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# An Example of Intracontinental Cross Faults Formation from the Vicinity of Karapınar (Konya – Central Anatolia)

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ABSTRACT:

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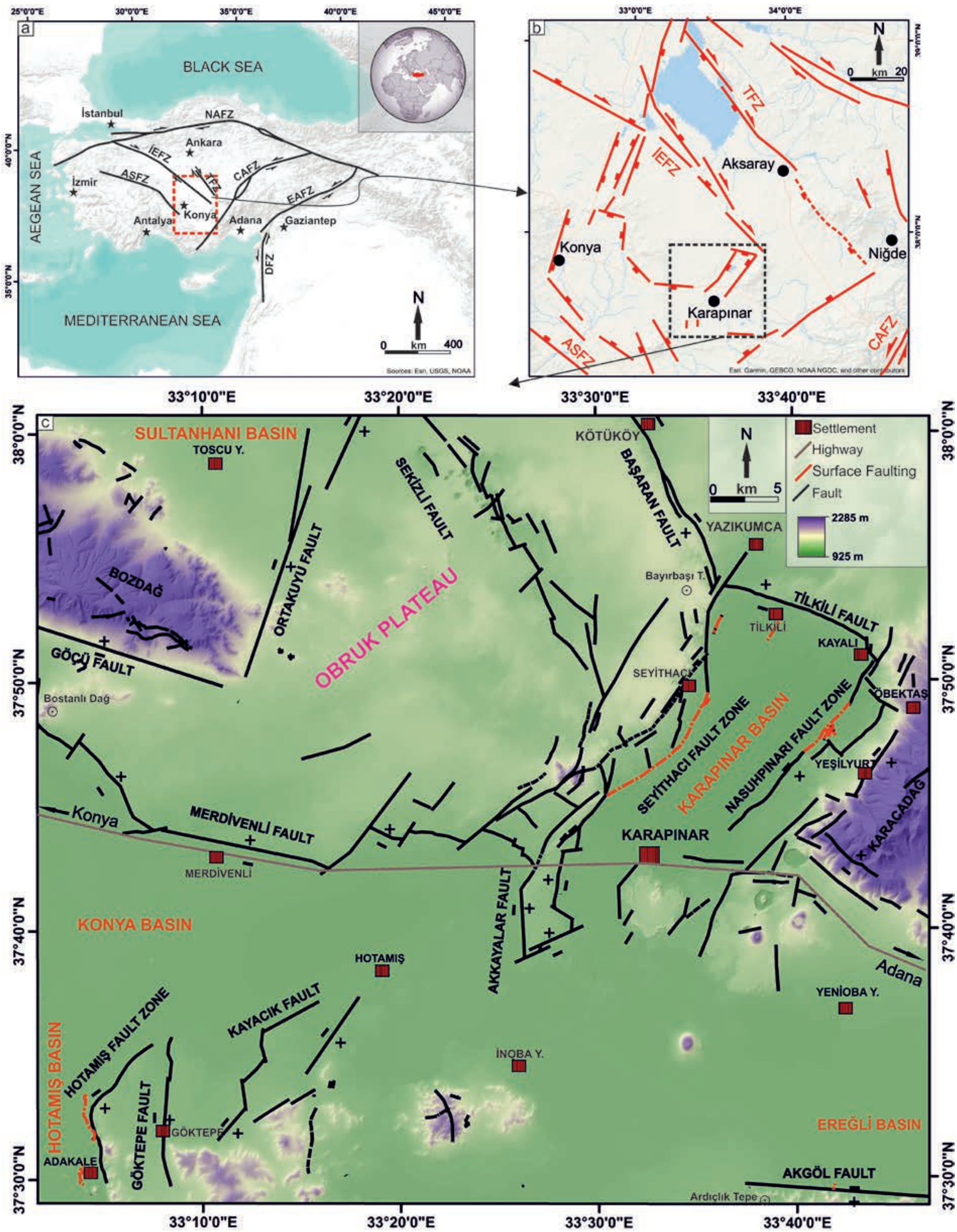
Karapınar (Konya, Turkey) is located in the central part of the Anatolian micro-plate which is characterized by differently oriented Neogene–Quaternary horst – graben structures. The basement of the region is composed of Mesozoic–Paleogene rocks. In the various Neogene basins, Miocene–Pliocene sedimentary and volcanic rocks overlie the basement rocks and form the secondary rock units. The youngest units are Plio-Quaternary aged terrestrial sediments and volcanics. The main structure of the study area consists of WNW-ESE and NE-SW trending intersecting graben-horst structures and the normal faults forming them. The approximately WNW-ESE trending basins are filled with Miocene–Pliocene sediments, while the NE-SW trending basins are filled with Pliocene–Quaternary sediments. Kinematic studies show that the faults in the study area are developed in all directions and the distribution of the slicken lines indicates that there is multidirectional crustal extension. The principal stress axes obtained from all the kinematic data show that $\sigma_1$ is nearly vertical, $\sigma_2$ and $\sigma_3$ are horizontal. If all faults are assumed to have been formed due to the same stress system, the study area is predominantly elongated in the NW-SE direction. However, detailed field observations and structural analyses indicate that the NE-SW trending fault systems are younger than the WNW-ESE trending faults. This indicates that firstly NNE-SSW and then NW-SE crustal extension developed in the study area respectively.

**Key words:** Karapınar; Graben; Normal Faults; Extension; Cross-Graben.

## INTRODUCTION

The geology of Turkey has been extensively shaped by the collision of the Eurasian and Gondwana continents (Brinkman 1976; Şengör 1980; Okay *et al.* 1986; Stampfli *et al.* 1991, 2001; Stampfli 2000, Stampfli and Borel 2002, 2004). The collision of the Arabian plate with the Eurasian plate in the Middle–Late Miocene along the Bitlis-Zagros suture zone and continued compression affect the recent tectonics of Turkey (Mc Kenzie 1972; Dewey and Şengör 1979; Şengör *et al.* 1985). Late Miocene and onwards compression formed the dextral North Anatolian fault zone (NAFZ) and the sinistral East Anatolian fault zone (EAFZ) and the Anatolian microplate which is bounded by these faults escaped to the westward (Text-fig. 1a). The subduction of the African plate under Anatolia-Greece along the Cyprus-Hellenic arcs is another factor affecting the recent tectonics of Turkey. Tectonic escape and subduction along the the Cyprus-Hellenic arcs caused the Anatolian microplate to move anti-clockwise towards the southwest (Mc Clusky *et al.* 2000). The left-lateral Dead Sea fault zone, which allows the African and Arabian plates to move northwards at different speeds, is one of the prominent structures that shaped the neotectonic period of Turkey (Text-fig. 1a). These main structures and movements have enabled the development of three main Neotectonic provinces




Text-fig. 1. Location map of the study area, (a) Major tectonic structures of Central and Western Anatolia (NAFZ: North Anatolian fault zone, EAFZ: East Anatolian fault zone, DFZ: Dead Sea fault zone, CAFZ: Central Anatolian fault zone, TFZ: Tuz Gölü fault zone, IEFZ: İnönü - Eskişehir fault zone, ASFZ: Akşehir fault zone), (b) Important faults around the study area, (c) Morphometric map of Karapınar region with main faults.

