu ve Kırıkkale-Erbaa Fay Zonu arasında Eldivan-Elmadağ Kıstırılmış Tektonik Kamasının (EKTK) durumunu gösteren blok diyagram.*

SW of Çankırı, a structure of the easternmost sector of EPCW is composed of two small wedges (Fig. 6a and b). These small scale wedges, having thrusted eastern and normal faulted western margins, fragment the Çankırı member of Kumartaş formation, as well as the Bayındır and Bozkır formations (Esat, 2004). The main eastern border of the EPCW is located further west and thrusted over the Çankırı member of the Kumartaş and Bozkır formations, and it is responsible for the accumulation of the clastic Deyim formation (Fig. 5). The main normal faulted western border of the EPCW outcrops around Çapar, where the Hançili formation and overlying Çankırı member of Kumartaş formation form a drag fold syncline in the hanging wall of the west-dipping normal fault (Fig. 6c). The same fault can be followed further north to the east of Karatekin village (Fig. 5) and to the east of Korgun town, where it controls the accumulation of the Deyim formation (Fig. 6d). The relative structural position of the Korgun location is shown in Figure 7a.

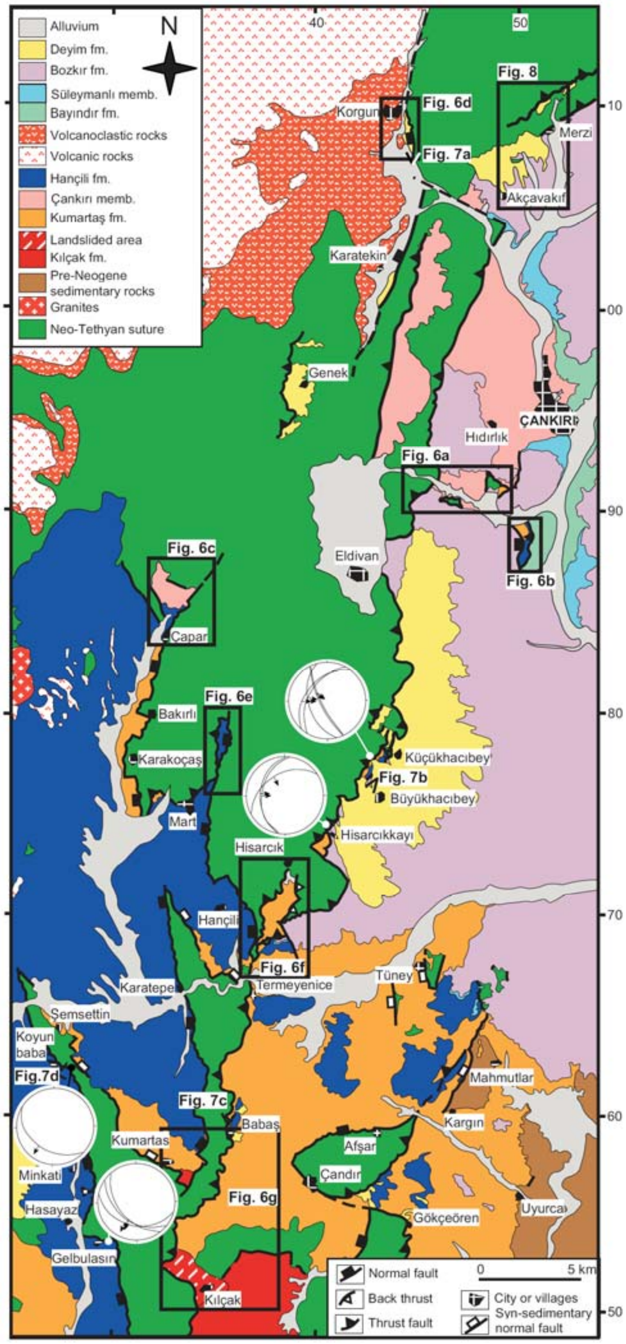


Figure 5. The geological map of the Eldivan-Elmadağ pinched crustal wedge (EPCW) in the western margin of Çankırı basin. For location see Fig. 1.

Şekil 5. *Çankırı havzasının batı kenarındaki Eldivan-Elmadağ kıstırılmış tektonik kamasının (EKTK) jeoloji haritası. Konumu için Şekil 1'e bakınız.*

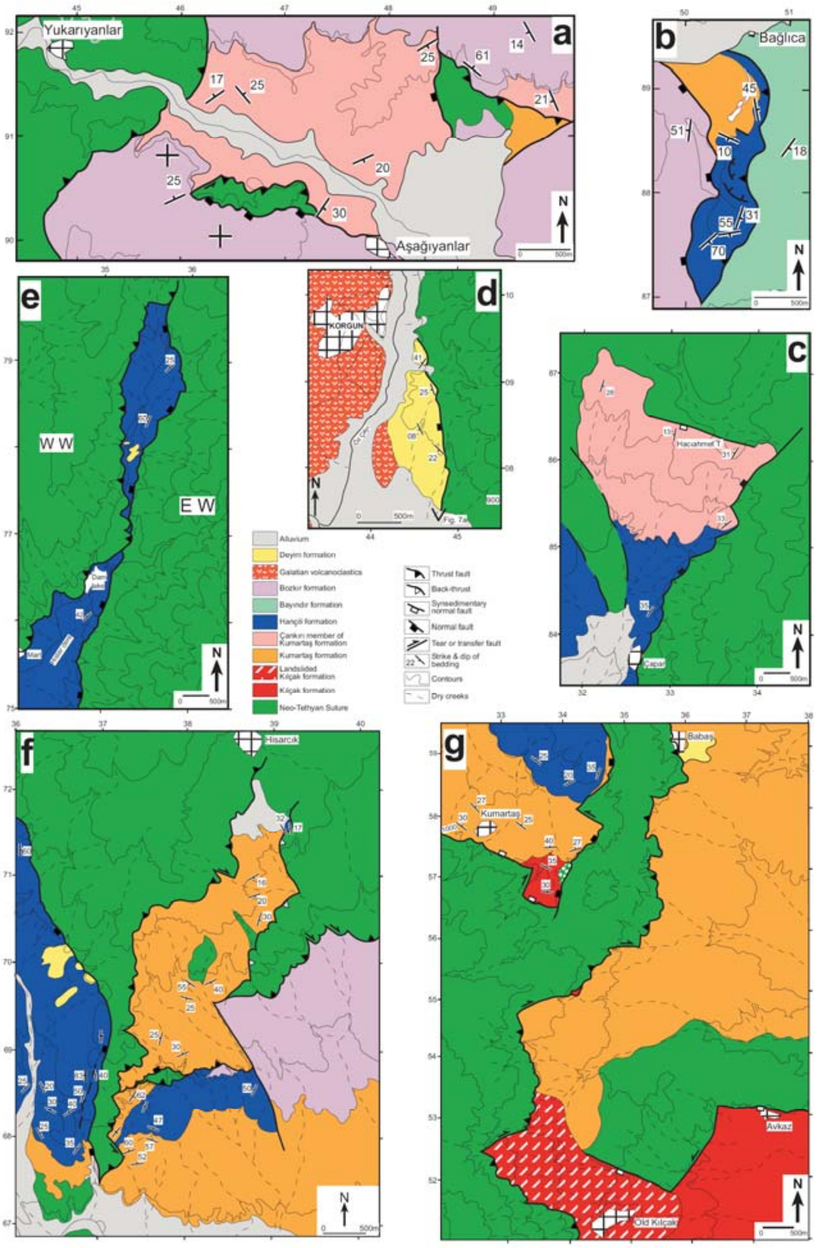


Figure 6. Detailed geological maps of the EPCW. a) Geological map of eastern margin of the EPCW at the SW of Çankırı. b) Details of the eastern small scale wedge. c) Geological map of Çapar area at the western margin of the EPCW (after Esat, 2004). d) Geological map of Korgun area. e) Geological map of north of the Mart village. f) Geological map of the Hisarcık village, the complex structure of eastern thrusted margin of EPCW. g) Geological map between the Kumartaş and Kılçak villages (after Özcan, 2003; Özcan et al., 2007). See Fig. 5 for locations.

Şekil 6. *EKTK'nın ayrıntılı jeoloji haritaları. a) Çankırı'nın GB'sında EKTK'nın doğu kenarının jeoloji haritası. b) En doğudaki küçük ölçekli kamanın ayrıntısı. c) EKTK'nın batı kenarında Çapar civarının jeoloji haritası (Esat, 2004'ten alınmıştır). d) Korgun civarının jeoloji haritası. e) Mart köyü kuzeyinin jeoloji haritası. f) Hisarcık köyü civarında EKTK'nın bindirmeli doğu kenarının karmaşık yapısı. g) Kumartaş ve Kılçak köyleri arasının jeoloji haritası (Özcan, 2003; Özcan vd. 2007'den alınmıştır). Haritaların konumları için Şekil 5'e bakınız*

