Bulletin of the Mineral Research and Exploration

http://bulletin.mta.gov.tr



Surface geometry, segmentation and kinematic features of Dodurga Fault, Eskişehir Fault Zone, NW Anatolia

İsmet ELMA[a*], Volkan KARABACAK[b], Çağlar ÖZKAYMAK[c,d], Ökmen SÜMER[e] and Doğukan Mert ÖZCAN[f]

[a] *Eskişehir Osmangazi University, Graduate School of Natural and Applied Sciences, Department of Geological Engineering, Eskişehir, Türkiye.*
[b] *Eskişehir Osmangazi University, Faculty of Engineering and Architecture, Geological Engineering, Eskişehir, Türkiye.*
[c] *Afyon Kocatepe University, Faculty of Engineering, Geological Engineering, Afyonkarahisar, Türkiye.*
[d] *Afyon Kocatepe University, Earthquake Application and Research Center, Afyonkarahisar, Türkiye.*
[e] *Dokuz Eylül University, Faculty of Engineering, Geological Engineering, İzmir, Türkiye.*
[f] *Afyon Kocatepe University, Graduate School of Natural and Applied Sciences, Department of Geological Engineering, Afyonkarahisar, Türkiye.*

Research Article

Keywords:
Eskişehir Fault Zone, Dodurga Fault, Holocene Fault, Kinematic Analysis, NW Anatolia.

Received Date: 15.01.2026
Accepted Date: 03.06.2026

ABSTRACT

The Dodurga Fault is an active right-lateral strike-slip fault, approximately 63 km long, striking NW-SE in northwestern Anatolia. Based on 1:25,000-scale active fault mapping, the fault is subdivided into two principal geometric segments. Segment 1 is approximately 16 km long and extends from Sulhiye in the west to Erikli in the east, whereas Segment 2 is 47 km long and is characterized by a right-stepping geometry and a 10°-15° southeastern deflection. Geological and geomorphological observations, together with kinematic analyses, indicate that the fault is dominantly right-lateral strike-slip in character. Stream channels offset by up to several kilometers along the fault trace support its long-term activity, and fault-plane kinematic indicators independently confirm dextral motion. Paleostress analyses of the kinematic data indicate that the recent deformation phase along the Dodurga Fault is governed by approximately N-S contraction and E-W extension. Empirical scaling relationships suggest that Segment 1 and Segment 2 are capable of generating earthquakes of Mw 6.47 and Mw 6.97, respectively. If both segments rupture together, the Dodurga Fault could potentially generate an earthquake of Mw 7.16.

1. Introduction

The neotectonic framework of Türkiye has been shaped by the convergence of the Arabian and Eurasian plates and the progressive closure of Neotethyan oceanic domains. Since the Late Miocene, crustal thickening in Eastern Anatolia has promoted the westward tectonic escape of the Anatolian Block, a process mainly accommodated by the North Anatolian Fault Zone (NAFZ) and the East Anatolian Fault Zone (EAFZ) (McKenzie, 1972; Şengör and Kidd, 1979; Le Pichon and Angelier, 1979; Şengör, 1980; Şengör and Yılmaz, 1981; Şengör et al., 1985). In addition to these first-order tectonic boundaries, numerous active fault systems within the Anatolian interior accommodate significant intracontinental deformation and contribute to the present-day seismic hazard.

One of these structures is the Dodurga Fault, a NW-SE-trending active right-lateral strike-slip fault

Citation Info: Elma, İ., Karabacak, V., Özkaymak, Ç., Sümer, Ö., Özcan, D. M. 2026. Surface geometry, segmentation and kinematic features of Dodurga Fault, Eskişehir Fault Zone, NW Anatolia. Bulletin of the Mineral Research and Exploration 180, 144-161. https://doi.org/10.19111/bulletinofmre.1962940.

**Corresponding author: İsmet ELMA, elma.ismet@gmail.com*

in northwestern Türkiye and an important component of the Eskişehir Fault Zone (EFZ) (Figure 1). The active faults between Eskişehir and Bursa were first grouped under the name Eskişehir-Bursa Fault Zone by Şaroğlu et al. (1987), who later subdivided this broader system into the İnönü-Dodurga Fault Zone, the EFZ, and the Kaymaz Fault. In that framework, the E-W-trending normal faults together with the NW-SE-trending right-lateral strike-slip faults between İnönü and Dodurga were assigned to the İnönü-Dodurga

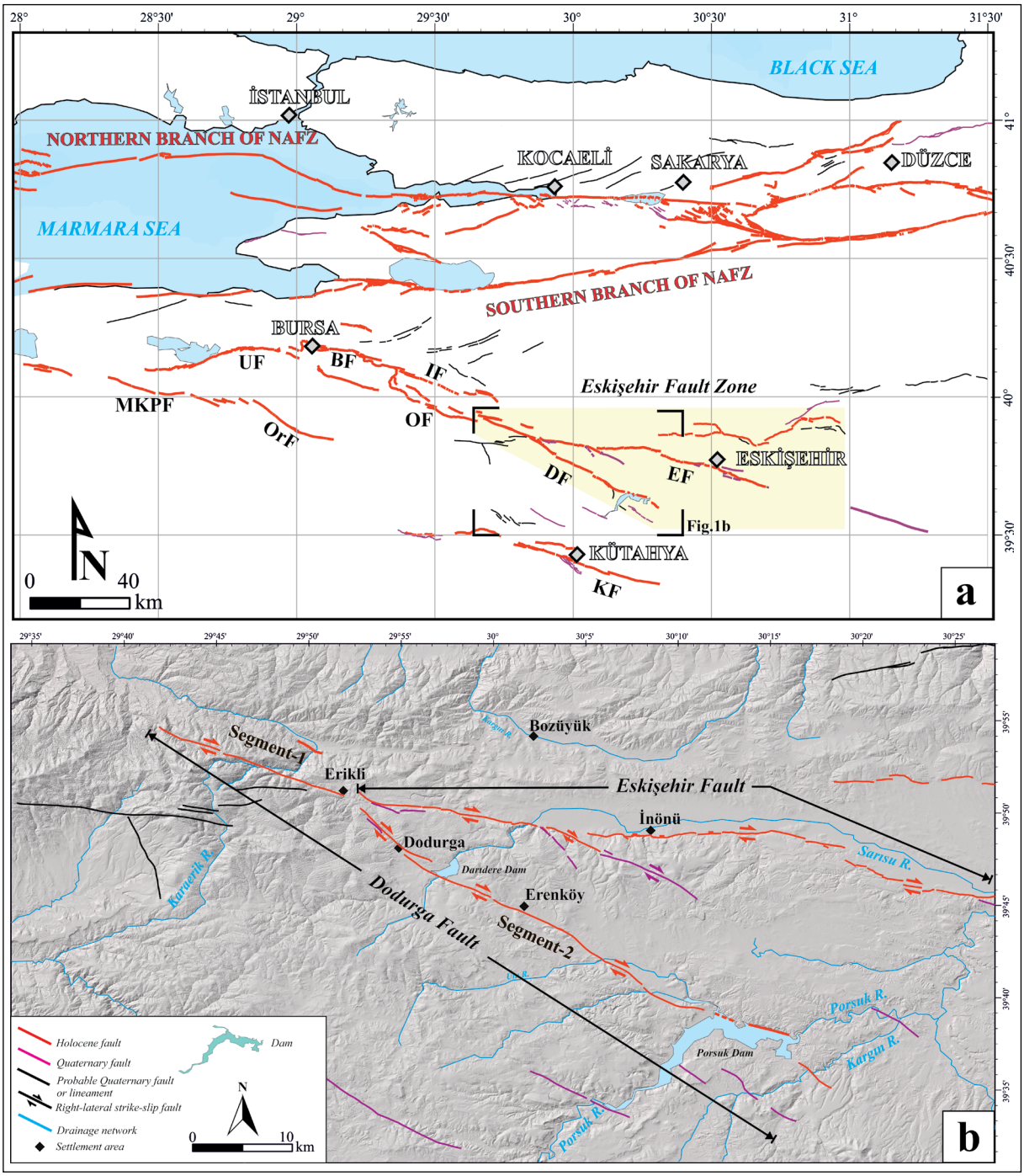


Figure 1- a) Active fault map showing the relationship of the EFZ with the main tectonic lines of NW Anatolia (Emre et al., 2013), b) The map showing the general extension of the Dodurga Fault and its segmentation (Faults were mapped by us based on Emre et al., 2013, Duman et al., 2017). Abbreviations: EF-Eskişehir Fault; DF-Dodurga Fault; KF-Kütahya Fault; İF-İnegöl Fault; OF-Oylat Fault; BF-Bursa Fault; UF-Ulubat Fault; MKPF-Mustafa Kemal Paşa Fault; OrF-Orhaneli Fault.