in Turkey: West Anatolian extension, East Anatolian contractional and Central Anatolian "OVA" provinces. The existence of cross fault systems and related grabens in Western and Central Anatolia has been revealed by many researchers (Koçyiğit 1984; Şengör 1987; Seyitoğlu and Scott 1996; Yılmaz *et al.* 2000; Bozkurt 2000 and 2001; Eren 1993, 1996 and 2004, Gürbüz *et al.* 2010; Koç *et al.* 2012; Aksoy 2019). The formation of the cross structures have been explained by different mechanisms such as tectonic escape (Dewey and Sengor, 1979; Şengör 1987; Şengör *et al.* 1985), back-arc extension caused by the Cyprus-Hellenic subduction system (McKenzie 1978; Le Pichon *et al.* 1979 and Meulenkarnp 1988), orogenic collapse (Seyitoğlu and Scott 1992 and 1996), an episodic two stage graben model (Koçyiğit *et al.* 1999), and combinations of these. According to Şengör (1980), the region is under an extensional tectonic regime, which is the continuation of decreasing extension in the Western Anatolia region, while according to Barka and Reilinger (1997), the Central Anatolia region is under a compressional regime parallel to the Cyprus arc. Koçyiğit and Özacar (2003) divided Central Anatolia into two sub-neotectonic provinces as the Eskişehir-Konya and Kayseri-Sivas regions. The Konya-Eskişehir neotectonic region is under an extensional tectonic regime, while the Kayseri-Sivas region is under an extensional tectonic regime with a strike-slip component. The boundary of these two neotectonic regions is delineated by the İnönü-Eskişehir fault zone and the Tuzgölü fault zone. Karapınar (Konya), which is located about 100 km east of Konya and attracts attention with its classic historical sinkholes and the rapidly increasing number of sinkholes in recent years, is located in the region called the Central Anatolian "OVA" province (Şengör 1980) (Text-fig. 1a). According to Koçyiğit and Özacar (2003), the region is located within the Konya-Eskişehir extensional sub-neotectonic region but, according to Barka and Reilinger (1997), this region is under a compressional tectonic regime. The NW-SSE trending Tuz Gölü fault zone is located close to the north of the study area and the branches of the fault which splay to the southwest extend towards the study area. In addition, the branches of the İnönü-Eskişehir-Sultanhanı fault zone, which bounds the southwestern edge of the Tuz Gölü Graben, extend into the study area. The Niğde fault zone (Koçyiğit 2003) bounds the study area to the southeast. Further south the NE-SW trending left-lateral strike-slip Ecemiş fault zone is located in a position which bounds the western part of The Anatolian diagonal shear zone (Seyitoğlu *et al.* 2022) (Text-fig. 1b). The WNW-SSE trending normal Göçü fault, which bounds the Bozdağ Mountains, is also located close to the west of the study area (Text-fig. 1c).

Neotectonic studies have been carried out in and around the study area. Lahn (1948) emphasized that the faults bounding the basins in Central Anatolia are important in terms of seismicity, and Koçyiğit (1984, 2000, 2003) described the fault systems in Central Anatolia in general. Eren (1993, 1996) stated that the region underwent extension in the Middle–Late Miocene, compression in the Late Miocene–early Pliocene and extension again during the Pliocene–Quaternary. Eren (2001, 2003a, 2017), during his studies in Konya basin, stated that there are NNE-SSW and E-W trending fault systems in the region and that the area firstly extended in a N-S and then in a WNW-ESE direction. Koç *et al.* (2012), in their study carried out in the northwest of Konya, suggested that the direction of extension in the region is NE-SW, which supports the idea of extension in NW-SE and NE-SW directions obtained in the Southern Taurus Mountains and that this is compatible with the location of the Cyprus subduction zone. Aksoy (2019) also emphasized the existence of two different extensional regimes around Konya.

In the literature as mentioned above, the study region in central Turkey has a significance for extensional neotectonic activity and the recent formation of notable sinkholes. This detailed study will shed light on the neotectonic features of Karapınar and its surroundings, which are bordered by the Kayseri-Sivas region in the north and the Konya-Eskişehir region in the west and characterised by intense sinkhole formation.

## METHODS

In this study, the faults observed around the Karapınar area were mapped in detail and kinematic data related to the faults were collected and evaluated in appropriate methods and diagrams. Throughout the area, numerous joint measurements were taken and analyzed by rose and point-contour diagrams. The relationships of the obtained data with other fracture systems were analyzed. Automatic lineation maps were derived from The Digital Elevation Model (DEM) map and their relations with the main faults in the studied area examined. Rose diagrams were prepared according to the trends of the lineaments from the lineation map and compared with the fracture structures in the study area. In addition, Wintensor software (Delvaux and Sperner 2003) was used for fault analysis and determination of paleo-stress orientations.

## GEOLOGICAL SETTING

The Karapınar (Konya) region consists of morphologically different oriented elevations and basins. The Mesozoic aged metamorphic and ophiolitic rocks, Miocene–Pliocene aged lacustrine rocks and Miocene–Quaternary aged volcanics crop out on the elevations, while Pliocene–Quaternary aged continental sediments are observed in the basins (Text-fig. 2). The Mesozoic aged rocks consist of metaclastics of terrestrial origin, dolomite marble, marble and metacherty marble from bottom to top. These units were overlain by ophiolitic melange and ophiolites due to the closure of the Neo-Tethys Ocean. These basement units are present on the Bozdağ in the west of the study area and between the Adakale and Inoba regions in the south. The rocks were deformed and metamorphosed during the closure of the Inner Tauride Ocean between the Late Cretaceous and Late Eocene and gained nappe-folds structures. The region had become terrestrial between the Late Eocene and Middle Miocene and then the basins had developed due to block faulting during the Late Miocene–Pliocene. Alluvial fans and lacustrine rocks were deposited in these basins. As a result of the magmatic activity simultaneously accompanying the block faulting, Miocene–Pliocene aged volcanic rocks and successive volcanoclastics were deposited. During the Plio-Quaternary period, the Miocene–Pliocene aged lacustrine rocks were uplifted due to the reactivation of block faults (Text-fig. 2), resulting in the development of the Obruk Plateau and basins with different trends. The alluvial fan, lacustrine and marsh sediments were deposited in these basins. In addition, due to the recent crustal movements, Plio-Quaternary aged volcanic complexes such as Karacadağ and Karadağ, maars such as Meke Lake, Acıgöl and young volcanic cones were formed in the region. (Text-fig. 2).