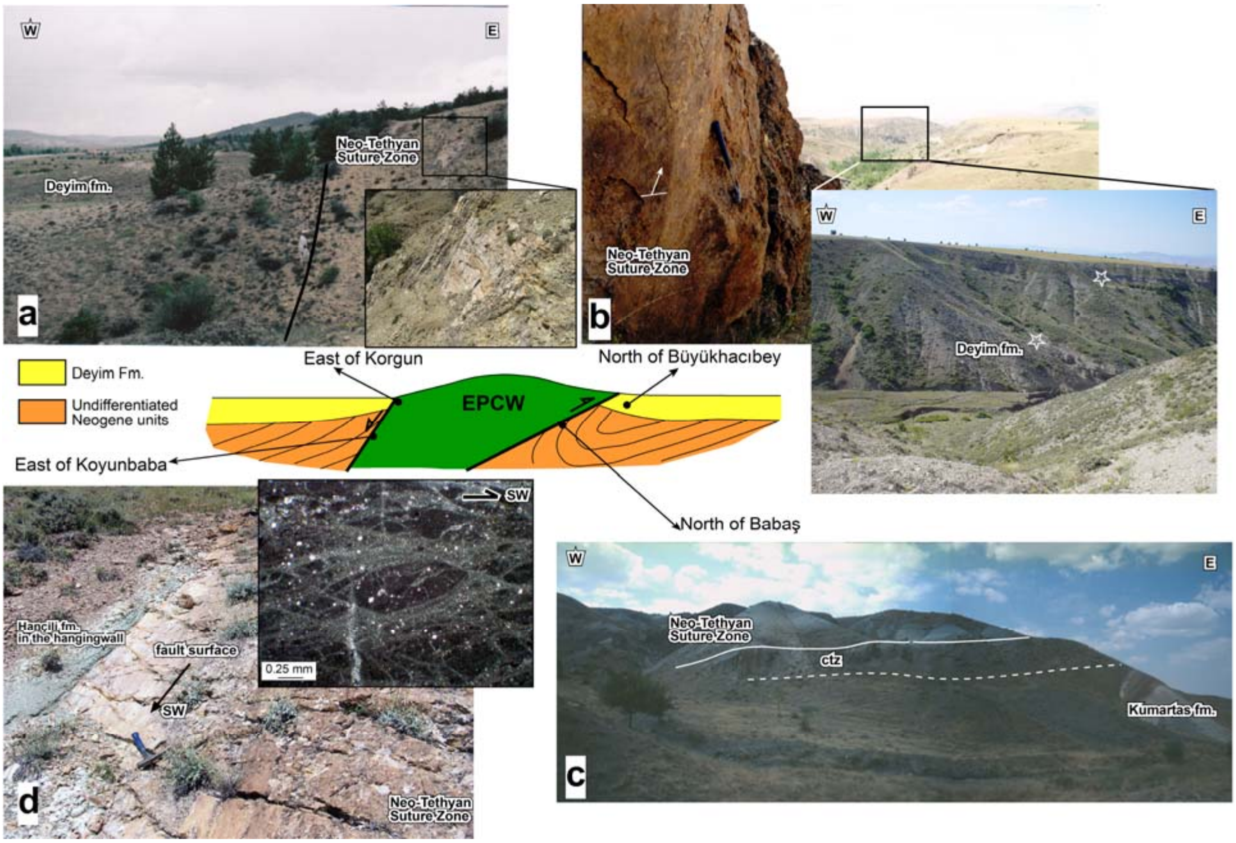


Figure 7. A simplified composite cross section of the EPCW, indicating geological observations from different structural levels a) Photo showing west dipping Korgun fault that limits the western border of the EPCW at the southeast of Korgun town. Corrugations indicate normal slip of the fault, see inset. b) The Deyim formation deposited in front of the eastern thrusted margin of the EPCW. Inset shows the intraformational unconformity in the Deyim formation. Stars indicate the strata having different dip values. c) A photo of SW dipping normal faulted western margin of the EPCW near the Koyunbaba village. Inset is a microphotograph obtained from an oriented sample showing top to the SW sense of shear. d) Thrusted eastern margin of the EPCW with a cataclastic zone (ctz) at the north of Babaş village. See Fig. 6 for all locations.

Şekil 7. *EKTK'nın farklı yapısal seviyelerindeki jeolojik gözlemleri basitleştirilmiş olarak gösteren birleşik enine kesit.. a) Korgun GD'sunda EKTK'nın batı kenarını temsil eden batıya eğimli Korgun fayına ait fotoğraf. Fay düzlemi üzerindeki ondülasyonlar normal fayı işaret etmektedir, küçük resme bakınız. b) EKTK'nın bindirmeli doğu kenarı önünde çökelen Deyim formasyonu. Küçük resim Deyim formasyonu içindeki formasyon içi uyumsuzluğu göstermektedir. Yıldızlar farklı eğimlere sahip tabakaları işaret etmektedir. c) Koyunbaba köyü yakınlarında EKTK'nın GB'ya eğimli normal faylı batı kenerını gösteren fotoğraf. Küçük resim fay yüzeyinden alınan yönlü örnek üzerinde üst GB makaslamayı gösteren mikrofotoğraftır. d)Babaş köyü kuzeyinde EKTK'nın bindirmeli doğu kenarındaki kataklastik zon (ctz). Konum bilgisi için Şekil 6'ya bakınız.*

Further south, along the line of Karakoçaş and Hisarcıkkayı villages (Fig. 5), the EPCW is composed of western and eastern wedges (here below WW and EW respectively) (Fig. 6e). The western margin of the WW has west-dipping normal fault surfaces separated by a few transfer faults. North of Mart village, the eastern margin of the WW is thrusted on the normal faulted western margin of the EW (Fig. 6e). This relationship shows that the WW is younger than the EW and indicates an out- of-sequence thrusting. The western normal faulted border of the EW can be followed continuously from north of Mart village to the north of the Termeyenice river (Fig. 5). The eastern margin of the EW also represents the main eastern border of the EPCW, which is clearly thrusted onto the Bozkır formation (Karabıyıkoğlu, 2000) (Fig. 5). In deep cutting valleys, overturned folds are common in older stratigraphic units such as the Kumartaş and Hançili formations between Küçükhacıbey village and the Termeyenice river (Fig. 5). In the same area, the late Pliocene – Pleistocene Deyim formation unconformably overlies the earlier sedimentary units. The differences in thickness of this formation and its intra-formational unconformities demonstrate that this clastic unit is accumulated in front of the thrusted eastern margin of the EPCW (Figs. 5 and 7b).

Further south around Hisarcık, tear faults, small ophiolitic wedges and back thrusting make the structure of the eastern margin of the EPCW more complex. Finally, the normal faulted western margin and thrusted eastern margin of the EPCW meet north of the Termeyenice river (Fig. 6f). South of the Termeyenice river, structurally lower levels of the EPCW are exposed due to relatively deeper erosion. In this area, the thrusted eastern margin of the EPCW is continuously followed towards the south and its best exposure can be seen north of Babaş village, displaying well developed fault zone features (Figs. 5 and 7c). The zone is characterised by intense fracturing and crushing in a hanging wall along this contact. This eventually results in the formation of cataclastic rocks, such as mainly breccias and lesser amounts of cataclasites. Cataclastic rocks contain angular and sub-rounded ophiolitic rock fragments in a fine grained matrix. Clasts and matrix materials of cataclastic rocks have no preferred orientation. An overturned syncline of the Kumartaş and Hançili formations is developed on the footwall. Beyond the fault zone, the rocks are relatively undeformed both in the hanging wall and the footwall (Fig. 7c). On the other hand, the western margin of the EPCW is exposed as two, en echelon, N-NW trending west- southwest dipping normal faults. Well-developed fault surfaces are exposed to several tens of metres in Koyunbaba village (Fig. 5), displaying a NW-striking fault surface dipping between 25 and 40^0 to the SW. The fault surface contains well-developed slickenside lineations which trend NE-SW and plunge SW (Fig. 7d). The fault surface is not planar but displays corrugations on a scale of centimetres to a meter. The corrugation axes are parallel to the lineations on the fault surface. A cataclastic zone occurs along the fault up to 1 meter wide. This zone consists of breccias and cataclasites with brittle kinematic indicators. The cataclastic zone locally displays cataclastic foliations, especially near the fault surface, characterized by short-fractures on a meso-scale that are parallel and subparallel to the main fault surface. The boundaries of the cataclastic zone and host rock are transitional and the degree of deformation decreases towards the host rock.

Both fault surface and the cataclastic zone of the fault comprise some kinematic indicators, such as trails of inclined planar structures, fractures, and deformed elements, indicating that the hanging wall of the fault moves to the SW (Fig. 7d-inset) (Önal et al., 2006). Thus, the brittle features (meso- and micro-scale) of the fault demonstrate that a SW-dipping normal fault juxtaposing the rocks of the Hançili formation over the Neo-Tethyan suture zone, constitutes the western margin of the EPCW (Figs. 6 and 7d). On the footwall of this fault, the syn-sedimentary normal faults limiting the intra-basinal highs and controlling the deposition of the Kılçak, Kumartaş and Hançili formations (Karadenizli et al., 2003; Savaşçı and Seyitoğlu, 2004) are exposed between the normal faulted western and thrusted eastern margins of the EPCW. Our detailed geological mapping and fossil determinations in the area demonstrate the existence of the Kılçak formation on both sides of the EPCW (Özcan et al., 2007) (Fig. 6g). Further to the east, a relatively small body of the EPCW also exists around Çandır village (Fig. 5).

Evidence for the timing and contemporaneous development of the normal faulted western and thrusted eastern margins of the EPCW are based on Neogene stratigraphy of the western Çankırı basin, dated by micromammalian fossils (Fig. 3). As documented above, the normal faulted western margin of the EPCW deforms the Kılçak, Kumartaş and Hançili formations. An apparent drag fold syncline can be observed on the hanging wall of the normal faulted western margin to the north of Çapar village (Fig. 6c). The location further northeast, immediately east of Korgun town, provides the youngest age for the normal faulted western margin of the EPCW. In this area, a west dipping normal fault surface limits the poorly sorted, very angular conglomerates and mudstones of the late Pliocene – Pleistocene Deyim formation. Its down-dip movement is documented by corrugations on the fault surface and drag folds in the hanging wall that creates increasing dip angles of the sedimentary strata of Deyim formation towards the fault (Figs. 6d and 7a). The intra-formational unconformities demonstrate a syn-tectonic accumulation of the Deyim formation that has been dated by micromammalian fossils in the other part of the Çankırı basin (MN 17: Upper Pliocene to lower Quaternary, Kaymakçı, 2000).