Fault Zone (Şaroğlu et al., 1987). Later, Şaroğlu et al. (2005) described the EFZ as comprising, from west to east, the Dodurga, Kandilli, İnönü, Osmangazi, and Kaymaz segments, and defined the northwesternmost segment extending from Tahtaköprü (Bursa) to the Porsuk Dam as the Dodurga Fault.

The Türkiye Active Fault Map identifies this NW-SE-trending structure as a Holocene fault approximately 56 km in length (Emre et al., 2013; 2018; Duman et al., 2018). More recent studies, however, suggest that the Dodurga Fault is an approximately 63-km-long active right-lateral strike-slip fault (Karabacak et al., 2024; Elma et al., 2025*c*). Given its mapped length, empirical fault-length relationships indicate that the fault is capable of generating an earthquake of Mw 7 or larger (Wells and Coppersmith, 1994; Pavlides and Caputo, 2004). Although no destructive historical earthquake has been unequivocally attributed to the Dodurga Fault, several moderate instrumental earthquakes have occurred in its vicinity, including the events of 11 August 1900 (M4.0), 9 August 1939 (M5.1), 23 February 1956 (M5.2), 28 March 1970 (M5.3), and 4 April 1970 (M4.3). In addition, ongoing microseismicity is concentrated mainly along the southeastern part of the fault. Together, these observations indicate that the Dodurga Fault is an active tectonic structure and a potentially important seismic source for Eskişehir and its surroundings.

Despite its tectonic and seismic significance, the Dodurga Fault has received comparatively limited attention relative to other components of the EFZ, particularly in terms of its detailed surface geometry, segmentation, kinematic characteristics, and the role of Dodurga Fault in regional deformation. A clearer definition of these properties is essential not only for understanding the tectonic architecture of the EFZ, but also for improving assessments of seismic source behavior in northwestern Anatolia.

This study addresses that gap through detailed geological and geomorphological field investigations combined with 1:25,000-scale active fault mapping. The main objectives are to define the surface geometry and segmentation of the Dodurga Fault, document the geomorphic and structural evidence for recent activity, characterize its kinematic features, and clarify its significance within the active tectonic framework of northwestern Anatolia.

2. General Geological Features, Segmentation and Fault Geometry

A wide range of lithostratigraphic units from the Triassic to the present crop out along the Dodurga Fault. The geological rock units are simplified into two primary groups: pre-Plio-Quaternary basement rocks and Plio-Quaternary rock units. From oldest to youngest, the pre-Plio-Quaternary basement rock units consist of Triassic rocks of the Tavşanlı Zone, the Arifler ophiolitic mélange and the Miocene Porsuk Formation. The Plio-Quaternary sequence comprises the Pliocene Ilıca Formation and the overlying old and recent alluvial deposits (Figure 2).

The basement throughout the study area is characterized by continental-derived rocks of the Tavşanlı Zone. Located north of the İzmir-Ankara Suture, the Tavşanlı Zone maintains a tectonic contact with the Sakarya Zone, a boundary represented regionally by the Eskişehir Fault (Okay, 2011). In the study area, the Tavşanlı Zone is represented by the İnönü marbles and İnönü blueschists, both of which underwent metamorphism under blueschist facies conditions (Okay, 1984; 2011). The İnönü marbles, first defined by Servais (1982), are medium to thick layered with a gray to light brown appearance and are widely exposed in the northwestern part of the Dodurga Fault. These units are conformably overlain by the İnönü blueschists, observed in the northwestern part of the fault and southeast of Dodurga. The basement units are tectonically overlain by the Arifler ophiolitic mélange (Küçükayman et al., 1987), which outcrops extensively in the central and eastern parts of the fault, particularly near Erenköy and Kümbetyeniköy; here the fault defines the structural boundary between the ophiolitic units and alluvium. The Pliocene Ilıca Formation unconformably overlies these basement rock units along the fault zone. Southeast of Erenköy, the formation consists of basalt and claystone, with the Dodurga Fault delineating the boundary between Pliocene claystones and younger alluvium.

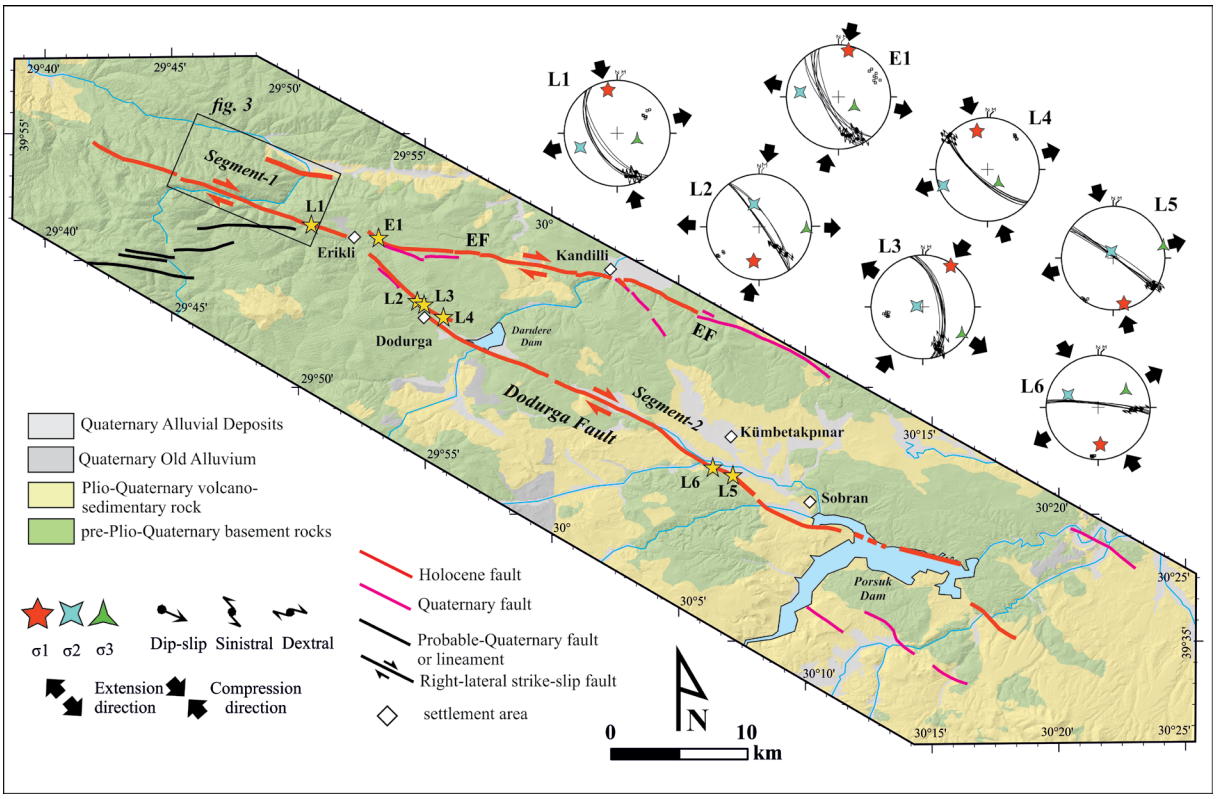


Figure 2- Simplified geological map of the study area showing distribution of paleostress data sites, equal area hemisphere stereoplots of kinematic data and computed results of the principal stress axes (the geology of the study area is modified after Gözler et al., 1985, faults were mapped by us based on Emre et al., 2013, Duman et al., 2017, EF-Eskişehir Fault).