## RESULTS

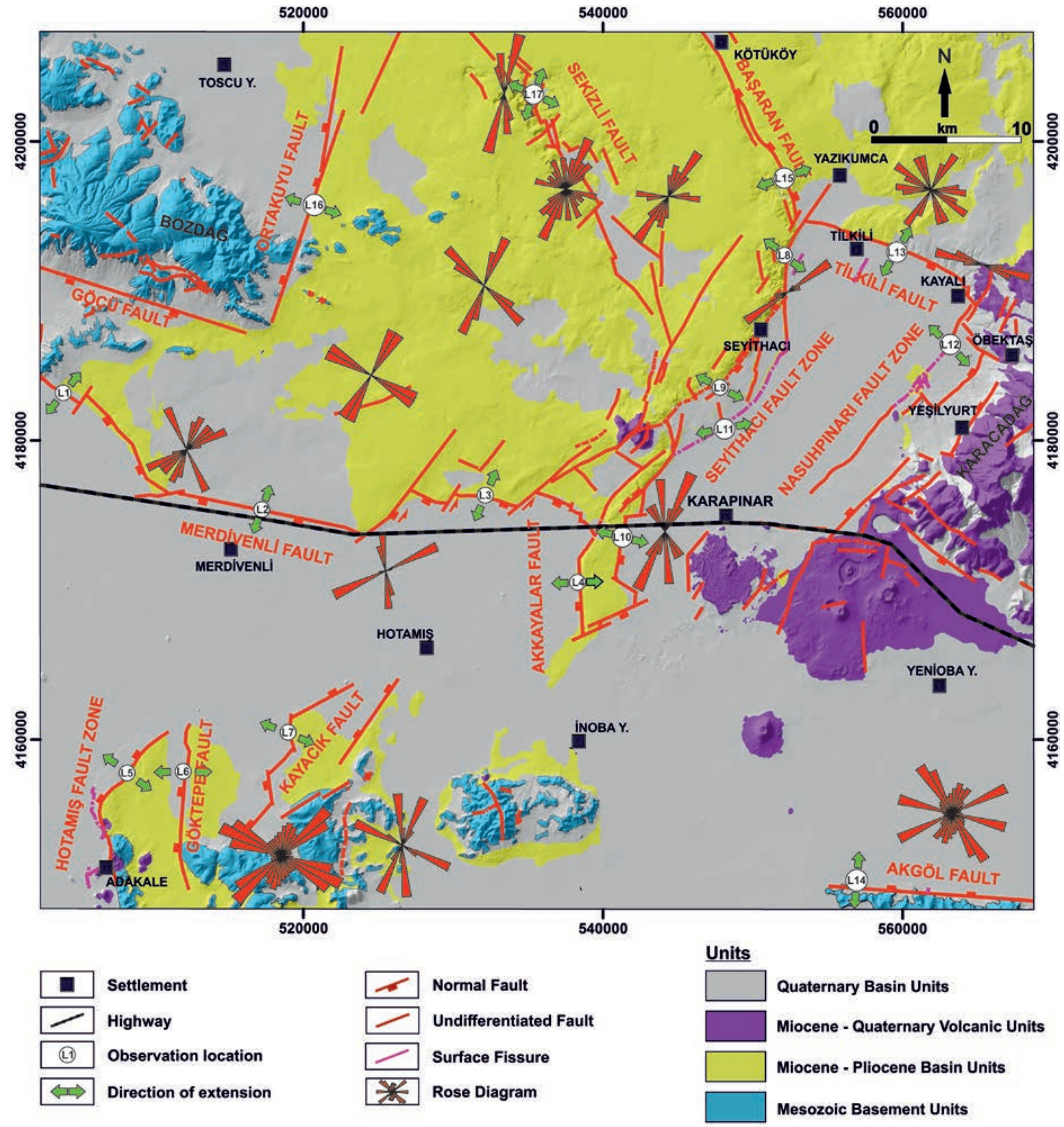
The main morphologic structures in the study area are shaped by NE-SW, NW-SE and WNW-ESE trending elevations and basins. The Obruk Plateau, Bozdağ, Inoba and Karacadağ volcanic hill form the important elevations in the region. Between these elevations there are the NW-SE trending Karapınar basin, the Hotamış basin, which is the westward extension of the Konya basin, and the Akgöl-Ereğli basin in the southeast (Text-figs 1c and 2). In accordance with the structure of the region, NW-SE and NE-SW trending fault systems constitute the dominant structure in the study area. Besides these, E-W and N-S trending faults are also located in the area (Text-fig. 2). Although the NE-SW trending structures and young volcanic hills seem to be younger than the other structures, the different trending fault systems acted as transfer faults for each other in the neotectonic period.

### Konya Basin

Konya basin is a composite basin and is bounded by faults orientated N-S to the west and WNW-ESE to the east (Text-fig. 1b) (Eren 2000). The eastern part of the basin is located in the study area and is delineated by the Merdivenli fault in the north, and the Akkayalar, Kayacık Göktepe faults and the Hotamış fault zone in the east.

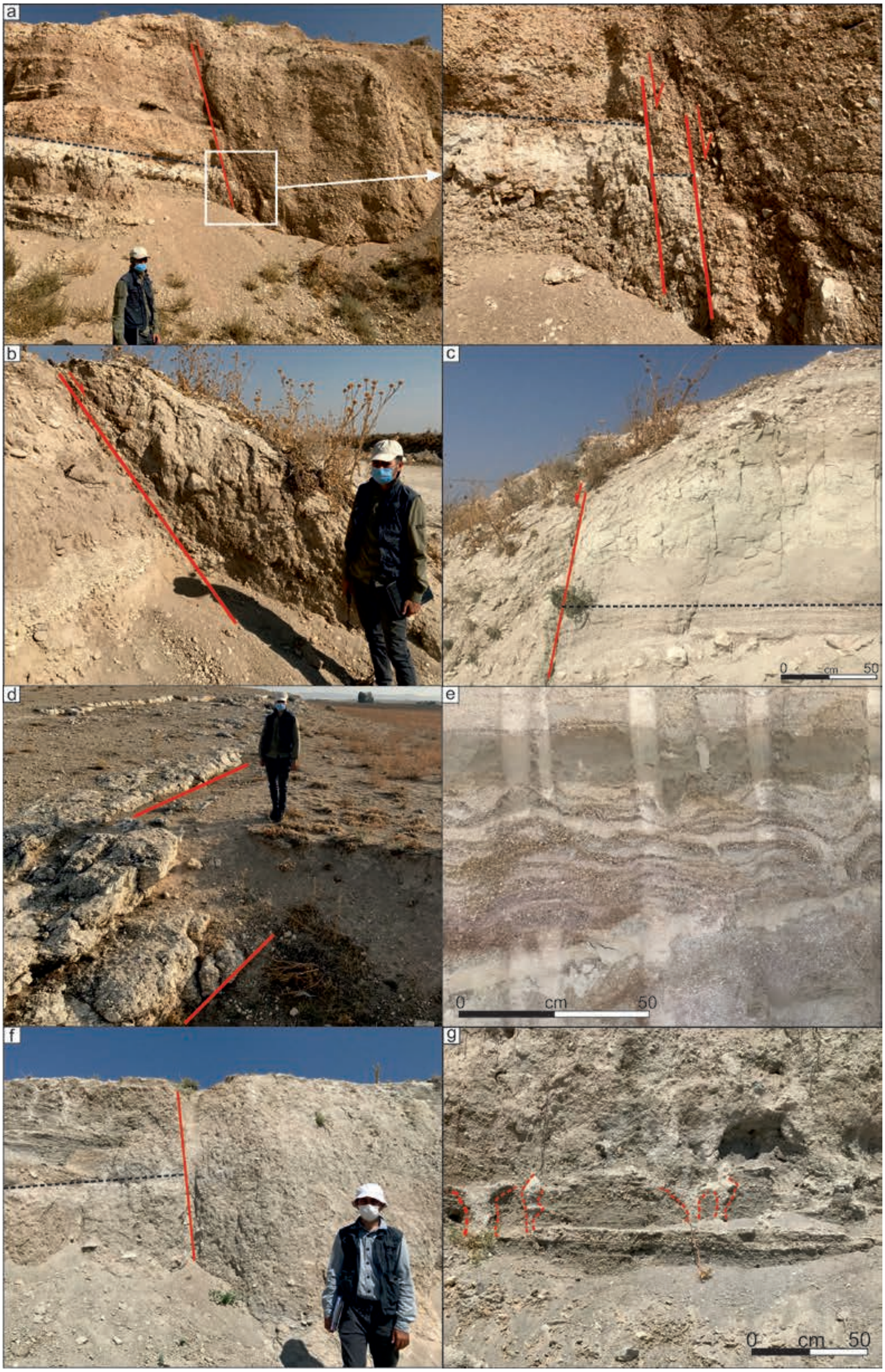
#### *Merdivenli Fault (MF)*

The Merdivenli fault (MF) (Eren *et al.* 2020) forms the contact between the Konya basin and the Miocene–Pliocene aged lacustrine sediments in the west of the study area, and is a WNW-ESE trending fault dipping to the southwest (Text-fig. 2). MF is a dip-slip normal fault with a length of approximately 38 km. MF is frequently cut by NE-SW oriented faults and can be divided into three parts according to this feature. The first section, which starts from the vicinity of Bozdağ in the west, has a NW-SE trend dips to the SW and is approximately 12 km in length. Along the fault, the hanging wall of the MF is made up of the Quaternary sediments of the Konya basin and the footwall consists of Mesozoic basement rocks and carbonate rocks of Miocene–Pliocene age. The MF forms a prominent structural terrace in the region extending from Bostanlıdağ in the west to Karapınar in the east. The fault can be observed very clearly in the sand quarry that cuts the fault trace (Text-fig. 3a). Neptunian dykes are observed in alluvial rocks running parallel to the fault. As a result of the kinematic analysis of the fault, the stresses in this section were determined as $\sigma_1$ – the maximum principal stress axis: 62°/057; $\sigma_2$ – the mean principal stress axis: 00°/148 and $\sigma_3$ – the minimum principal stress axis: 28°/238 (Text-fig. 4a, L1). The second part of the fault around Merdivenli is clearly observed morphologically for approximately 13 km in an E-W direction. In this section, the fault was offset 4 km to the north by a NE-SW trending transfer fault. The Miocene–Pliocene lacustrine rocks of the Konya basin and Plio-Quaternary aged rocks sit side by side and the