The youngest sedimentary unit thrusted by the eastern margin of the EPCW is the Pliocene Bozkır formation (Fig. 3), which is well dated by micromammalian fossils indicating an MN 14 zone (early Pliocene) (Karadenizli et al., 2004). For this reason, the initiation age of the thrusted eastern margin of the EPCW must be post early Pliocene. Moreover, the thrusts control the accumulation of the Deyim formation, as clearly evidenced by intra-formational unconformities (Fig. 7b) and syn-tectonic wedge geometries at Büyükhacıbey, Küçükhacıbey and around Merzi villages (Fig. 5). 1.5 km SW of Merzi village (Fig. 8), a small scale tectonic sliver deformed the Bozkır and lower parts of the Deyim formation, but this sliver is covered by the upper part of the Deyim formation in the west. The eastward continuation of this tectonic sliver acted as a blind thrust and created an asymmetric anticline in the Bozkır formation. The upper part of the Deyim formation is accumulated on this structure, having well developed thickness differences that indicate the syn-tectonic deposition of the Deyim formation (Fig. 9a and b).

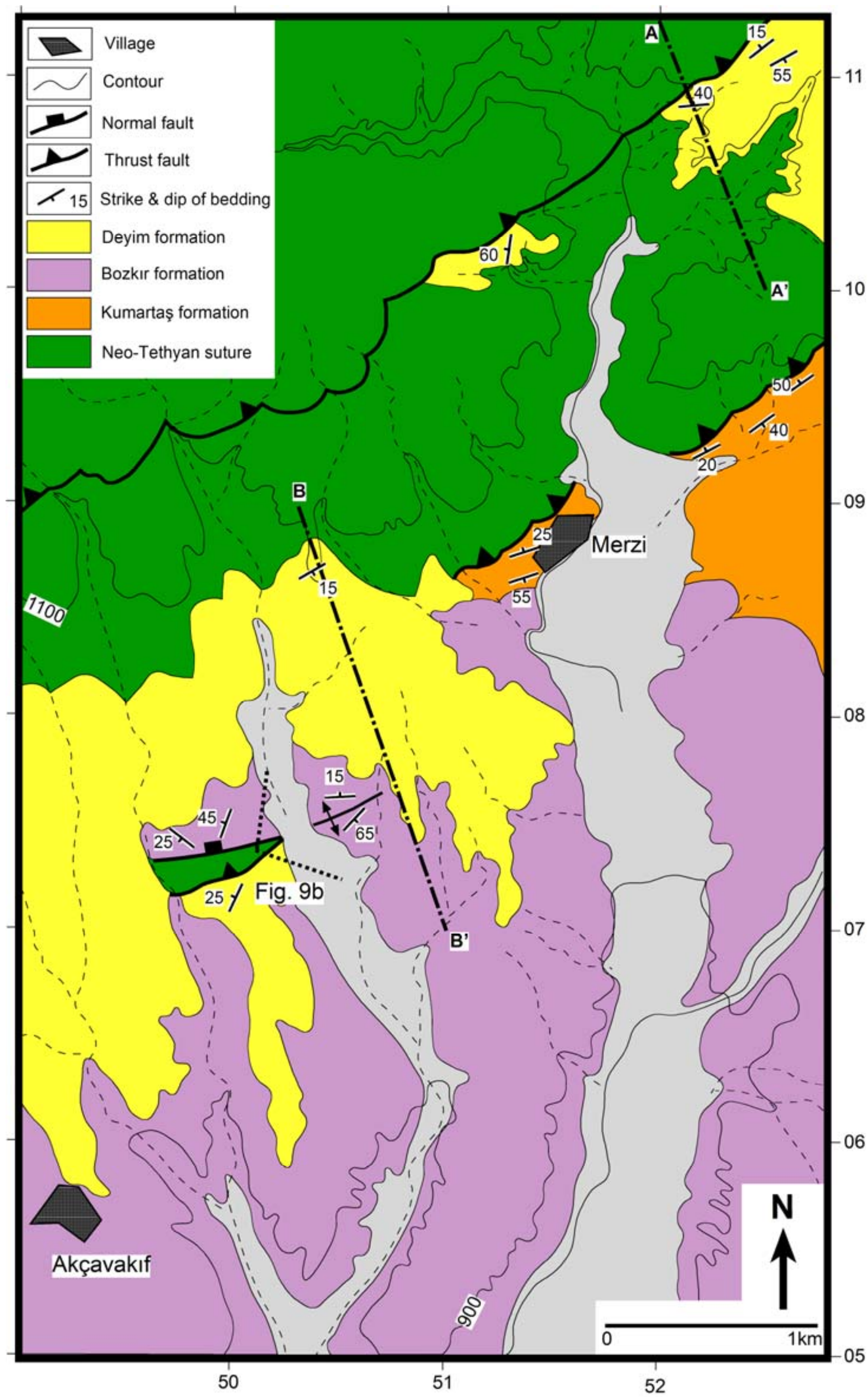


Figure 8. The geological map of the Akçavakıf- Merzi area.

Şekil 8. *Akçavakıf – Merzi arasının jeoloji haritası.*

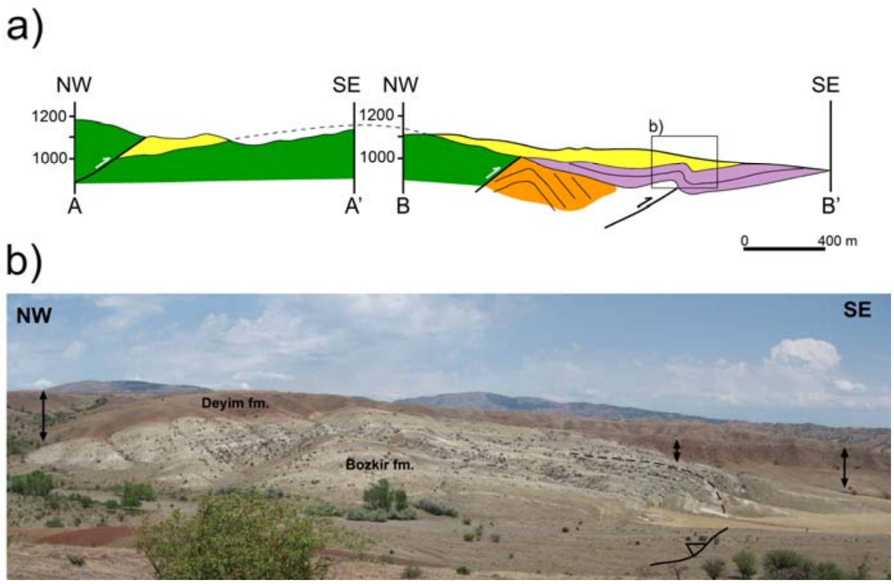


Figure 9. a) The cross sections show relationship between the thrusted eastern margin of the EPCW and the Deyim formation. b) Evidence of syn-tectonic deposition of the Deyim formation. Arrows indicate the thickness differences in the Deyim formation. For locations see Fig. 8.

Şekil 9. *a) Deyim formasyonu ile EKTK'nın bindirmeli doğu kenarının ilişkisini gösteren enine kesit. b) Deyim formasyonunun tektonikle eş zamanlı olarak çökeldiğine ait veri. Oklar Deyim formasyonundaki kalınlık farklarını göstermektedir. Konum bilgileri için Şekil 8'e bakınız.*

A post-early Pliocene activation time of both the normal faulted western and the thrusted eastern margins of the EPCW is documented by the syn-tectonic, clastic-dominated Deyim formation. The coeval development of normal and thrust faults under the NW-SE compression might have occurred in a fashion similar to the elastic model developed by Yin (1993). Similar cases have also been observed in the Himalayas, as shown by Burchfiel et al. (1992), and in Algeria during El Asnam earthquake (King and Yielding, 1984), although the scales are different.

Seyitoğlu et al. (2000) proposed that the EPCW was created as a neotectonic structure by a NW - SE trending contraction developed between the NAFZ and the KEFZ. The southern sector of the EPCW is a key area for testing this proposal (Fig. 1). If it is correct, the southern sector of the EPCW should be restricted along the KEFZ's trend, and no thrust faults affecting Neogene sediments should be observed to the south of the KEFZ where it is beyond the contractional area. Indeed, the geometry of the Neo-Tethyan suture zone shows a dramatic change south of Elmadağ that corresponds to the meeting point between the EPCW and the trend of the KEFZ (Fig. 1). In this location, a NNE trending thrust fault within the late Miocene – Pliocene (?) (Saraç, 2003) sedimentary unit of the Balaban basin is observed (Figs. 10 and 11a) and this sector is considered as a thrusted eastern margin of the EPCW. This thrusting can be followed southwards until the approximately E-W trending right lateral transpressional strike-slip of the Akarlar fault that passes between

Yayla and Akarlar villages (Figs. 1 and 10). This active strike-slip fault causes a right lateral displacement on the line of creeks and creates a rapid uplift of its northern block, that is evidenced by a down-cutting of the creeks creating steep cliffs (Figs. 11 b and c) (İleri, 2007). To the south of this fault (Fig. 1) no thrusting disrupts Miocene sedimentary successions (i.e. in the Akkaşdağı area, Seyitoğlu et al., 2005). This, in turn, indicates that the EPCW is a neotectonic element of NW Central Anatolia created by the NAFZ and the KEFZ.