Detailed geological and geomorphological observations along the Dodurga Fault are described from west to east for each segment. The NW-SE-trending Dodurga fault begins south of Sulhiye (İnegöl) and extends to the northwest of Başören (Kütahya), across two main segments. Segment 1 is approximately 16 km long, extending from south of Sulhiye to south of Erikli with a linear orientation of N30°-40°W. While the fault trace is well exposed within the basement rocks, it becomes less distinct south of Erikli. Mapping along Segment 1 reveals right-lateral stream offsets, confirming the right-lateral strike-slip character of the fault. One of the most prominent geomorphological indicator is the right-lateral offset of Karaerik Stream, which flows northeastward almost perpendicular to the main fault and its synthetic fault branch further north. The maximum offset is measured as 7±0.7 km (Figure 3a), representing the maximum displacement measured by us on this segment. The morphotectonic structures along Segment 1, such as southwest dipping fault scarps, are clearly observed northwest of Erikli (Figure 3b, c).

Segment 2, with a length of 47 km, begins southeast of Erikli and extends to the northwest of Başören, exhibiting a right-stepping geometry relative to Segment 1. This segment differs in orientation from Segment 1 by 10-15°, forming a geometric and seismogenic boundary at the right step-over. The fault trace disappears near the eastern entrance of Dodurga town but reappears as a single branch that undergoes a 500 m southward jump southeast of Dodurga town. From there, it continues uninterrupted along the southern margin of the Darıdere Dam to southeast of the Çokcapınar village, where another right step-over occurs. The fault, curving left south of the Sobran village, extends toward the Porsuk Dam. Along the extension of the fault toward the Porsuk Dam, the Porsuk Valley exhibits a pronounced right-lateral deflection consistent with active faulting. The extension of the fault in this area has been mapped using a digital terrain model with a spatial resolution

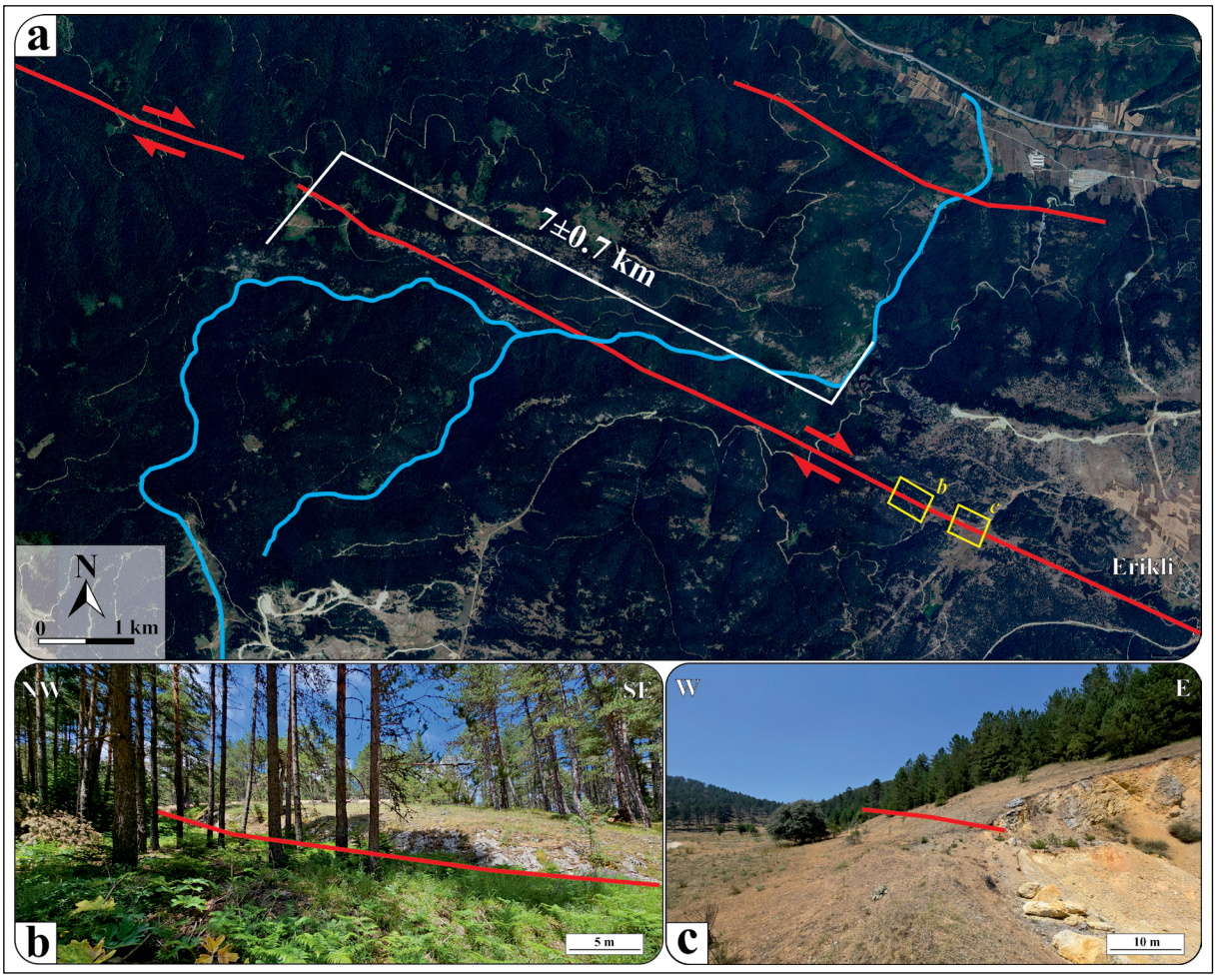


Figure 3- a) Approximately 7±0.7 kilometers stream offset indicating the right-lateral faulting on the Segment 1, b-c) significant morphological scarps along the Dodurga Fault. See, Figure 2 for the location.

of 5 m, taking advantage of linear features. The fault bordering the Porsuk Dam Lake area to the north is represented by parallel faults ranging from 2 to 5 km in length further east.

In the northwestern part of Segment 2, the fault serves as a structural boundary between the basement rock units and Holocene deposits south of Dodurga and Darıdere Dam. The trace of faulting is quite evident in the morphology of this area (Figure 4b, c). One of the most prominent morphotectonic structures observed along the Dodurga Fault is an elongated ridge structure developed parallel to the fault, 4 km southeast of Erenköy (Figure 4d). In this area, it can be seen that both sides of the ridge are morphologically controlled by the fault and that the fault continues to the southeast (Figure 4e). Another important morphological indicator of faulting is the offset observed in stream beds. From the elongated ridge structure onwards, along the southeasterly continuation of the fault, streams are right-laterally offset by 55±5 m, 10±1 m, 7±1 m, and 165±13 m, respectively (Figure 5a, b). Farther to the southeast along the same fault segment, the Ulu Stream near Sobran village shows a 325±25 meters displacement (Figure 5c). In addition, abandoned channel remnants east of this area are also right-laterally offset, indicating repeated fault activity. After crossing the fault, the stream flowing northeastward follows the ridge it encounters and bends to the right. It is noteworthy that the valley hosting the Porsuk Dam reservoir on Segment 2, exhibits a pronounced morphological right-lateral deflection. In this area, a right-lateral offset of 6.2±0.2 km was measured along the Porsuk River (Figure 5d). representing the