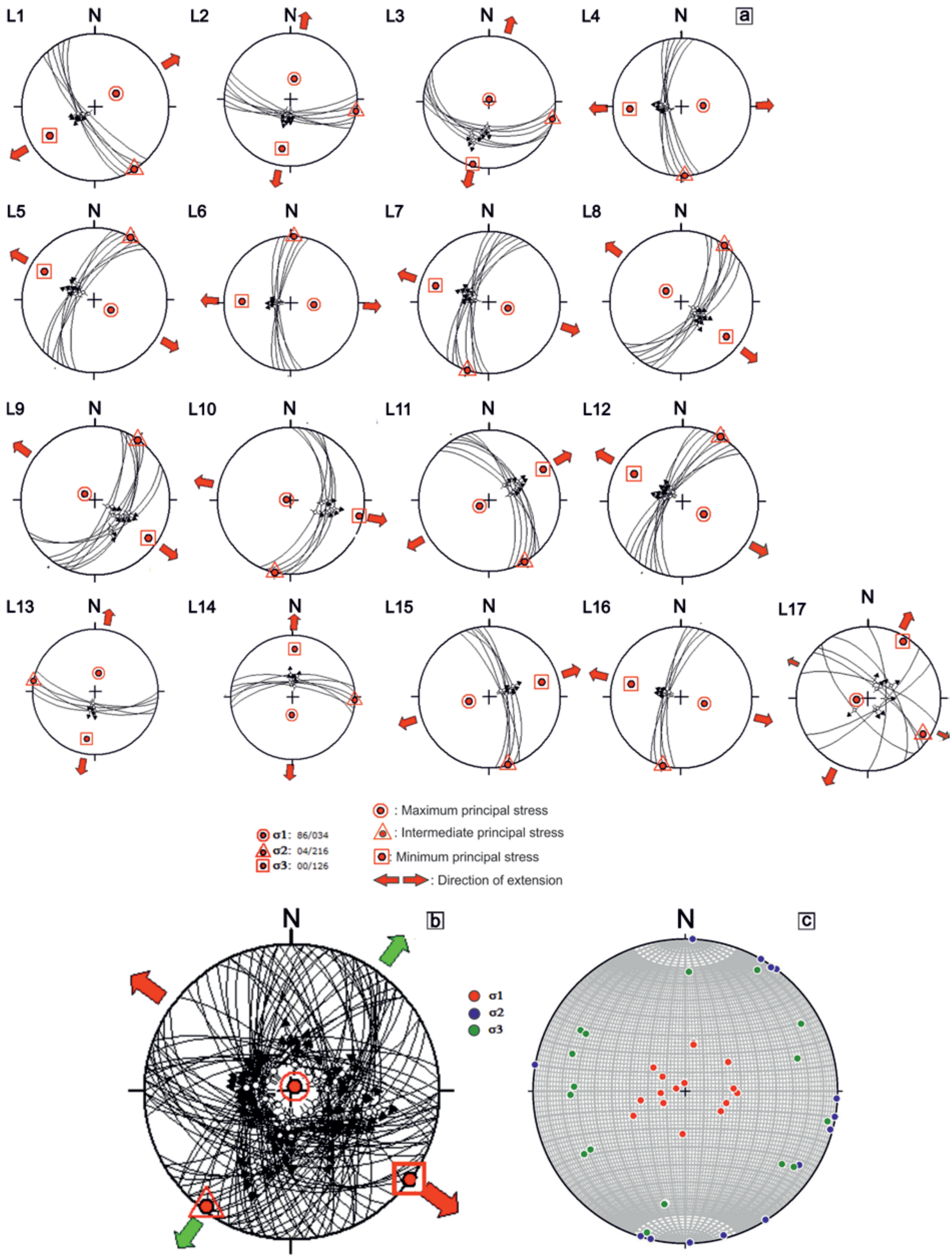



Text-fig. 2. Geological map of the study area including major fault systems and strike-rose diagrams for fracture measurements (green arrows indicate the axis of maximum extension direction).

southern part has subsided. Small faults and related fractures cutting Quaternary aged rocks are observed along the sand quarries (Text-fig. 3b). The kinematic data obtained from this section show a NNE-SSW trending extension, and the principal stress axes were determined as $\sigma_1$: 64°/010, $\sigma_2$: 00°/100 and $\sigma_3$: 26°/190 (Text-fig. 4a, L2). The WNW-ESE trending third part of the fault, which is located in the easternmost part is 14 km long. MF ends by being cut by the Akkayalar fault (AF) in the east (Text-fig. 2). The westernmost branch of the Seyithaci fault zone (SFZ) intersects the MF in its central part. In this section, the fault forms the contact between the Mio-Pliocene and Quaternary sediments of the Konya basin and is covered by the youngest Quaternary aged rocks. In the study area, small sinkholes running parallel to




Text-fig. 3. Several views from faults of the study area (a) the appearance of the western part of the Merdivenli fault (MF) in the sand quarry, (b) The view of the middle segment of the MF, (c) a view from the Akkaya fault (AF) within the Quaternary aged units and (d) at the contact of the Miocene–Quaternary units, (e) seismite structures observed within the Quaternary aged units, (f) one of the syntetic fault of the Hotamış fault (HFZ) within the Quaternary aged units around Adakale, and (g) The liquefaction structures observed in the same section.




Text-fig. 4. (a) Solutions for kinematic indicators of faults measured in the different parts of the study area, (b) The principal stress axes related to the solutions of the all faults, (c) The kinematic solutions related to all faults in the investigation area. (Text-fig. 2).

this fault are observed in both the hanging wall and footwall blocks. The kinematic data of this section again indicates NNE-SSW extension. The principal stress axes that created faulting are $\sigma_1$: 86°/357; $\sigma_2$: 01°/105 and $\sigma_3$: 04°/195 (Text-fig. 4a, L3).

*Akkayalar Fault (AF)*

The Akkayalar fault (Göçmez *et al.* 2001) is parallel to the SFZ to the west of Karapınar and together they form an NNE-SSW trending horst structure (Text-fig. 2). AF, which is a west-dipping normal fault, has a length of approximately 14 km and consists of two main parts. The first part of AF in the north is approximately 8 km long and dips to NW. Along this fault, the Insuyu formation and Quaternary alluvial rocks are juxtaposed. Travertine was observed in the southernmost part of the fault. Again, in the sand quarry in this section, it is clearly observed that the fault cuts Quaternary aged rocks (Text-fig. 3c, d). The second part of the AF, which has a N-S trend and is approximately 5.5 km long, forms a topographically significant steep slope and is interrupted by a normal fault in the south. The AF is a normal fault and in some sections, slickenlines showing a little left-lateral movement were observed. In the cuts of the sand quarries, seismites are seen which show the movement of the fault (Text-fig. 3e). As a result of kinematic analyses in this section, principal stress axes were found as $\sigma_1$: 64°/087, $\sigma_2$: 00°/178 and $\sigma_3$: 26°/268 (Text-fig. 4a, L4). These data show that the fault is predominantly a normal fault and that there is an extension in the E-W direction in this section.

*Hotamış Fault Zone (HFZ)*

The Hotamış fault zone (Ulu *et al.* 1994) (HFZ) is a N-S oriented fault located in the southwest of the study area. HFZ starts from the southeast of Adakale in the study area and continues in a NNW-SSE direction for approximately 5 km (Text-fig. 2). Small faults parallel to the main fault and clastic dykes were also observed in the Quaternary rocks east of Adakale (Text-fig. 3f and g). Widespread surface deformations and small-scale sinkholes are also found in the southern part of the fault zone. After this place, the HFZ continues in a NNE-SSW direction for approximately 7 km. A significant scarp and vegetation changes parallel to this scarp, old spring outlets and polished fault planes are observed along the fault. The principal stress axes were determined as $\sigma_1$:68°/120, $\sigma_2$: 00°/030 and $\sigma_3$: 22°/300 (Text-fig. 4a, L5).