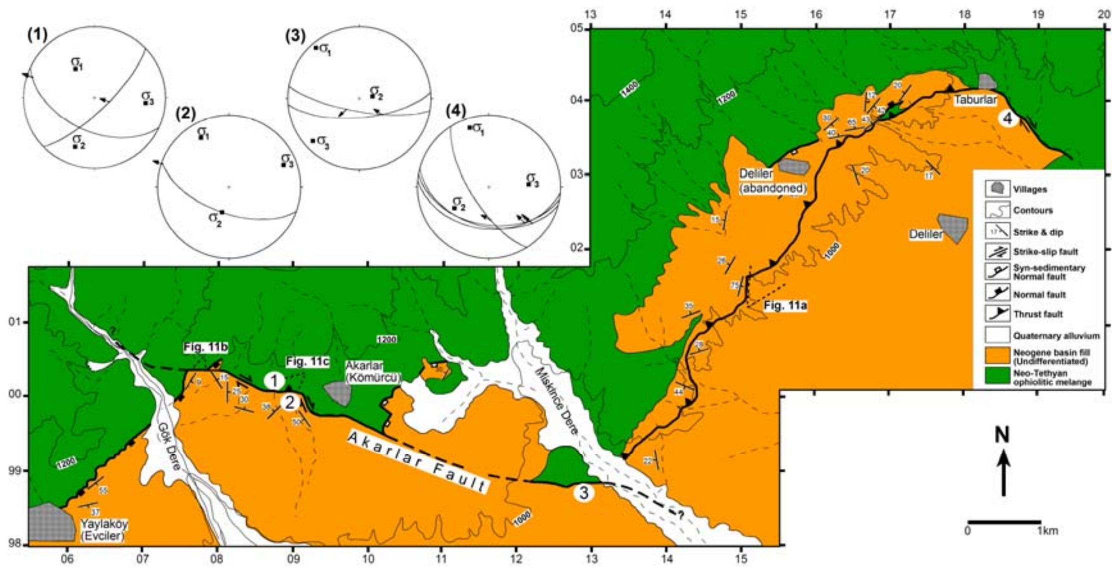


Figure 10. The geological map of the southern edge of the EPCW (after İleri, 2007). The numbers on the map indicate locations of fault slip data presented on the lower hemisphere, equal area stereographic projections.

Şekil 10. *EKTK'nın güney sınırının jeoloji haritası (İleri 2007'den alınmıştır). Harita üzerindeki numaralar, eşit alan alt yarımküre streografik projeksiyonlarda gösterilen fayların kayma verilerini işaret etmektedir.*

THE ROLE OF THE EPCW ON THE INTERNAL DEFORMATION OF THE ANATOLIAN PLATE: GPS AND SEISMOLOGICAL DATA

Strain Analysis and Relative Velocity Vectors

While GPS data within the region (Reilinger et al., 1997; McClusky et al., 2000; Reilinger et al., 2006) are too sparse for the detection of low-rate deformation, they are very useful in quantifying the first-order deformation of Central Anatolia. We used the most recent GPS velocity vectors of 11 sites from Reilinger et al. (2006), which lie in the northern part of Anatolia (Fig. 12). We formed polygonal elements and defined a homogenous strain within each element. While different polygonal elements can be chosen, the detection of relatively small-scale processes requires elements as small as possible, namely triangles. On the other hand, configuration of relatively sparse networks and the need to focus on the area of interest do not always allow for freedom to form the smallest elements. In this respect, we chose a mixed approach which involves polygons of different sizes with an effort to form as many smallest elements as possible.

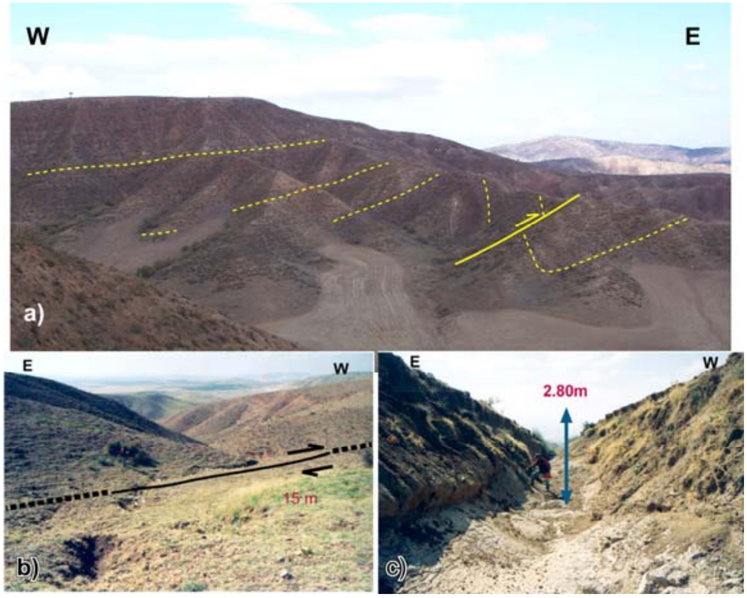


Figure 11. a) Thrusted eastern margin of the EPCW deforms upper Miocene-Pliocene(?) basin fill of the Balaban basin. Dashed yellow lines indicate bedding of the sedimentary succession. b) Right lateral displacement on the line of creeks along strike-slip fault that limits the southern margin of the EPCW. c) Steep cliffs in the down cutting creeks indicating recent rapid uplift of the EPCW. See Fig.10 for locations.

Şekil 11. *a) EKTK'nın bindirmeli doğu kenarı Balaban havzasının üst Miyosen-Pliyosen (?) çökellerini deforme etmiştir. Kesikli sarı çizgiler sedimanter birimlerdeki tabakalanmayı göstermektedir. b) EKTK'nın güney kenarını sınırlayan sağ yanal atımlı fayın derelerde meydana getirdiği sağ yanal ötelenme. c) Derine doğru hızla kazılmış dere yataklarındaki dik kenarlar, EKTK'nın yakın zamanda hızla yükseldiğini göstermektedir. Konum bilgileri için Şekil 10'a bakınız.*

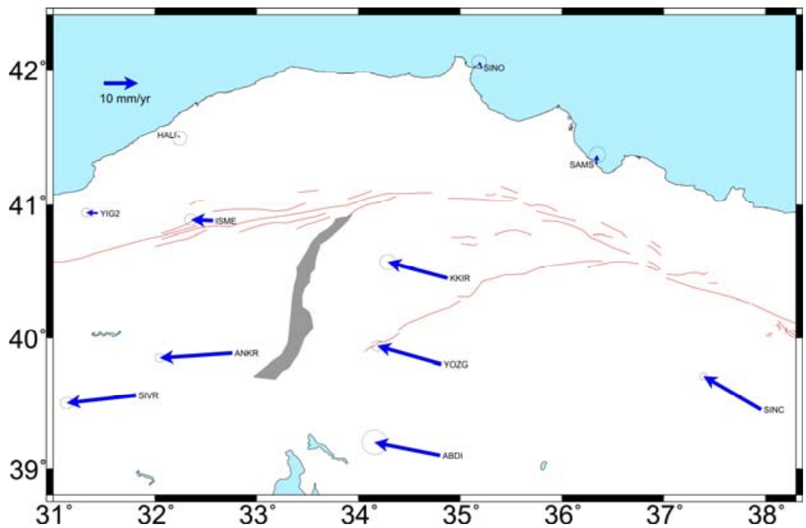


Figure 12. GPS velocities relative to a Eurasia-fixed frame. Error ellipses are at 95% confidence level, velocities are taken from Reilinger et al. (2006).

Şekil 12. *Avrasya sabit alınarak göreli Küresel Konumlama Sistemine ait hızlar. Hata elipsleri %95 güven seviyesindedir, hızlar Reilinger vd. (2006)'dan alınmıştır.*

For the computation of strain parameters, tensor elements were obtained from velocity observations through linear least squares in which rotation rates and tensor elements are simultaneously estimated. Following the method given in Feigl et al. (1990), the observed velocities can be decomposed into two parts as follows:

$$u = Lx + \dot{t} \qquad (1)$$

where u : velocities, $\dot{t}$: translation rates, x : position vector, and L :a matrix consisting of rigid body rotation ($\dot{\omega}$) and strain rates ($\dot{e}$) matrices given as

$$L = \dot{e} + \dot{\omega} \qquad (2)$$

(Feigl, 1990). While the rigid body rotation rate matrix $\dot{\omega}$ is a square matrix with a main diagonal consisting of zeros:

$$\dot{\omega}_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} - \frac{\partial u_j}{\partial x_i}\right),\ i \neq j \qquad (3)$$

$$\dot{\omega}_{ii} = 0,\ i = j$$

Strain tensor is symmetric and defined as:

$$\dot{e}_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) \qquad (4)$$

in Turcotte and Schubert (1982), where partial derivatives correspond to gradients of north and east velocities, respectively. The computed strain rates are shown in Figure 13. One obvious result from these strain rates is that the Çankırı basin is, in general terms, under a strike-slip strain. The high contraction rate observed in the ISME-SAMS-KKIR block is attributed to its proximity to the NAFZ and its bending. On the other hand, the direction of the NW-SE contraction in the ISME-KKIR-ANKR-SIVR block is compatible with the geological observations. Geologically observed thrusting on the eastern side of the EPCW and recently observed thrusts in the further west of the EPCW (Kutluay, 2007) are nearly perpendicular to the contraction direction obtained from strain analysis. One particular result is that the area to the south of the KEFZ is almost non-deforming, which implies that the deformation has been localized between the NAFZ and the KEFZ.

The obtained contraction rate for the block (ISME-KKIR-SAMS) is about 140 ± 20 nanostrain/yr at an azimuth of 316.7° ± 2.1° (~ N43W), which corresponds to a contraction rate of 1.4 mm/yr over 10 km. The NW-SE contraction in the ISME-KKIR-ANKR-SIVR block is about 80 ± 20 nanostrain/yr at an azimuth of 305.2° ± 2.1° (~ N43W), which corresponds to a contraction rate of 0.8 mm/yr over 10 km. If we assume that this contraction is accommodated by a narrow corridor such as the EPCW, rather than by the whole block homogeneously, then the EPCW should have taken up a shortening of 2.8 km since late Pliocene (~3.5 Ma).