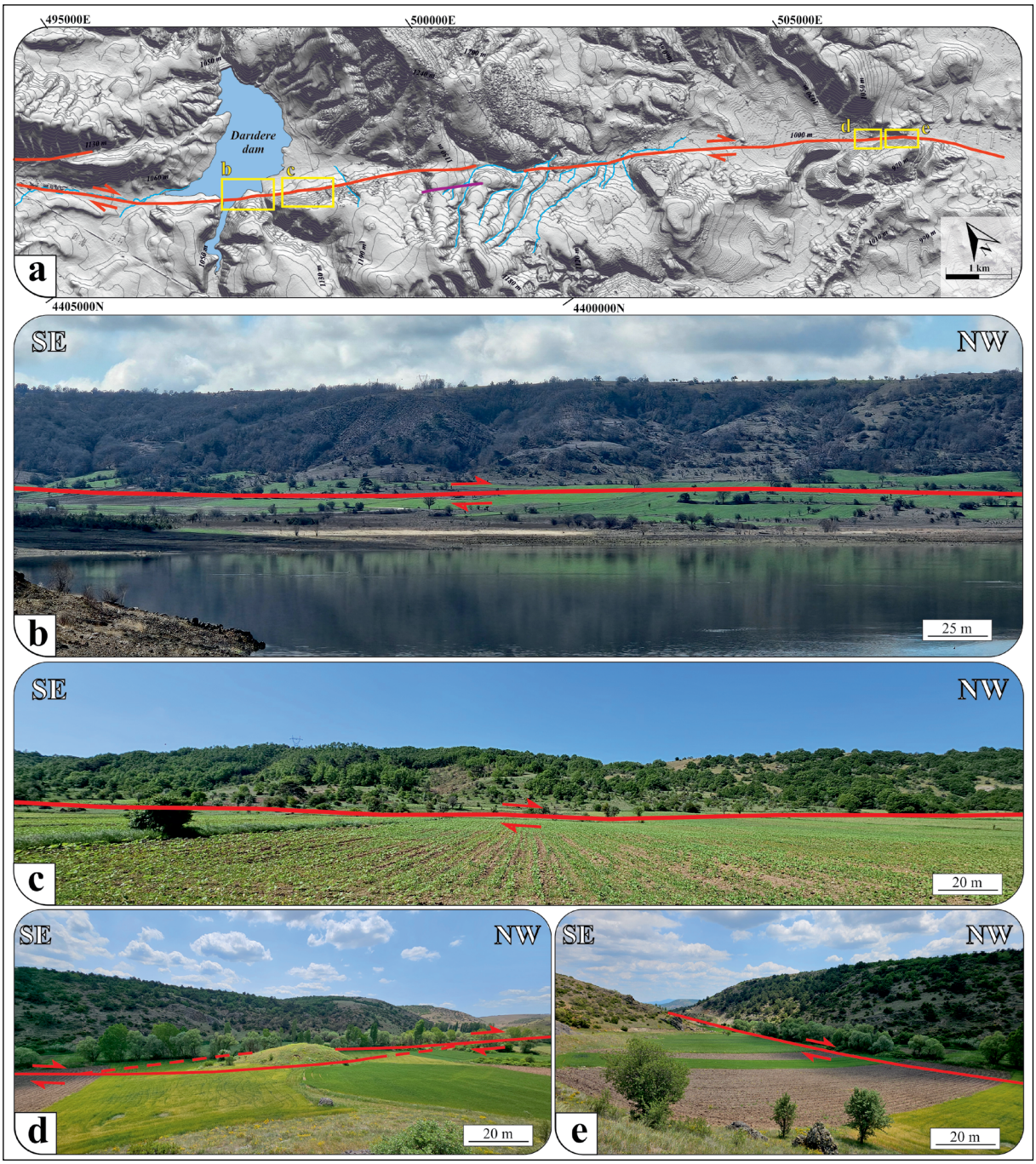


Figure 4- Field photographs and map view showing the linear geometry of the Dodurga Fault between Darıdere Dam and Erenköy a) The extension of the Dodurga Fault between Darıdere Dam and Erenköy (yellow rectangles indicate the locations of the related figures), b) morphology of the fault in the vicinity of the Darıdere Dam, c) southeastern continuation of the fault from the Darıdere Dam, d) elongated ridge structure developed along the fault, e) morphology of the fault located to the southeast of the elongated ridge

maximum displacement measured on this segment. These morphotectonic structures and right-lateral offset in the young fluvial channels provide important evidence for the fault's active control over the current morphology.

3. Kinematic Analysis of the Dodurga Fault

To understand the nature of the faulting and to reveal the paleostress regime in the region, 43 fault-slip data were collected from six different locations along the Dodurga Fault. Slickenlines, fault grooves