*Göktepe Fault (GF)*

The N-S trending and west-dipping Göktepe fault (GF) is observed around Göktepe village for a length of approximately 11.5 km. It is observed lying between Miocene–Pliocene and Quaternary alluvial rocks in the southwest of the study area, east of the Adakale fault (Text-figs 1c and 2). A section of the fault, 1 m wide and 6–7 m deep, was exposed along a channel opened perpendicular to the GF around Göktepe, and it was observed that the horizontal caliche formations in this outcrop were cut by the GF and suffered a vertical slip of approximately 1 m. There is a vertical uplift of approximately 1m in the topography in the eastern block throughout the zone. Sinkhole formations were also observed along the hanging wall of the fault in the northern part of the GF. Kinematic analyzes of the fault indicate that this section extended in an E-W direction (Text-fig. 4a, L6).

*Kayacık Fault (KF)*

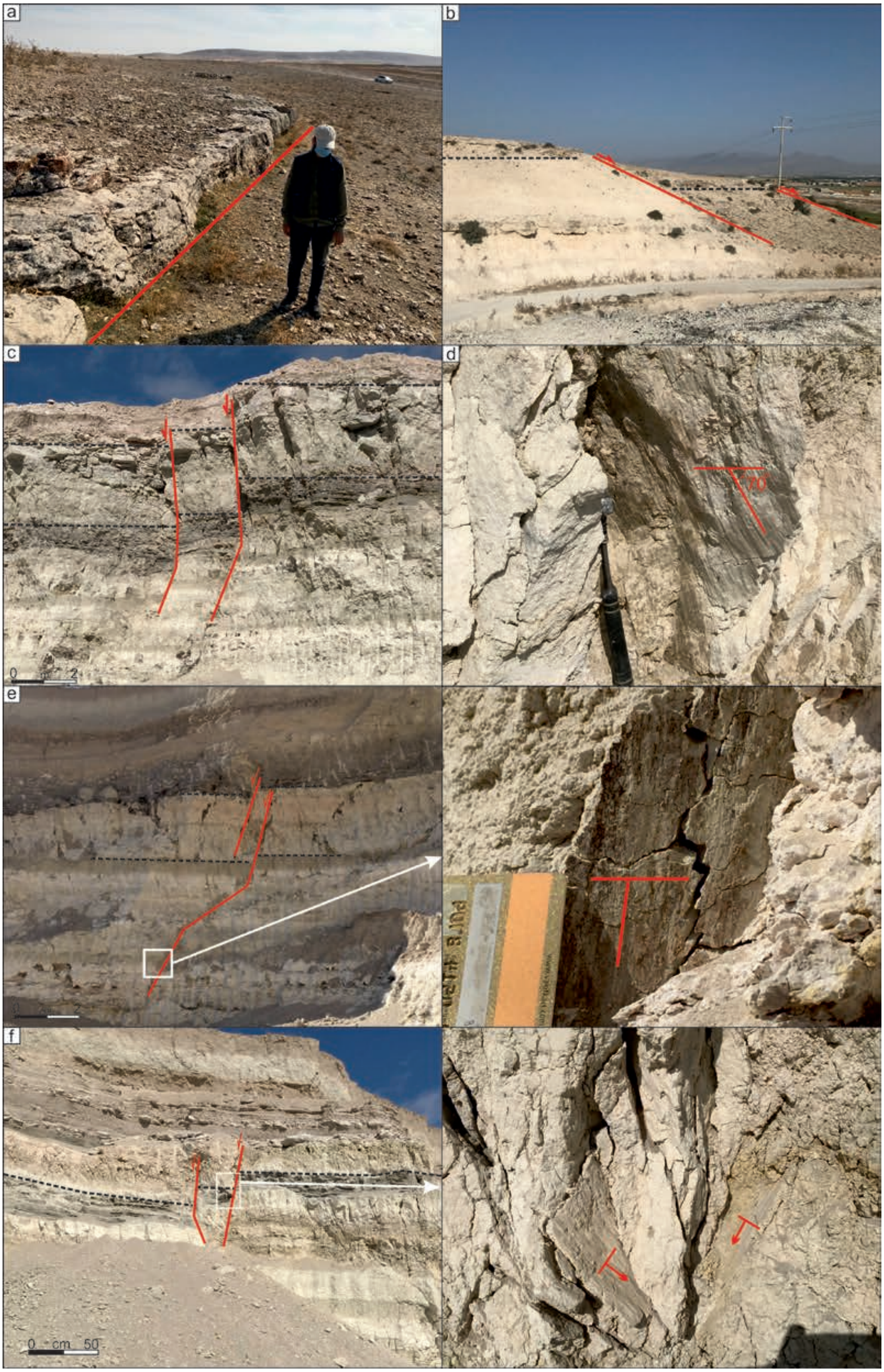
In the study area, the KF is observed in a NE-SW direction, 5 km southwest of Hotamış, with a length of approximately 12 km (Text-fig. 2). Miocene–Pliocene aged rocks and Quaternary aged basin sediments confront each other along the fault around Ortaoba (Text-fig. 5a). Synthetic small faults developed parallel to the main fault in the section where the contact is observed indicate that the fault is a west-dipping normal fault. Kinematic measurements taken along the fault indicate that this section has undergone extension mainly in the NW-SE direction (Text-fig. 4a, L7).

**Karapınar Basin**

Karapınar basin is a NE-SW orientated Pliocene aged subsiding basin. The basin is bounded by the Seyithaci fault zone in the west, Nasuhpınarı fault zone in the east, Tilkili fault in the north and Karacadağ volcanics uplifted by small scale faults in the south.

*Seyithacı Fault Zone (SFZ)*

The NE-SW trending Seyithacı fault zone (SFZ) (Karapınar fault, Göçmez *et al.* 2001) bounds the Karapınar basin to the northwest in the central part of the study area. This fault cuts Quaternary rocks and forms a horst structure with a conjugate fault which is located to the west (Text-figs 2 and 5b). SFZ, which is approximately 35 km long in a NE-SW direction,




Text-fig. 5. (a) Miocene and Quaternary aged units juxtaposed by the Kayacik fault in the vicinity of Ortaoba, (b, c) Field views of the Seyithacı fault zone (SFZ), **(d)** Striated fault surface of the NFZ**,** (e) the view of the Tilkili fault (TF) in the Quaternary sand deposits, and (f) The view of small-scale graben – horst structures in the Quaternary aged sediments.