Structural data

A total of 21 fault slip measurements were obtained from both the normal faulted western and the thrusted eastern margins of EPCW (Table 1). The fault slip data from the normal faulted western margin of EPCW has σ_3=N50E, 09NE, indicating a NE-SW extension (Fig. 14 a). The fault slip data obtained from thrust faults limiting the eastern margin of the EPCW provide σ_1=N75W, 02NW, representing a NW-SE contraction (Fig. 14 b). These data can be evaluated as a kinematically compatible population. All fault slip measurement data indicate σ_1=N51W, 08SE and σ_3=N34E, 30 NE (Fig. 14c) that conform with the strain analysis of the ISME-KKIR-ANKR-SIVR block (see Fig. 13).

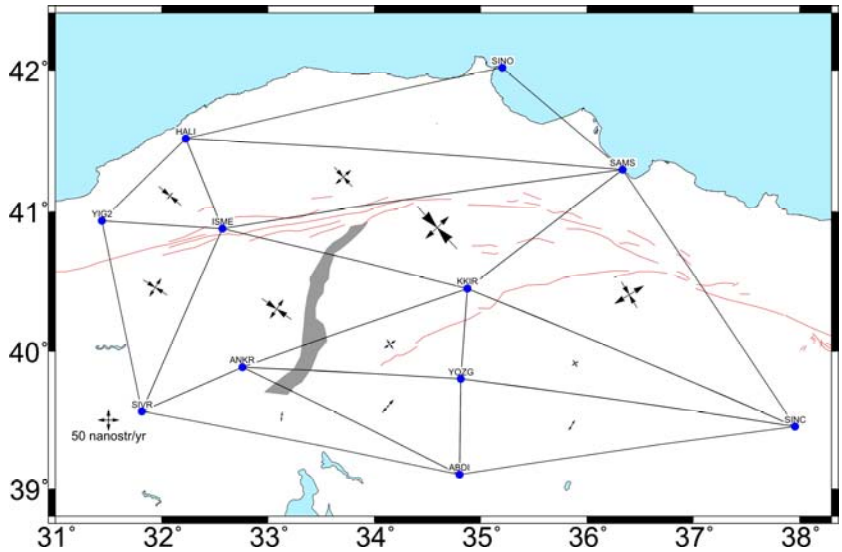


Figure 13. Principle strains computed at the centroids of each element. The velocities are taken from Reilinger et al. (2006).

Şekil 13. *Her elemanın merkezinde hesaplanan ana yamulmalar. Hızlar Reilinger vd. (2006)'dan alınmıştır.*

Seismicity and Focal Mechanisms

The seismicity of the region from 1900 to 1999 and from 2000 to the present is shown in Figures 15 a & b respectively. All earthquake locations were obtained from the Kandilli Observatory and Earthquake Research Institute (KOERI). On the basis of Figures 15 a and b, the existence of some clusters can clearly be seen on the maps. Each clustering region in the figures is shown by a numbered rectangular area. The high seismicity in the region of A1 was a result of a moderate earthquake (Ms=5.6) that occurred around Mecitözü (Çorum) on 14 August 1996, and continuing seismic activity in this area can be seen at A7 in Fig. 15b. A dramatic increment is observed specially in the areas A2 – A6 after 2000 (Figure 15b). Indeed, the 6 June 2000 Orta (Çankırı) earthquake (Mw=6.0) and the 31 July 2005 (Mw=5.3) and 20 December 2007 (Ml=5.6) Bala earthquakes played important roles in increasing the seismicity in the areas A2 and A5, respectively. The area of A3 is a local clustering region in the west of the EPCW. The clustering regions at A4 and A6 are directly related to the seismic activity on the EPCW.

Our local seismic network (AnkNET) has been established in the region to observe seismic activity on the EPCW and other main neotectonic elements around Ankara, following 19. 09 2007. The first results of this monitoring are presented in this section. The most recent 10 events with a magnitude (Md) between 2.2 and 3.1 have been analyzed to determine their focal mechanisms (Fig. 15c) (Appendix I). The majority of focal mechanism solutions belong to thrust faulting, indicating a NW-SE contraction, and this agrees with GPS and structural data obtained from fault surfaces (see Figs. 13 and 14). Earthquakes due to normal faulting provide focal mechanism solutions that indicate a NE-SW extension. These seismic data support the contention of geological observations presented in this paper that normal and thrust faults work simultaneously in the region.

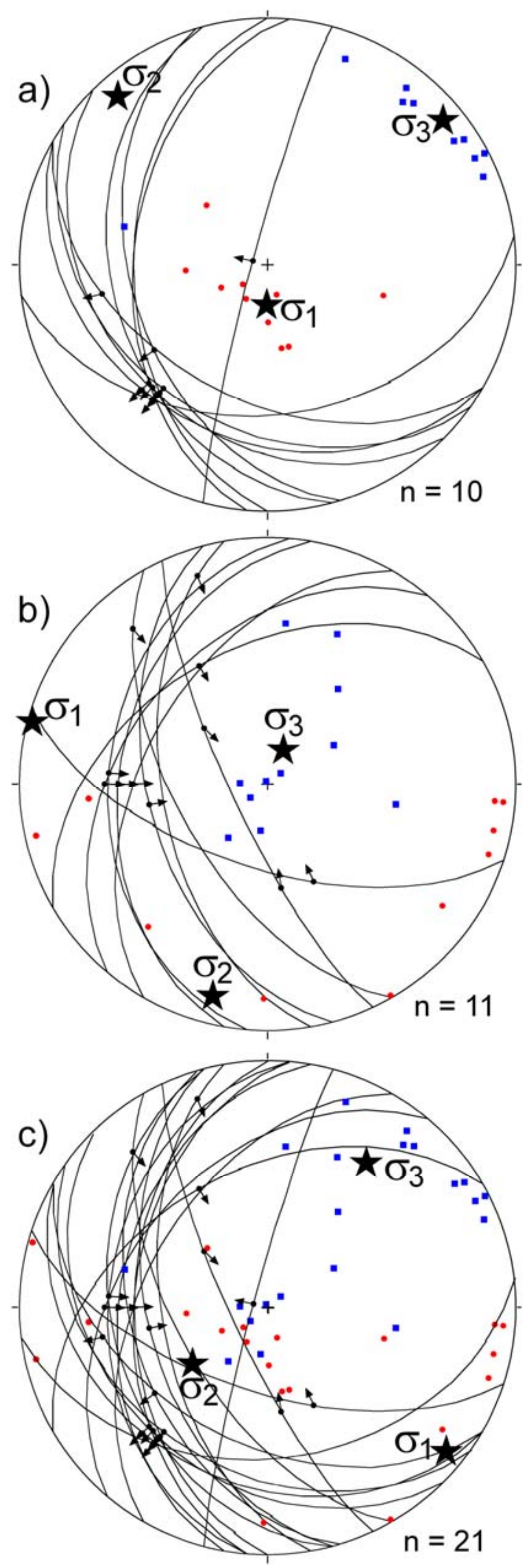


Figure 14. Lower hemisphere, equal area stereographic projections of structural data from EPCW. For detail see Table 1. Filled blue squares and red circles are extension and shortening axes respectively. a) Normal fault planes and slickenlines from western margin of the EPCW. σ_1= N02E, 77SW; σ_2= N42W, 10NW; σ_3= N50E, 09NE b) Thrust planes and slickenlines from eastern margin of the EPCW. σ_1= N75W, 02NW; σ_2= N14E, 12SW; σ_3= N25E, 78NE c) All available fault slip data from the western and eastern margins of the EPCW. σ_1= N51W, 08SE; σ_2= N52E, 59SW; σ_3= N34E, 30NE.

Şekil 14. *EKTK'dan elde edilen yapısal verilerin eşit alan alt yarımküre stereografik projeksiyonu. Detaylar için Tablo 1'e bakınız. İçi dolu mavi kareler genişleme, kırmızı daireler sıkışma eksenlerini temsil etmektedir. a) EKTK'nın batısından elde edilen Normal fay düzlemleri ve kayma çizikleri. σ_1= N02E, 77SW; σ_2= N42W, 10NW; σ_3= N50E, 09NE b) EKTK'nın doğusundan elde edilen bindirme düzlemleri ve kayma çizikleri. σ_1= N75W, 02NW; σ_2= N14E, 12SW; σ_3= N25E, 78NE c) EKTK'nın doğu ve batı kenarındaki fayların tümünden elde edilen kayma çizikleri. σ_1= N51W, 08SE; σ_2= N52E, 59SW; σ_3= N34E, 30NE.*