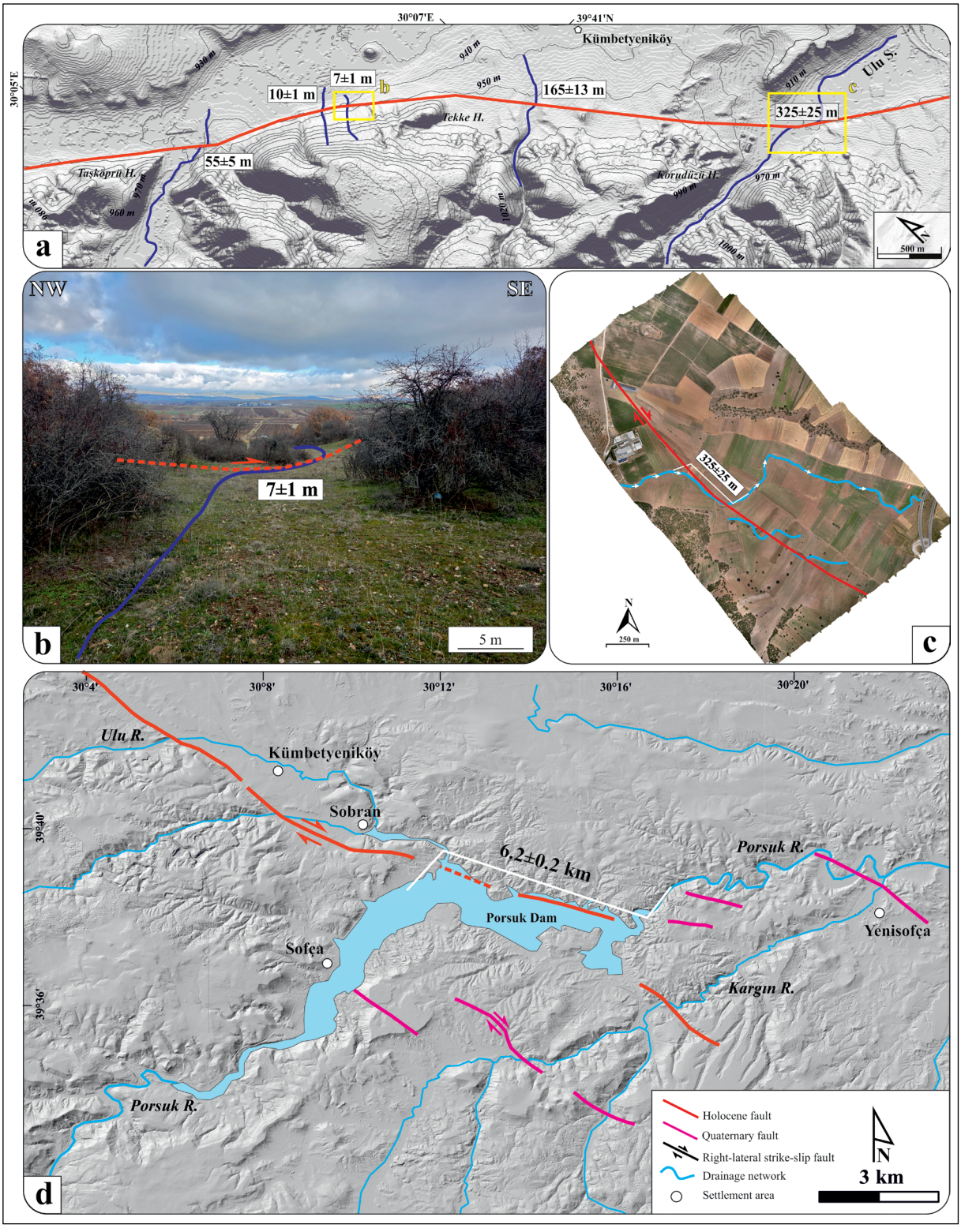


Figure 5- a) The DEM image showing the location of stream offset along the Dodurga Fault near Kümbetakpınar and Sobran villages, b) Approximately 7±1 meters stream offset which indicate the right-lateral faulting near Kümbetakpınar village, c) Aerial imagery showing stream offset along Ulu River (325±25 meters stream offset indicating the right-lateral faulting), d) right-lateral morphological offset along the Porsuk Dam

and corrugations indicating the kinematics of faulting are prominently preserved on the slip planes along the geometrically distinct segments. These kinematic indicators consistently suggest a predominant right-lateral strike-slip fault character. The data obtained from the fault planes were analyzed using the Direct Inversion Method (INVD) developed by Angelier (1990).

Along the western Segment 1, the fault trace is well-developed within the Triassic marble and schist units of the Tavşanlı Zone. Kinematic measurements conducted on well-preserved fault planes in this segment (Location 1) yielded fault strike orientations between N28°W and N36°W, dip angles of 50°-65°, and rake values ranging from 18° to 24° (Figure 6). Paleostress inversion of these measurements indicates that σ1;17°/348°, σ2; 27°/249°, and σ3; 57°/108°. The near-vertical orientation of σ3 and a calculated stress ratio (ϕ = 0.414) between 0.25 and 0.75 suggest that the NW-SE trending strike-slip faults developed under a pure compressional regime associated with NE-SW contraction and NW-SE extension.

Well-preserved slickenlines were observed northwest of Dodurga within the Triassic marbles at Location 2 along Segment 2. Fault planes and dip angles have values ranging between N34°W / N36°W and 72°/ 86°, respectively (Figure 7). Rake values vary between 28° and 52° SE, and all indicators confirm a right-lateral strike-slip character. The trends and plunges of the stress axes (σ1, σ2, σ3) at this location were calculated as 189°/34°, 347°/54° and 092°/11°, respectively. The vertically positioned σ2 axis and a computed stress ratio (ϕ = 0.361) indicate that the NW-SE trending faults formed within a pure strike-slip stress regime associated with NE-SW extension and NW-SE contraction.

Location 3, situated approximately 100 m southeast of Location 2, exposes additional fault

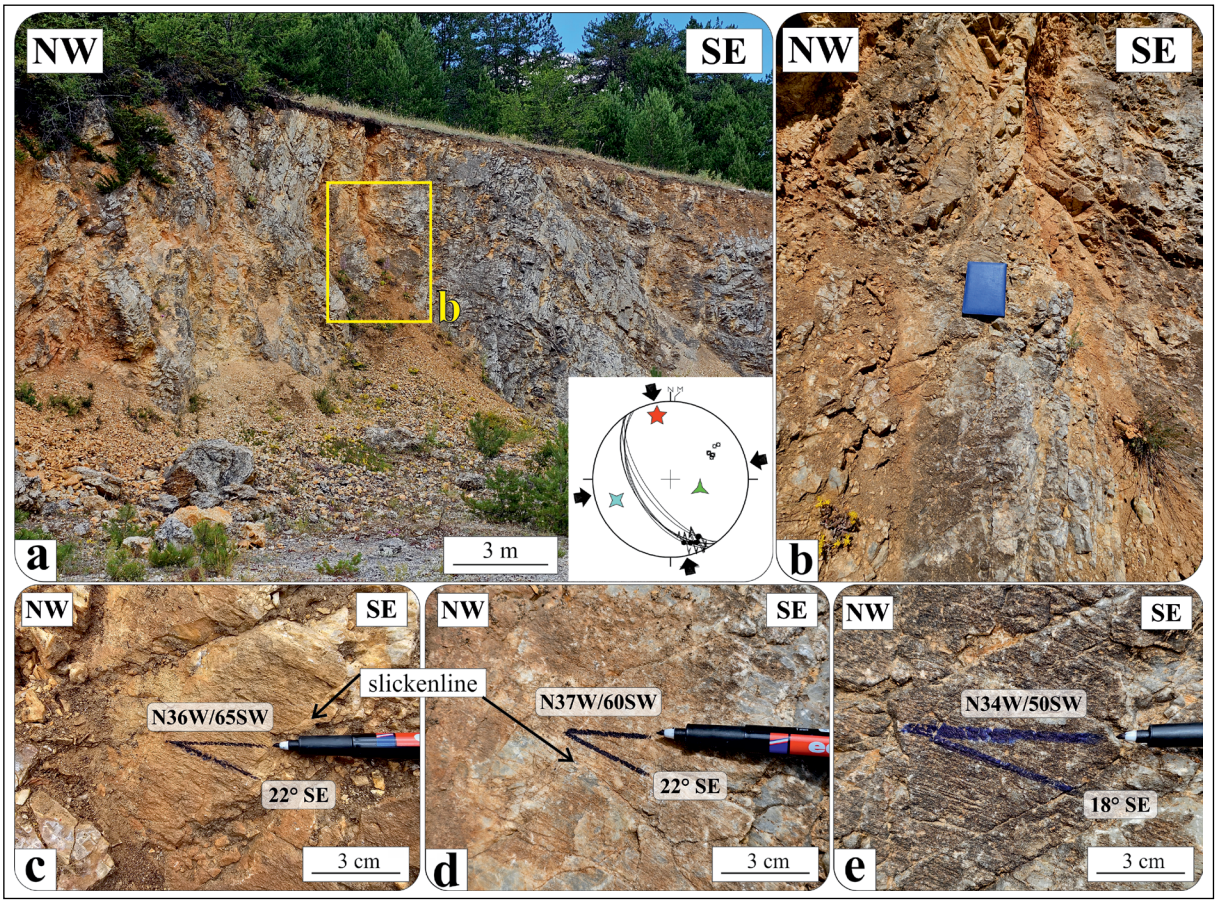


Figure 6- Field photographs of the Dodurga Fault surfaces along the Segment 1 (Location 1, See, Figure 2 for location), a-b) General view of the fault scarps northwest of Erikli, c-e) close-up views of the different slickenlines of the fault planes.