begins to the east of Bayırbaşı Hill and continues southwestwards to the east of Hotamış. SFZ consists of three main sections. In the first part of the SFZ, which is approximately 12 km long and which is located to the west of Tilkili, the Miocene–Pliocene aged formation and the Quaternary aged basin sediments come side by side along the fault dipping to the SE. The Başaran fault had been cut by the SFZ in the north. The SFZ reaches a width of approximately 3.5 km around Seyithacı. Many outcrop-scale faults parallel to the SFZ (Text-fig. 5c) and the Nasuhpınarı fault zone (NFZ) are observed in the sand quarry to the east of Tilkili. These indicate that faults parallel to the SFZ continue under the youngest basin sediments. From the kinematic measurements taken in this section, the principal stress axes were determined as σ1: 69°/306, $\sigma_2$: 00°/ 037 and $\sigma_3$: 21°/127. It has been determined that the fault has a normal fault character in accordance with field observations (Text-fig. 4a, L8). Accordingly, it is understood that the region is extending in a NW-SE direction. Around Seyithacı, there is a geologically interesting section of the fault zone approximately 12 km long where two main fault sections are observed (Text-fig. 2). The first fault section located in the west of the fault zone has a length of approximately 13 km. Along this section, which forms the main scarp, the Insuyu formation, and Quaternary rocks are juxtaposed. The second part in the east, which is approximately 11 km long is in the form of surface faulting. A vertical offset of at least 2 m was observed along this surface faulting. The majority of the sinkholes formed in recent years are located on the relay ramp between these two faults, and faults parallel to the SFZ are observed inside the sinkholes. The relay ramp is approximately 2.5 km wide and contains many faults parallel and oblique to the SFZ. As a result of the kinematic data analysis in this section the principal stress axes were determined as $\sigma_1$: 76°/302, $\sigma_2$: 01°/035 and $\sigma_3$: 14°/125. This indicates a NW-SE directed extension (Text-fig. 4a, L9). The third part of the fault, which is approximately 12 km long, forming morphologically very distinct steepness, extends from the end of the second part to the south of the Konya-Karapınar road. In the south of this section, which is approximately 10 km long and cut by small-scale oblique faults, the direction of the fault changes towards the NNE. Since the SFZ is cut by an ESE-WSW oriented dip-slip normal fault in the southernmost part, it becomes unclear under the cover from this section onwards. The kinematic data give $\sigma_1$: 85°/286 (vertical), $\sigma_2$: 00°/193 and $\sigma_3$: 05°/102 (horizontal). The extension in this part has a WNW-ESE trend, unlike the other two sections, (Text-fig. 4a, L10). From kinematic measurements taken from a NNW-SSE trending fault within the relay ramp the principal stress axes were determined as $\sigma_1$: 77°/240, $\sigma_2$: 00°/150 and $\sigma_3$: 13°/060. The data indicate NE-SW directed extension (Text-fig. 4a, L11).

*Nasuhpınarı Fay Zonu (NFZ)*

The NE-SW trending Nasuhpınarı fault zone (NFZ) (Koçyiğit 2003 and Emre *et al.* 2013) borders the eastern side of the Karapınar basin and is 20 km in length. The fault zone forms a zone about 4 km wide running east of Kayali and Karapınar settlement. The western part of the basin moved down along the northwest dipping fault (Text-fig. 2). Small-scale faults parallel to the main fault are observed in the fan deposits on the fault plane. Together with the Seyithaci fault zone (SFZ), it formed the Karapınar Graben. Many smaller scale graben-horst structures are observed to the east of Kayali which mimic this structure. Due to the declining of the groundwater level, surface faults and surface fissures parallel to the NFZ have developed in the west of Siyeklik Plateau. There are also NW-SE trending surface faults parallel to the NW trending faults that cut the fault. The Karacadağ volcanics and Quaternary aged basin sediments are juxtaposed with the NFZ. Field measurements taken from the north of the fault zone prove that the zone is oriented N 20–40° E, 65–80° NW, and has a left-lateral strike-slip component on the normal fault character with a rake angle of 70° (Text-fig. 5d). Kinematic analyses show that the crust in this section where the fault is located has undergone NW-SE directional extension. According to the diagram, $\sigma_1$ – is approximately vertical (64°/121), $\sigma_2$ – (0°/030) and $\sigma_3$ – (26°/300) are approximately horizontal (Text-fig. 4a, L12).

*Tilkili Fault (TF)*

The Tilkili fault (Törk *et al.* 2019) bounds the northern part of the Karapınar basin and is approximately 13 km long with a WNW-ESE trend (Text-fig. 2). Tilkili fault (TF), which is a south dipping dip-slip normal fault, brings side by side the Miocene–Pliocene aged lacustrine rocks and the Quaternary aged rocks of the Karapınar basin. The Quaternary sediments of the sand quarry located in the eastern part of Kayalı are cut by faults parallel to the SFZ and NFZ. In this section, there are graben and horst structures that mimic the small-scale model of the Karapınar Graben (Text-figs 5e, f and 6a). Here, the TF, which forms the contact between the lacustrine and alluvial deposits, is covered by 3–5 m


Text-fig. 6. (a) The view of small-scale graben - horst structures in the Miocene limestone, (b) sedimentary dyke formed parallel to the Tilkili fault (TF), filled with young sediments covering it, (c) North to south view of the steepness formed by the Akgöl fault (AF), (d) Synthetic faults related to the Sekizli fault zone (SKFZ), and (e, f) Orthogonal fissure sets observed within the Miocene aged units.

thick alluvial rocks, and this cover is cut by faults belonging to SFZ and NFZ (Text-fig. 5f). Parallel to the Tilkili fault, there are sedimentary dykes (neptunian) filled with overlying youngest alluvial rocks (Text-fig. 6b). From the kinematic measurements of the fault $\sigma_1$, $\sigma_2$, and $\sigma_3$ were determined as 65°/011;

00°/280 and 25°/190 respectively (Text-fig. 4a, L13), indicating that this section extended horizontally in the NNE-SSW direction

**Ereğli Basin**

The Ereğli basin, trending east-west, is bounded by the Karacadağ volcanic highs in the north and the Mesozoic units of the Bolkar Mountains in the east. The Akgöl fault, one of the most important structural elements of the Ereğli basin, is in the southeast of the study area.

*Akgöl Fault (AF)*

The Akgöl fault (AF) (Eren *et al.* 2020), in the southeast of the study area, forms the boundary between the Ardıçlık hill elevation, where Mesozoic rocks are exposed, and the Quaternary rocks of the Akgöl basin (Text-fig. 6c). AF is an E-W trending and south-dipping normal fault with a length of approximately 12 km in the study area (Text-figs 1c and 2). AF is cut by NW-SE and NE-SW trending oblique faults along its continuation. In areas close to the AF, sinkhole formations and surface faultings oriented perpendicular to the fault have also been identified. Kinematic measurements taken along the fault indicate that this section has undergone extension mainly in the N-S direction. The stress axes are determined as $\sigma_1$: 67°/183, $\sigma_2$: 00°/093 and $\sigma_3$: 23°/002 (Text-fig. 4a, L14).

**Obruk Plateau**

The southern tip of the Obruk Plateau, one of the most important morphological elements of Central Anatolia, is located in the study area. The plateau is bounded by the Merdivenli fault in the south, the Seyithacı fault zone in the east and the Ortakuyu fault in the west. Within the plateau, the Başaran fault and the Sekizli fault zone are prominent structural elements of the region (Text-figs 1c and 2).

*Başaran Fault (BF)*

The NW-SE oriented Başaran fault (BF), which is approximately 28 km long is cut by the SFZ to the west of Tilkili village (Text-fig. 2). The Plio-Quaternary aged alluvial rocks in the Kötüköy vicinity, where the fault passes, were deposited in a rhomboidal shaped long narrow basin. Due to this relationship, the BF, which is predominantly a normal fault, has a right-lateral strike-slip component. Likewise, oblique slip faults belonging to the BF are observed in the sand quarries around Tilkili, and these faults are cut by the fault systems forming the Karapınar graben (Text-fig. 5d). The stress arrangement presents a normal fault character with a right-lateral strike component. The kinematic data of the fault shows NE-SW extension. The principal stress axes were determined as $\sigma_1$: 66°/258, $\sigma_2$: 02°/265 and $\sigma_3$: 24°/074 (Text-fig. 4a, L15).

*Ortakuyu Fault (OF)*

The Ortakuyu fault (Eren *et al.* 2020) is a NNE-SSW trending dip-slip normal fault zone in the northwest of the study area and east of Toscu. Along the OF, Quaternary aged alluvial units are juxtaposed with Mesozoic aged basement and Mio-Pliocene aged lacustrine units. It intersects with the SKFZ in the north and delineates the Obruk Plateau from the northwest (Text-figs 1c and 2). It is approximately 30 km in length. The fault data indicated that the principal stress axes were $\sigma_1$ (62°/105), $\sigma_2$ (00°/195) and $\sigma_3$ (28°/285) (Fig 4a, L16). Kinematic data regarding the fault show that this part of the upper crust extended in a WNW-ESE direction.