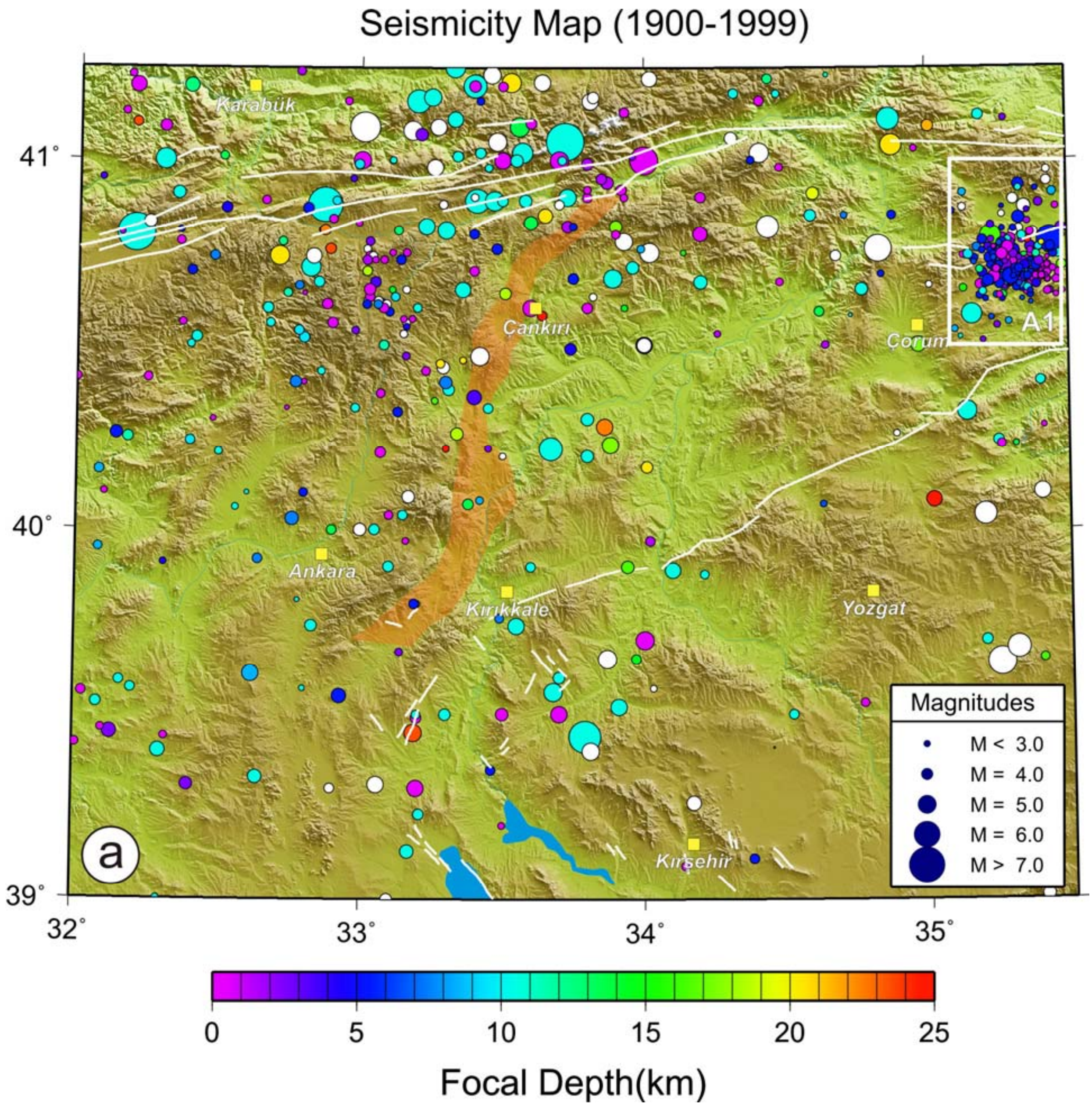
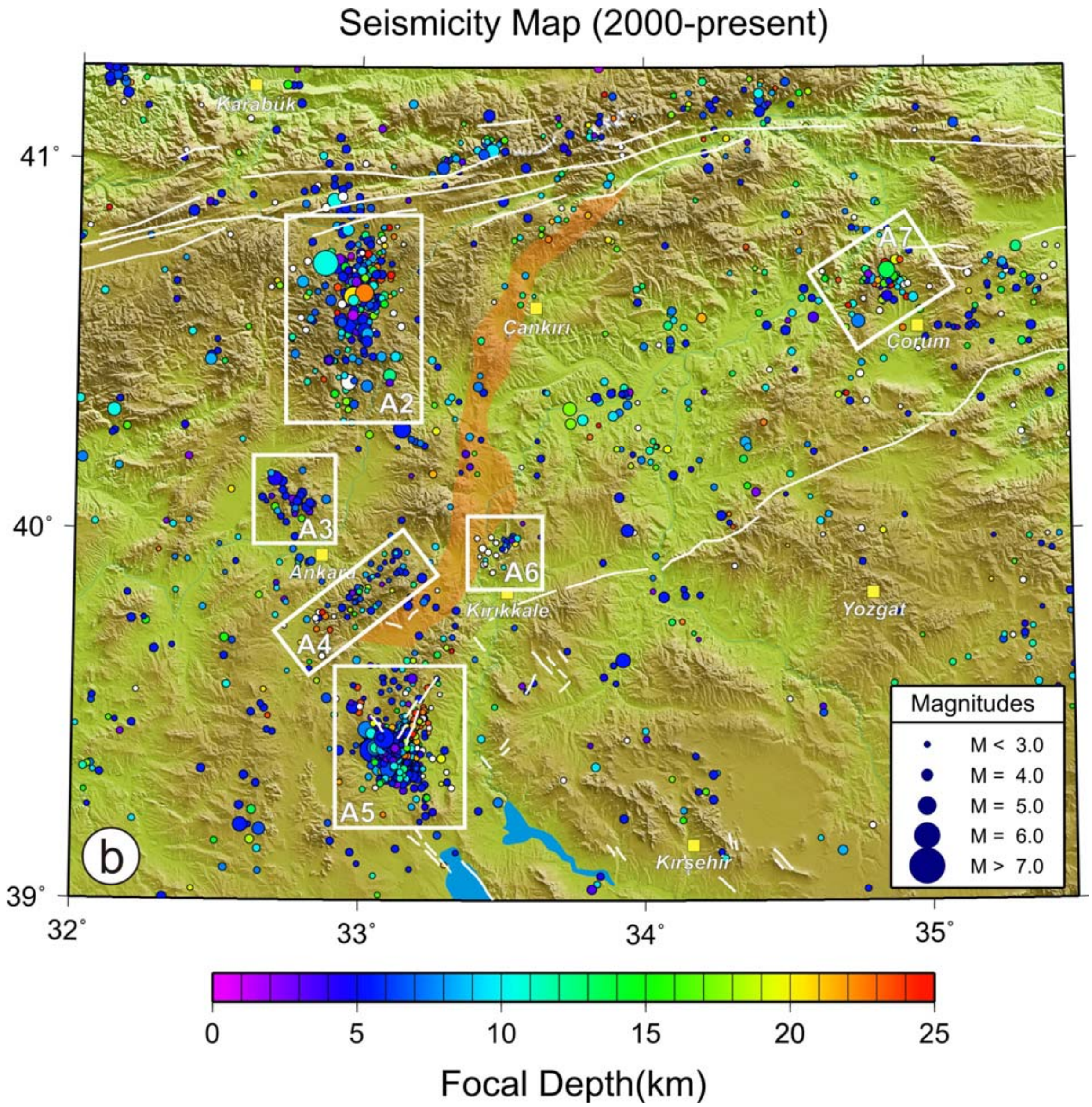


Figure 15. The seismicity map of the region during 1900-1999 a) and 2000-Present b). The rectangular areas denote the earthquake clustering regions. c) Focal mechanisms of selected 10 earthquakes. Sizes and colors of the beachballs are scaled by magnitude and depth respectively. Triangles denote seismic stations of AnkNET. Shaded area represents overall location of the EPCW.

Şekil 15. *Bölgenin depremselliği a) 1900-1999, (b) 2000-Günümüz. Dikdörtgen alanlar depremlerin yoğunlaştığı kesimleri göstermektedir. c) Seçilmiş 10 depremin odak mekanizması çözümleri. Çözümlerin sunulduğu balonların çapı ve rengi depremin büyüklüğüne ve derinliğine göre ayarlanmıştır. Üçgenler AnkNET istasyonlarını temsil etmektedir. Gölgeli alan EKTK'nın genel durumunu göstermektedir.*


Seismicity Map (2000-present)
Karabük
Çankırı
Çorum
Ankara
Kırıkkale
Yozgat
Kırşehir
A2
A3
A4
A5
A6
A7
b
Magnitudes
M < 3.0
M = 4.0
M = 5.0
M = 6.0
M > 7.0
41°
40°
39°
32°
33°
34°
35°
0
5
10
15
20
25
Focal Depth(km)