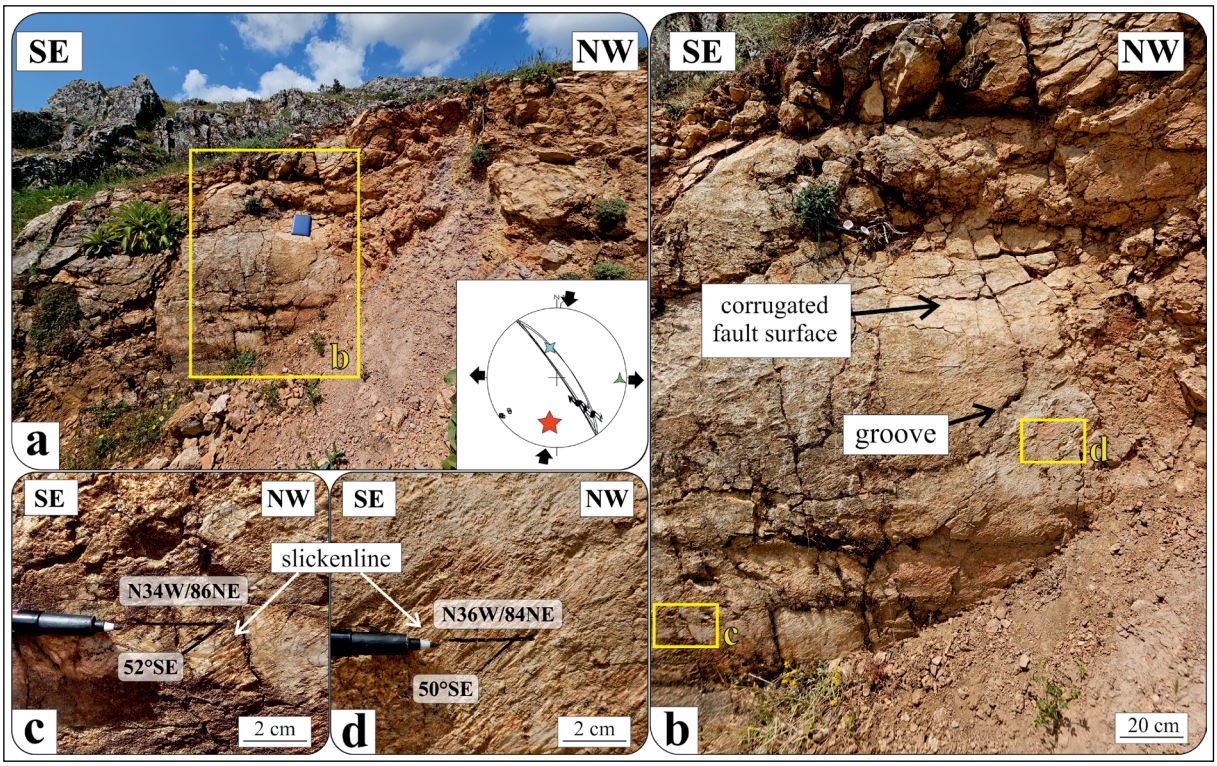


Figure 7- a-b) General views of the fault planes measured northwest of Dodurga settlement area, (Location 2, See, Figure 2 for location), c-d) close-up views of the slickenlines

planes within Triassic marbles. Strikes range between N8°W and N10°W, dips between 56° and 66°, and rake values vary between 18° and 40° (Figure 8). Well-preserved fault corrugations at this site exhibit geometries consistent with right-lateral motion. Stress inversion results suggest the presence of nearly vertical σ2 axis and horizontal σ1 and σ3 axes. The trend and plunge of the intermediate stress axis (σ2) is calculated as 278/80, whereas the σ1 and σ3 principal stress axes are calculated as 034°/04° and 125°/09°, respectively. The results of paleostress calculations (vertical σ2 and ϕ = 0.916) indicate a transtensional tectonic regime dominated by NE-SW contraction and NW-SE extension.

At the eastern entrance of Dodurga (Location 4), fault planes within Triassic calcschist strike 046°-052° with dip angles between 70° and 74°. Measured rake angles vary from 0° to 10° (Figure 9). Stress inversion of the kinematic data reveals a vertical orientation of the minimum principal stress axis (σ3; 140°/63°). The maximum principal stress axis (σ1) trends 345° with a near horizontal plunge of 25°, whereas the intermediate principal stress axis (σ2) trends 250° and plunges at 10°. The vertical σ3 orientation and a stress ratio (ϕ) of 0.388 suggest that the NW-SE trending right-lateral strike-slip faults in the region formed under a pure contraction tectonic regime characterized by NW-SE contraction and NE-SW extension.

In the southeastern part of the Segment 2, near Kümbetakpınar, fault planes developed within ophiolitic rocks strike N52°W-N58°W and dip steeply (82°-90°). Rake values are low (0°-10°), and slickenlines plunge toward the southeast (Figure 10a-c). Stress inversion analyses manifest the presence of nearly vertical σ2 axis (344°/79°), accompanied by a subhorizontal σ1 axis (167°/11°) and horizontal σ3 axis (077°/00°). The assessment of the orientation of the principal stress axes and the computed stress ratio (ϕ = 0.661) indicate that right-lateral strike-slip faults formed under a pure strike-slip tectonic regime, associated with NW-SE contraction and NE-SW extension.

Approximately 500 m northwest of Location 5, an additional set of well-preserved fault-slip data was collected from Triassic ophiolites at Location 6. Here,

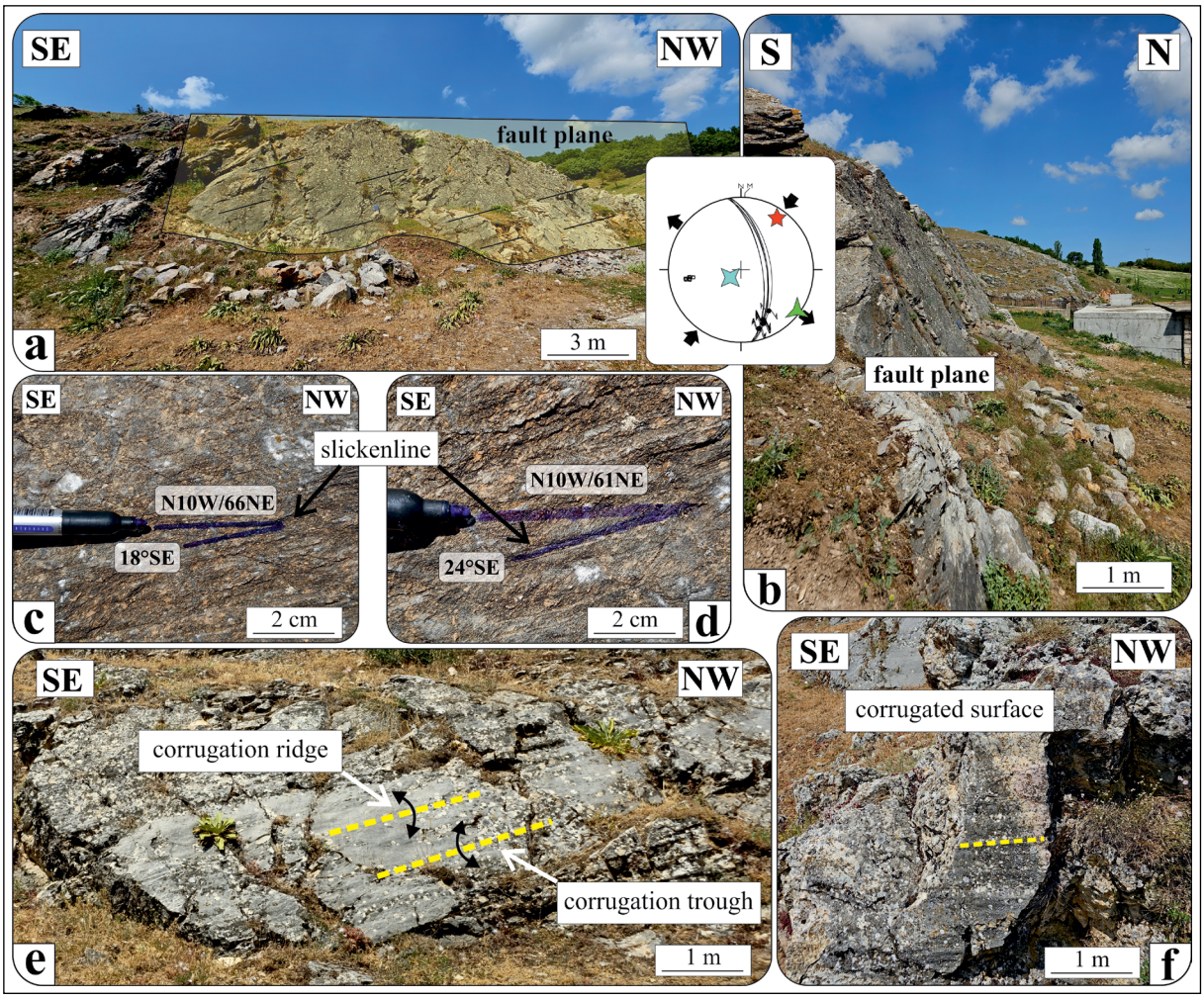


Figure 8- a-b) General views of the fault surfaces observed northwest of Dodurga, (Location 3, See, Figure 2 for location), c-d) close-up views of the different slickenlines of the fault plane, e-f) field photographs of the fault corrugations (yellow dashed lines indicate the corrugation ridges).

fault planes strike between N80°W and N84°W and dip 82°-85° to the NE, and the measured rake values range from 18° to 38° (Figure 10d-e). Paleostress inversion indicates a nearly vertical σ2 axis and a high stress ratio (ϕ = 0.960), suggesting a transtensional component superimposed on the dominant right-lateral strike-slip deformation.