*Sekizli Fault Zone (SKFZ)*

The NW-SE trending Sekizli fault zone (SKFZ) forms a zone 26 km long and 2 km wide. Most of the classical sinkholes were formed in the area where the SKFZ is located. The faults belonging to the SKFZ have the characteristics of dip-slip normal faults, and in addition, strike-slip faults cutting the SKFZ have also been observed in the field. SKFZ is interrupted by the branches of SFZ in its southeastern part. Sinkholes have been interrupted along the SKFZ (Text-fig. 6d). Additionally, monoclinal folds have developed in Miocene–Pliocene aged rocks. Kinematic analysis of this fault shows that the region has undergone extension mainly from NE-SW directions. It also reveals that there are two different fault systems in the region and the existence of a NW-SE trending secondary extension. The principal stress axes were determined as $\sigma_1$: 77°/265, $\sigma_2$: 11°/123 and $\sigma_3$: 08°/031 (Text-fig. 4a, L17).

The Data on faults in the study area show that the majority of the faults in the region are normal faults. When we look at the distribution of faults, it is clearly seen that the faults in the study area have developed in all directions and the distribution of slickenlines clearly shows that the upper crust has an extension in every direction. However, the principal stress axes obtained from all data have orientation $\sigma_1$: vertical, $\sigma_2$: 04º/216, and $\sigma_3$: 00º/126 (Text-fig. 4b).

Accordingly, if it is accepted that all faults are formed due to deformation under the same stress system, the study area has expanded predominantly in the NW-SE direction. However, when looking at the field data and cutting relationships, the NE-SW trending fault systems are younger than WNW-ESE trending fault systems. In this case, it is seen that first NNE-SSW and then NW-SE oriented crustal extension developed in the study area (Text-fig. 4b, c). In the first extension phase, N-S trending faults served as transfer faults to WNW-ESE trending fault systems, while in the NW-SE extension phase, WNW-ESE trending faults served as transfer faults. Again, while the Konya, Ilgın, Altınekin and Karapınar basins with a NNE-SSW trend are filled with younger Quaternary sediments, Miocene–Pliocene aged sediments crop out in approximately E-W trending structures (Text-figs 1b, c and 2). WNW-ESE grabens and their Miocene–Pliocene fills and horst structures are elevated along the footwalls of NNE-SSW normal faults (Eren 2003a; Hüseyinca and Eren 2007; Eren 2011). Considering the focal mechanism solutions of earthquakes occurring in the region, while the strike-slip fault system is dominant in the north of the Karapınar basin and along the Tuzgölü fault, earthquakes with normal fault solutions have been recorded around Karapınar, Konya, Kızılören, Ilgın, Tuzlukçu and Sultandağı (Text-fig. 8 and https://m.emsc.eu/). Earthquakes occurring in the Konya and Karapınar basins indicate current crustal expansion in the region, mostly in the WNW-ESE direction.

**Joints**

In addition to faults, there are other fractures, namely systematic joints, veins and fissures, in almost all rocks in the study area, except for the recent alluviums. In order to compare the fracture systems in the study area with the main faults and sinkholes, nearly 3000 joints and fractures were measured at 26 different points, and their distribution throughout the area was shown by rose diagrams (Text-fig. 2). Observations made on the rocks in the area show that tensile cracks, generally perpendicular to each other, developed intensively in Miocene–Pliocene lacustrine limestones, especially in regions where sinkholes are densely located (Text-fig. 6e, f ). Again, the fact that the directions of these fractures develop parallel to the young faults show that they are related in origin. When we look at the rose diagrams of joint measurements in Mio-Pliocene lacustrine and Plio-Quaternary rocks, they show that fracture sets with N30°-40°E, N60°-70°W and N0°-10°E trends are prominent in the region (Text-fig. 2). As a result, the geometric analyzes of the joints and fracture systems in the diagrams show that the dominant trend in the N30°-40°E position in the study area is a fracture system developed parallel to the Seyithacı–Nasuhpınarı fault zones and fault systems parallel to them. N60°-70°W trending fracture sets represent fractures belonging to Merdivenli fault, Tilkili fault, and smaller fault systems, and prove that these developed as tension fractures.

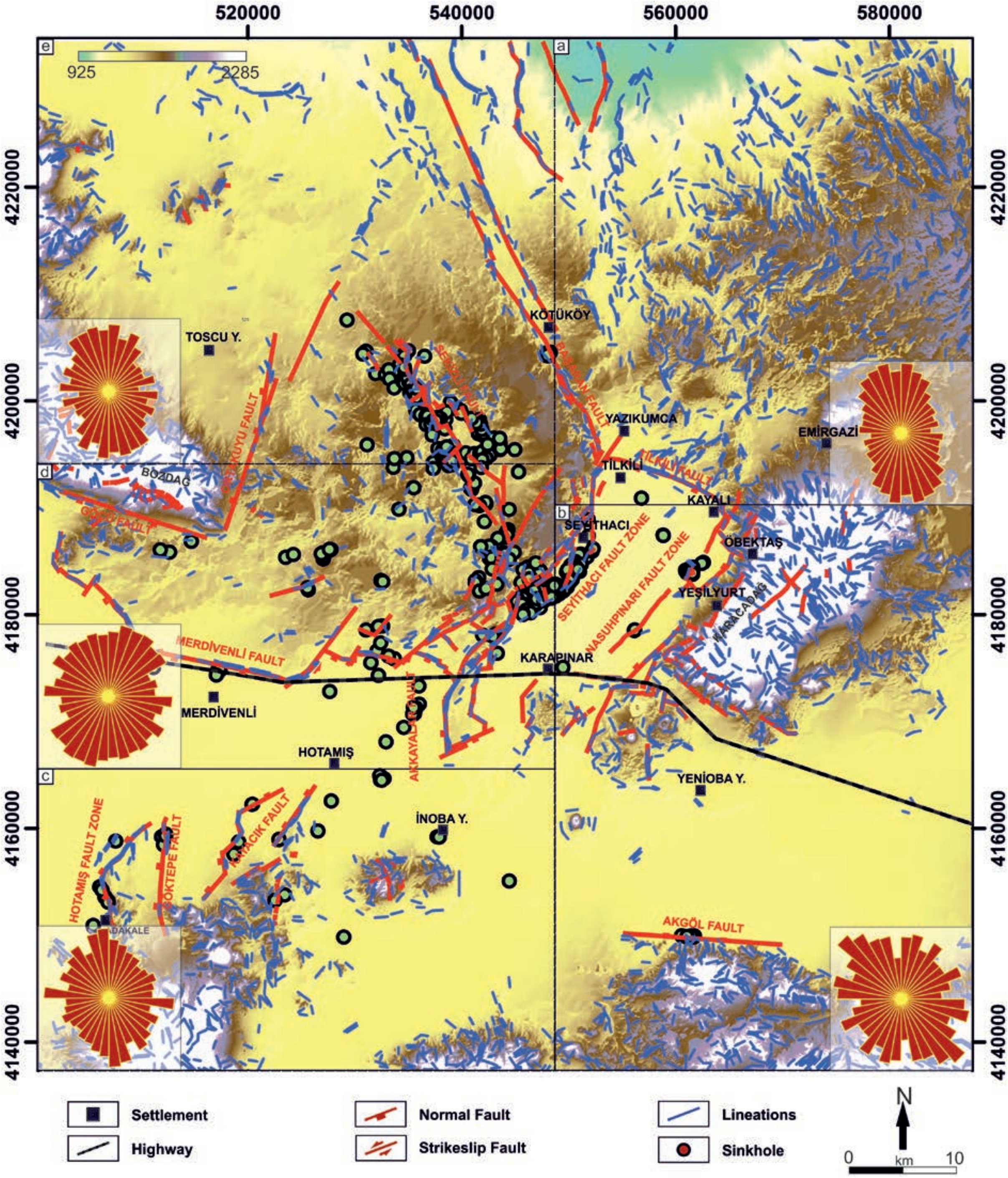
**Lineation and linear structures**

Automatic lineament maps of Karapınar and its surroundings were created using slope gradient maps derived from Digital Elevation Model (DEM) (Text-fig. 7). These lineament maps determined in this way were directly compared with the faults, other fractures and sinkholes detected by field studies. In order to see the relationship between lineaments and faults in the study area, the area was divided into five main areas depending on the fault trends, and the fault-linearity relationships in these areas were examined separately (Text-fig. 7a–e). In the lineament obtained from the slope gradient map, it is clearly seen that most of the lineaments are parallel to the faults. Radial lineament trends are observed especially in Karacadağ and other parts where volcanic elevations occur. In the rose diagram of the orientation of the prepared lineaments, it is seen that the NW-SE and NE-SW trending fractures are dominant. Most of the sinkholes in the northwest of Karapınar are located in areas with a high density of lineaments developed parallel to fault zones.