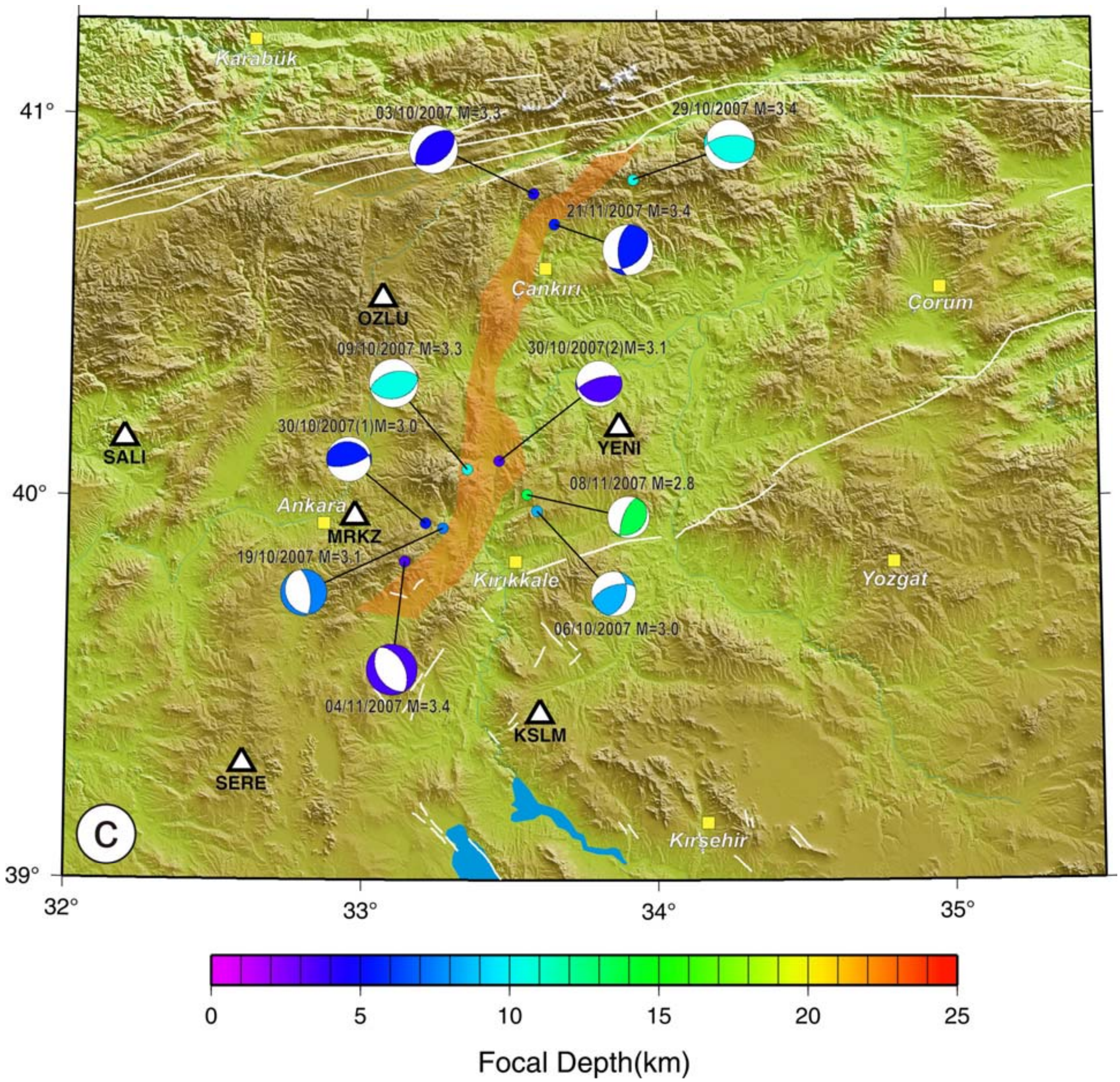

Karabük
41°
03/10/2007 M=3.3
29/10/2007 M=3.4
21/11/2007 M=3.4
Çankırı
Çorum
OZLU
09/10/2007 M=3.3
30/10/2007(2)M=3.1
30/10/2007(1)M=3.0
SALI
YENI
40°
Ankara
MRKZ
08/11/2007 M=2.8
19/10/2007 M=3.1
Kırıkkale
Yozgat
06/10/2007 M=3.0
04/11/2007 M=3.4
KSLM
SERE
C
Kırşehir
39°
32°
33°
34°
35°
0
5
10
15
20
25
Focal Depth(km)

Table 1. Fault slip measurements from the normal faulted western and thrust faulted eastern margins of the EPCW.

Tablo 1. *EKTK'nın normal faylı batı kenarı ve bindirmeli doğu kenarından elde edilen fay çizikleri.*

Location (UTM)	Strike	Dip	Trend	Plunge	
40 632 - 74 483	N05E	36NW	N86W	37NW	Reverse
40 523 – 74 407	N10E	40NW	E-W	36W	Reverse
42 782 – 77 539	N40E	42NW	E-W	34W	Reverse
40 632 - 74 483	N60E	44NW	N30W	45NW	Reverse
42 782 - 77 539	N30E	49NW	E-W	45W	Reverse
42 782 - 77 539	N15W	50SW	N80E	50SW	Reverse
45 882 - 91 246	N10W	55SW	N17W	12NW	Reverse
42 782 - 77 539	N30W	60SW	N39W	18NW	Reverse
49 276 - 91 292	N72W	62SW	N75E	47SW	Reverse
45 882 – 91 246	N25W	78SW	N08W	55SE	Reverse
42 782 – 77 539	N25W	78SW	N47W	62NW	Reverse
48 480 – 91 395	N60W	45SW	N80E	35SW	Normal
27 972 - 62 350	N55W	35SW	N40E	36SW	Normal
33 239 – 66 870	N15E	85NW	N75W	85 NW	Normal
28 591- 61 350	N17W	44SW	N53E	43SW	Normal
27 973 – 62 354	N60W	30SW	N45E	26SW	Normal
27 973 – 62 354	N-S	45W	N40E	35SW	Normal
27 973 – 62 354	N05E	45NW	N45E	35SW	Normal
27 973 – 62 354	N15W	37SW	N43E	34SW	Normal
29 836 – 53 708	N83E	39SE	N40E	27SW	Normal
29 836 – 53 708	N45W	32SW	N40E	30SW	Normal

DISCUSSION

One of the key locations on the post-collisional history of Central Anatolia is the western margin of the Çankırı basin where different tectono-sedimentary models have been proposed. Previous studies (Akyürek et al. 1980; Hakyemez et al. 1986; Koçyiğit et al. 1995) mapped the Neo-Tethyan suture zone as a double vergent thrusting towards the east and west. Koçyiğit et al. (1995) interpreted the Miocene sediments as deposited in front of the thrust sheets and they suggest that, following the Pliocene, the shortening ceased as indicated by the development of vertical faults that cut the thrust zone. It is suggested that these vertical faults control the accumulation of the Deyim formation. The thrusting of Neo-Tethyan suture zone rocks onto Neogene successions is used as evidence of continuing intracontinental convergence until the Pliocene (Ankara Orogenic Phase) (Koçyiğit et al. 1995). However, during our field studies, two different normal fault systems were distinguished in the region (Fig. 6). The younger ones are normal faults on the western margin of the EPCW. The older ones are syn-sedimentary normal faults controlling the accumulation of lower – middle Miocene sedimentary units, namely the Kılçak, Kumartaş and Hançili formations (Savaşçı, 2003; Karadenizli et al., 2003; Savaşcı and Seyitoğlu, 2004). This indicates that intracontinental convergence due to the closure of the Neo-Tethyan Ocean must have ceased prior to the Early Miocene. In other words, the Ankara Orogenic Phase model of Koçyiğit et al. (1995) is not confirmed by our field observations.

Kaymakçı (2000) reported that the Kılçak formation, which is interpreted as being deposited in front of the thrust sheets, is the last product of the compressional regime caused by intracontinental convergence between the Sakarya continent and the Kırşehir block. Kaymakçı (2000) suggests that during the early-middle Miocene, there was an extensional tectonic regime due to orogenic collapse (see also Seyitoğlu et al., 1997) that created a normal faulted topographical high separating the Hançili basin in the west and the Çankırı basin in the east. This separation is believed to have created different stratigraphies, such as the Kumartaş (Altıntaş) and Hançili formations in the Hançili basin, and the Çandır formation in the Çankırı basin. Normal faults that limit the topographical high were later inverted to double vergent thrust faults under transpression, following the late Miocene (Kaymakçı, 2000; Fig. 4.23). However, our geological map of the area (Fig. 5) shows that the Kılçak, Kumartaş and Hançili formations crop out in both the western and the eastern sides of the EPCW, indicating fragmentation of a single Çankırı basin by the EPCW. These observations invalidate the tectono-sedimentary model that Kaymakçı (2000) and Kaymakçı et al. (2001; 2003) proposed for the western margin of the Çankırı basin.

Adıyaman et al. (2001) proposed an extensional escape wedge immediately west of our study area supporting the model of Chorowicz et al. (1999). This extensional wedge was limited by the NAFZ and by the left lateral strike-slip Korgun Fault which plays an important role in accommodating the south-westerly extension of the wedge, and this model requires no early – middle Miocene sedimentary succession deposited under extensional tectonics to the east of the Korgun Fault (Adıyaman et al., 2001; Fig. 11). However, an early – middle

Miocene sedimentary succession that accumulated under extensional tectonics (Şen et al., 1998; Seyitoğlu et al., 2000; Savaşçı and Seyitoğlu, 2004) has been described in the east of the Korgun Fault. In addition, the detailed field observations presented in this paper indicate that the Korgun Fault corresponds to the western margin of the EPCW that was activated following the late Pliocene. Consequently, the Korgun Fault has no capacity to control the sedimentation of the early – middle Miocene successions in the region. This, in turn, invalidates Adıyaman et al.'s (2001) extensional wedge model for the region.

A recent study by Rojay & Karaca (2008) suggests that normal faulting postdates the reverse faults in the south of the Galatian Volcanic Province indicating a NW-SE and ENE-WSW extensional regime. Our data presented in this paper do not concur with this suggestion.

Our geological, GPS and seismological data indicate that the NW-SE contraction is dominant between the NAFZ and the KEFZ. The contractional nature of the EPCW supports the view that the Anatolian plate is pushed from the east (Şengör, 1980; Şengör et al., 1985; 2005) rather than pulled from the southwest due to the Hellenic trench (Chorowicz et al., 1999; Mart et al., 2005; Reilinger et al., 2006). Moreover, the GPS horizontal velocities of McClusky et al. (2000; Fig. 2) in a Eurasia-fixed reference frame show a fan shape distribution on the north of the Bitlis suture zone, and this, together with the regional paleomagnetic data of Gürsoy et al. (2003; Fig. 8), indicate indentation tectonics due to the Arabian plate. This relationship demonstrates that stations with positive north velocities in Central Anatolia such as the KKIR, YOZG and ABDI are influenced by the indentation tectonics of the Arabian plate.

Conclusions

The NNE-trending EPCW is located between Çankırı and Ankara and limited by coevally developed thrust and normal faults in the eastern and western margins, respectively. It is a post - early Pliocene neotectonic structure developed under the NW-SE compression created by the NAFZ and KEFZ, and accommodates a 2.8 km shortening within the Anatolian plate. It is clear that this structure plays an important role on the internal deformation of the Anatolian plate and should be regarded as a potential source in the earthquake risk assessment of Ankara and Çankırı.

Acknowledgements

This paper is one of the results of projects sequentially supported by TUBITAK (198Y014), TUBITAK-CNRS (101Y108), CNRS-INSU (ECLIPSE), MTA 16-A3, and Ankara University (2001.070.5053; 2005.074.5008 HPD; 2006.074.5052).

Appendix I

The regional waveforms recorded by digital broadband stations of the Ankara University Seismic Network (AnkNET) are used in the focal mechanism solutions in NW central Anatolia. The seismic stations of AnkNET are shown in Figure 15c. For the computation of the source parameters of the events, a full waveform moment tensor inversion method was applied to three component broadband seismograms provided by AnkNET.