The kinematic evidence from slickenlines, fault grooves and corrugations across all six locations confirms that the Dodurga Fault is a right-lateral strike-slip fault (Figure 2). While the overall character of fault is strike-slip, local variations exist: northwestern parts of fault locally exhibit a reverse slip component under compressional regime, particularly near the Eskişehir Fault. Central and southern parts of fault demonstrate a transition between pure strike-slip and transtensional regimes. Stress inversion analyses of kinematic measurements obtained from fault planes at Location 1 indicate the right-lateral strike-slip faulting with a steeply plunging σ3 axis (108°/57°). Although the maximum (σ1) and intermediate (σ2) principal stress axes also exhibit significant plunge, their orientations are determined as 348°/17° and 249°/27°, respectively (Table 1). The calculated stress ratio (ϕ = 0.414) suggests that the NW-SE trending right-lateral strike-slip faults at this location developed under a compressional strike-slip tectonic regime. Kinematic indicators measured along fault planes at Locations 2,3, and 5 reveal that the intermediate principal stress (σ2) is close to vertical, with orientations of 247°/54°, 234°/75°, and 344°/79°, respectively (Table 1). Paleostress computation results indicate

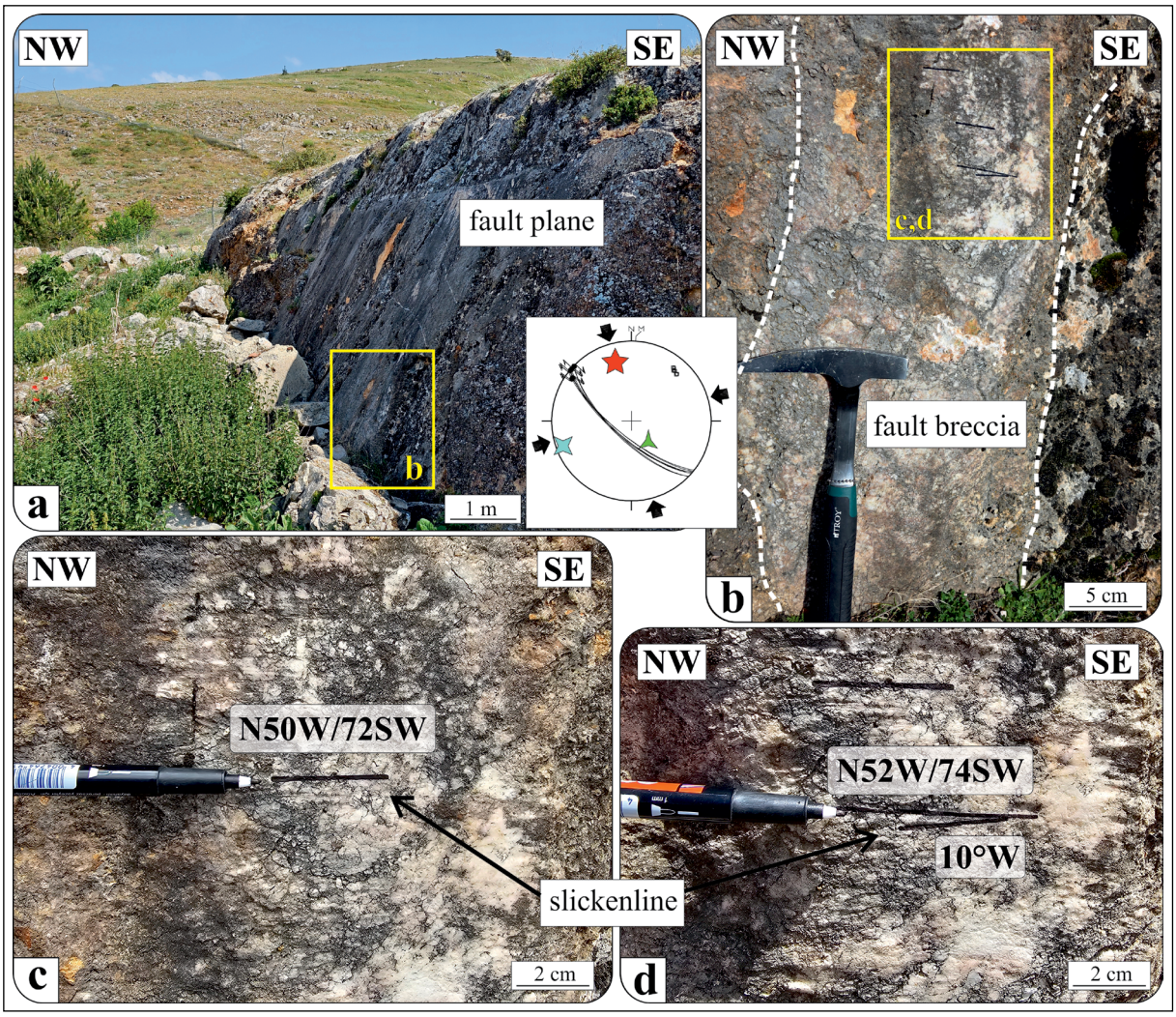


Figure 9- a-b) General views of fault planes east of Dodurga, (Location 4, See, Figure 2 for location), c-d) close-up views of the different slickenlines of the same fault plane.

nearly horizontal σ1 (34°) and σ3 (11°) axes at Location 2, and similarly nearly horizontal positioned σ1 (14° and 11°) and σ3 (05° and 00°) axes at Locations 3 and 5. Evaluation of the principal stress configurations together with the stress ratios (ϕ = 0.361-0.916) indicates the coexistence of pure strike-slip and transtensional tectonic regimes affecting the NW-SE trending right-lateral strike-slip faults in these areas. At Location 4, inversion of kinematic data shows that the maximum (σ1) and intermediate (σ2) principal stresses are oriented subhorizontally, plunging at 25° and 10°, respectively, whereas the minimum principal stress (σ3) has a plunge of 63° (Table 1). The calculated stress ratio (ϕ = 0.388) indicates deformation under a pure compressional stress regime, consistent with the geometry of the strain ellipsoid.

The combined kinematic dataset from all six localities shows that the Dodurga Fault is dominantly a right-lateral strike-slip fault (Figure 2). At the same time, the inversion results indicate that the stress field is not uniform along strike. Segment-scale and locality-scale variations range from transpressional/compressional strike-slip conditions in the northwestern part of the fault to pure strike-slip and transtensional conditions in its central and southeastern sectors. Overall, the data are most consistent with a regionally strike-slip regime characterized by approximately N-S to NNW-SSE contraction and E-W to ENE-WSW extension, upon which local rotations and oblique components are superimposed.