## DISCUSSION AND CONCLUSION

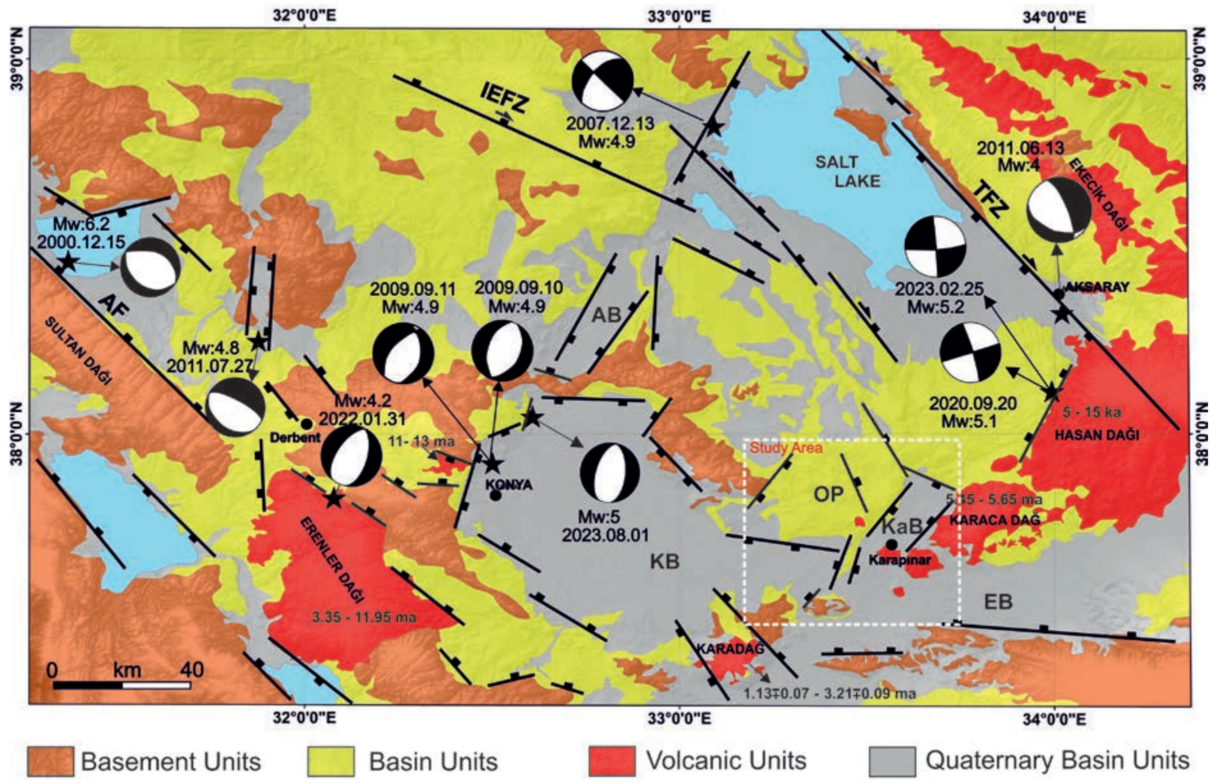
If it is accepted that the faults around Karapınar were formed due to the same stress system, the study area is predominantly extended in the NW-SE direction. Cross graben formation, which develops in different directions in Western and Central Anatolia (Koçyiğit 1984; Şengör 1987; Seyitoğlu and Scott 1996; Yılmaz *et al.* 2000; Bozkurt 2000 and 2001; Gürbüz *et al.* 2010; Koç *et al.* 2012) is also observed in the Konya and Karapınar regions.

In the Konya region, Eren (1993, 1996) mentioned two different episodes of graben formation in the Miocene–Pliocene and the Late Pliocene–




Text-fig. 7. Automatic lineament map and related rose diagrams in the study area (further explanation in text)

Quaternary and noted the existence of thrusts in the Miocene–Early Pliocene transition. Koç *et al.* (2012) explained the graben formation in the region by dividing the Miocene–Pliocene rocks in the Konya region into two groups. In his study on the Konya graben, Eren (2004) stated that the graben carries the evolution of crustal extension first in a north-south direction and then in an east-west direction. KOFZ, which delineates the western edge of the Konya graben, has uplifted and suspended E-W




Text-fig. 8. Figure showing focal mechanism solutions of earthquakes due to faults in Karapınar and its surroundings and ages (Besang *et al.* 1977; Asan *et al.* 2019; Friedrichs *et al.* 2020; Gençoğlu *et al.* 2022) of volcanic formations (AF: Akşehir Fault, IEFZ: İnönü-Eskişehir Fault Zone, TFZ: Tuzgölü Fault Zone, KB: Konya Basin, AB: Altınekin Basin, KaB: Karapınar Basin, EB: Ereğli Basin).

trending grabens and intervening horsts. Aksoy (2019) also mentioned two episodes of graben formation in the region.

Considering the field data and cutting relationships, the NE-SW trending fault systems are younger than the WNW-ESE trending fault systems. In this case, it is seen that crustal extension in the NNE-SSW direction first developed in the study area, and then extension in the NW-SE direction developed (Text-fig. 4b, c). In the first extension phase, NE-SW trending faults served as transfer faults to WNW-ESE trending fault systems, while in the NW-SE extension phase, approximately E-W trending faults served as transfer faults.

While the Konya, Ilgın, Altınekin, and Karapınar basins, trending approximately NE-SW, are filled with younger sediments in their upper levels than the other basins, Miocene–Pliocene aged sediments crop out in the structures trending approximately E-W (Eren 2003 a and b; Hüseyinca and Eren 2007). These data support the formation model mentioned above. In addition, while volcanic formations such as Erenlerdağ and Sille-Tatköy, aged 3.35–11.95 Ma (Besang *et al.* 1977) and 11–13 Ma (Asan *et al.* 2019) respectively, are observed within E-W trending grabens, there are volcanic rocks aged 1 Ma and younger (Besang *et al.* 1977; Friedrichs *et al.* 2020; Gençoğlu *et al.* 2022) within or on the edge of N-S trending grabens. These data support the formation sequence mentioned above (Text-fig. 8).

Considering the focal solutions of the earthquakes occurring in the region, while the strike-slip fault system is dominant in the north of the Karapınar basin and along the Tuzgölü fault, normal fault solutions have been recorded around Karapınar, Konya, Ilgın and Sultan Dağı (Text-fig. 8) (Eren 2011; https://m.emsc.eu/). Earthquakes occurring in the Ilgın, Konya and Karapınar basins show current crustal extension in the region, mostly in the WSW-ESE direction (Text-fig. 8). Koçyiğit (2003) stated that the Tuzgölü fault zone forms the border between the Konya-Eskişehir and Kayseri-Sivas Neotectonic regions. According to the focal mechanism solutions of the earthquakes that occurred around Karapınar and Tuzgölü, the Sultanhanı fault zone in the southwest of Salt Lake constitutes the border between the two regions.

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