The moment tensor inversion method for multiple point sources has been developed and extended to full waveform data at regional or local distances by Zahradnik et al (2005), based on Kikuchi and Kanamori (1991). This method allows full waveform inversion, on the basis of the discrete wavenumber method of Bouchon (1981) and Coutant (1989). The moment tensor is calculated by minimizing the difference between observed and synthetic displacement in the least square sense at any predefined trial source position and any origin time. More detailed information about the method can be obtained from Zahradnik et al (2005).

For the focal mechanism solution, the events selected are given in Table A1. During the processes, only digital seismograms recorded by three component broadband seismometers were used for the focal mechanism determination.

In our analyses, a simple velocity model (Toksöz et al., 2003) was used for computation (Table A2). This velocity model is also used for the earthquake location procedure by AnkNET. Only seismograms with quality waveforms (high Signal/Noise) were considered for the computation. Before the inversion, for all velocity seismograms, instrument correction was carried out and all records were then windowed between 200 and 400 sec for the analyses.

After all computations, the source parameters of the selected 10 earthquakes were obtained. The resulting source parameters and moment magnitudes of the events are given in Table A3 and shown in Figure 15c.

Table A1. List of the events recorded and analyzed in this study. The hypocentral locations were computed by AnkNET.

Tablo A1. *Bu çalışmada kaydedilen ve incelenen depremlerin listesi. İç merkez konumları AnkNET verilerinden hesaplanmıştır.*

AnkNET						
Event No	*Date*	*Origin Time*	*Latitude*	*Longitude*	*Depth*	*Magnitude (Md)*
1	03/10/2007	11:26:19.71	40.7968	33.5763	4.8	3.1
2	06/10/2007	11:35.08.88	39.9660	33.5892	8.2	2.6
3	09/10/2007	13:54:51.11	40.0748	33.3520	10.4	2.6
4	19/10/2007	04:24:42.37	39.9205	33.2708	7.6	2.7
5	29/10/2007	01:31:16.00	40.8337	33.9170	10.7	2.7
6	30/10/2007	10:07:20.90	39.9332	33.2113	5.0	2.4
7	30/10/2007	14:17:51.43	40.0965	33.4597	3.0	2.2
8	04/11/2007	06:21:32.32	39.8328	33.1412	3.2	2.9
9	08/11/2007	10:40:57.51	40.0088	33.5563	13.5	2.9
10	21/11/2007	01:15:29.57	40.7158	33.6478	5.0	2.9

Table A2. Crustal P-wave velocity model used in the inversions (Toksöz et al., 2003). S-wave velocities and densities are calculated amprically.

Tablo A2. *Kabuksal P-dalga hız modeli (Toksöz vd., 2003) tersçözümlerde kullanılmıştır. S-dalga hızları ve yoğunluklar ampirik olarak hesaplanmıştır.*

Depth of layer top(km)	*Vp(km/s)*	*Vs(km/s)*	*ρ(gr/cm³)*
0.0	5.00	2.81	2.70
5.0	5.40	3.03	2.78
10.0	6.15	3.46	2.93
20.0	6.40	3.60	2.98
36.0	7.80	4.38	3.26

Table A3. The results of the inversion for the 10 events analyzed in this study.

Tablo A3. *Bu çalışmada incelenen 10 depremin tersçözüm sonuçları.*

AnkNET													
Event No	*Date*	*Depth (km)*	*Mw*	*Nodal Plane 1*			*Nodal Plane 2*			*P-axis*		*T-axis*	
				strike	*dip*	*rake*	*strike*	*dip*	*rake*	*Azim.*	*Plunge*	*Azim.*	*Plunge*
1	03/10/2007	3.0	3.3	58	44	101	222	47	80	319	2	63	83
2	06/10/2007	5.0	3.0	251	60	126	16	46	44	316	9	213	59
3	09/10/2007	3.0	3.3	254	53	87	79	37	93	346	9	152	82
4	19/10/2007	18.0	3.1	352	67	-82	153	24	-108	275	67	76	22
5	29/10/2007	5.0	3.4	119	35	120	264	61	71	7	14	135	69
6	30/10/2007(1)	6.0	3.0	74	69	77	287	25	120	173	23	322	65
7	30/10/2007(2)	3.5	3.1	101	23	116	254	70	80	351	24	146	65
8	04/11/2007	2.5	3.4	332	49	-88	149	41	-92	259	87	60	4
9	08/11/2007	5.0	3.1	185	57	119	320	43	53	254	8	149	65
10	21/11/2007	5.0	3.4	183	58	62	48	42	126	292	9	41	66

GENİŞLETİLMİŞ ÖZET

Orta Anadolu'nun KB'sında Çankırı havzasının batı kenarında yeralan Neo-Tetis Kenet Zonu, Kuzey Anadolu Fay Zonu (KAFZ) ve Kırıkkale-Erbaa Fay Zonu (KEFZ) arasında gelişen KB-GD sıkışma nedeniyle neotektonik bir yapı olarak yeniden hareketlenmiş ve KKD gidişli batı kenarı normal faylı, doğu kenarı ise bindirmelerle sınırlı bir tektonik kama oluşturmuştur (Şekil 1, 3, 4) (Seyitoğlu vd. 2000).

Bu makalenin amacı Eldivan-Elmadağ Kıstırılmış Tektonik Kaması (EKTK) olarak isimlendirilen bu neotektonik yapının ayrıntılarını ortaya koymak ve bu yapının Anadolu levhasının deformasyonundaki rolünü tartışmaktır. EKTK Çankırı havzasının Neojen çökellerini deforme ettiğinden bu havzanın stratigrafisini gözden geçirmek gerekir. Çankırı havzasının Neojen stratigrafisi Erken Miyosen yaşlı Kılçak formasyonu (Şen vd. 1998) ile başlar. Bu birim Alt -Orta Miyosen Kumartaş formasyonu tarafından uyumlu olarak üzerlenir (Özcan vd. 2007). Kumartaş formasyonu yanal ve düşey olarak Hançili formasyonuna geçer (Karadenizli vd. 2003; Savaşçı & Seyitoğlu, 2004). Kumartaş formasyonu'nun Çankırı üyesi, Üst Miyosen Bayındır formasyonu ve onun Süleymanlı üyesi tarafından üzerlenir (Karadenizli vd. 2004). Bunu Pliyosen Bozkır formasyonu izler (Varol vd. 2002). Üst Pliyosen - Pleyistosen Deyim formasyonu ise tüm birimleri uyumsuzlukla örter (Şekil 3).

EKTK'nın bindirmeli doğu kenarı Çankırı'nın batısında gözlenir, güneybatısında ise ana yapının küçük ölçekli kopyaları dikkat çekicidir. Daha güneyde EKTK batı ve doğu kama olmak üzere iki kamadan oluşur. Batı kamanın doğu kama üzerine bindirdiği Mart köyü kuzeyinde açıkça gözlenmektedir. Termeyenice civarında EKTK'nın bindirmeli doğu kenarının derin kazılmış vadilerde Kumartaş ve Hançili formasyonlarını deforme ettiği ve Bozkır formasyonu üzerine itildiği görülür. Bindirmenin en iyi izlendiği yerlerden biri olan Babaş köyü yakınında bindirme zonunda iyi gelişmiş kataklastik zon bulunur. Kuzeye doğru yapısal olarak daha üst kesimlerin gözlendiği Büyükhacıbey, Küçükhacıbey ve Merzi civarında görüleceği gibi EKTK'nın bindirmeli doğu kenarı Deyim formasyonunun çökelimini denetlemektedir.

EKTK'nın batı kenarı ise normal faylarla sınırlıdır. Koyunbaba ve Karatepe civarında normal faylar KKB gidişli ve GB'ya eğimlidir. Üzerlerindeki hareketin normal fay olduğu mikrotektonik çalışma ile belirlenmiştir (Önal vd. 2006). ETTK'nın normal faylı batı sınırı kuzeye doğru devam eder. Karatekin ve Korgun'un doğusunda fay düzlemleri açıkça görülür ve Deyim formasyonunun çökelimini denetler. Jeolojik ilişkilere göre EKTK Erken Pliyosen sonrasında etkin olmuş olmalıdır (Şekiller 5, 6, 7, 8, 9).

EKTK'nın KAFZ ve KEFZ arasında neotektonik bir yapı olarak geliştiğini onun güney sınırını inceleyerek de denetleyebiliriz. Elmadağ güneyinde Balaban havzasının batı kenarında EKTK'nın doğu kenarına ait bindirme, havzanın Miyosen – Pliyosen çökellerini deforme etmiş ve D-B gidişli sağ yanal Akarlar fayına bağlanmıştır (Şekil 10 ve 11). Bu fayın güneyinde herhangi bir bindirmeye rastlanmamıştır.

Yayınlanmış Küresel Konumlama Sistemi verileri (Reilinger vd. 2006) değerlendirildiğinde

(Şekiller 12 ve 13) bölgedeki sıkışmanın KB-GD yönlü olduğu görülmektedir. Bu veri EKTK'nın konumu ile uyum içinde olup, aynı zamanda EKTK'nın normal ve bindirmeli sınırlarından elde edilen yapısal veriler de birbirlerine uyumludur (Şekil 14).

Bölgedeki sismik etkinlik Ankara Üniversitesi tarafından kurulup işletilen AnkNET adlı sismik ağ tarafından gözlenmektedir. İlk veriler arasından seçilen 10 depremin odak mekanizma çözümleri de (Şekil 15) EKTK'nın batı kenarı normal faylı, doğu kenarı bindirmeli neotektonik bir yapı olduğunu göstermektedir. Bu sıkışmalı yapının varlığı Anadolu levhasının GB'dan çekiliyor olmasından ziyade GD'dan itildiğini göstermesi açısından önemlidir.

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