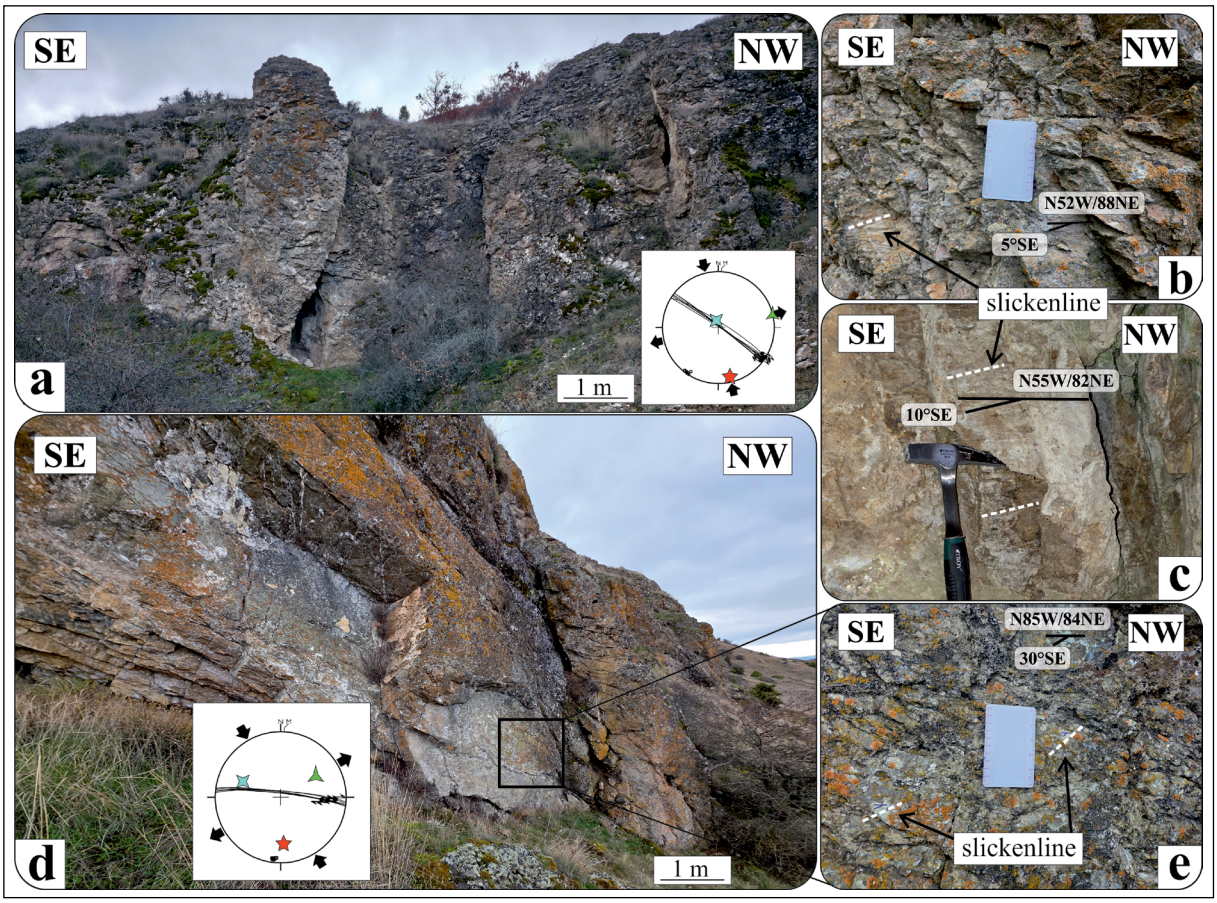


Figure 10- General view of the fault plane observed south of Kümbetakpınar, (Locations 5 and 6, See, Figure 2 for location) b-c) close-up views of slickenlines on the fault plane, d) general view of the fault plane observed within the ophiolitic units approximately 500 m northwest of location 5, e) close-up view of the slickenlines on the fault plane.

Table 1- Characteristics of stress states used to reconstruct stress regimes [Abbreviations: ϕ-ratio of stress magnitude differences (ϕ= (σ2- σ3) / (σ1- σ3); ANG- the average angle between observed slip and computed shear, in degrees; #-number of faults slip data; principal stress axes: σ1, the maximum, σ2, intermediate and σ3, minimum principal stress axes].

Location	Fault orientation	Fault type	#	σ1	σ2	σ3	φ	ANG
L1	NW-SE	Right lateral	7	348/17	249/27	108/57	0.414	5
L2	NW-SE	Right lateral	7	189/34	347/54	092/11	0.361	13
L3	NW-SE	Right lateral	8	034/04	278/80	125/09	0.789	16
L4	NW-SE	Right lateral	7	345/25	250/10	140/63	0.388	14
L5	NW-SE	Right lateral	7	167/11	344/79	077/00	0.661	5
L6	NW-SE	Right lateral	7	176/30	293/38	060/38	0.960	14

4. Discussion

A major deformation corridor extending southeastward from the Uludağ Uplift into the Anatolian Block has long been recognized in northwestern Türkiye. The eastern sector of this corridor is represented by the EFZ and its associated branches. Within this tectonic framework, the EFZ comprises the Eskişehir Fault, the Dodurga Fault, and the northern boundary faults of the Eskişehir Basin, together constituting an important source of seismic hazard for Eskişehir and its surroundings. The principal branch crossing the city centre is referred to as the Eskişehir Fault (Elma et al., 2024; Elma et al., 2025*a*;

Karabacak et al., 2024; Sümer and Karabacak, 2024), whereas the southern branch, which trends obliquely at a relatively low angle to the Eskişehir Fault, is defined as the Dodurga Fault (Şaroğlu et al., 1987; 2005; Emre et al., 2013; 2018; Karabacak et al., 2025; Elma et al., 2025*c*). Although the Eskişehir Fault has received considerable attention because of its direct relevance to the urban area, the Dodurga Fault has remained comparatively less well constrained in terms of its detailed geometry, segmentation, kinematics, and tectonic role within the EFZ.

The results presented here show that the Dodurga Fault is a well-developed active right-lateral strike-slip structure composed of two principal geometric segments: a 16-km-long western segment and a 47-km-long eastern segment. The mapped fault geometry, linear fault traces, step-overs, structural boundaries, elongated ridge development, and right-lateral offsets observed in both large-scale and small-scale drainage elements collectively demonstrate that the fault exerts a strong control on the present-day morphology. In particular, the kilometer-scale offsets documented along Segment 1 and Segment 2, together with the metre- to kilometre- scale offsets preserved in younger fluvial systems, indicate that the fault has been repeatedly active and has accumulated substantial right-lateral displacement over time. These geomorphic observations are consistent with the fault-plane kinematic indicators, which independently confirm the dominantly dextral character of the Dodurga Fault.

The paleostress results further indicate that, although the fault is consistently right-lateral in kinematic sense, the stress field is not uniform along strike. Instead, the data suggest local transitions from compressional or transpressional strike-slip conditions in the northwestern part of the fault to pure strike-slip and locally transtensional conditions in its central and southeastern sectors. Despite these local variations, the overall stress configuration derived from the combined dataset is compatible with a regional deformation regime characterized by approximately N-S to NNW-SSE contraction and E-W to ENE-WSW extension. This interpretation is broadly consistent with previously published structural, paleostress, and geodetic observations from northwestern Anatolia (Gürer et al., 2003; Heidbach et al., 2016; Selçuk et al., 2016; Akgün and Özden, 2019; Karabacak et al., 2022; Alçiçek et al., 2023; Çakır and Uzel, 2023), as well as with the westward motion of Anatolia indicated by GPS data (Reilinger et al., 2006; Aktuğ et al., 2013). It is also compatible with paleostress results reported from the western segment of the Eskişehir Fault, where a similar N-S contraction and E-W extension has been identified (Elma et al., 2025*a*). In this respect, the Dodurga Fault appears to form part of a broader strike-slip deformation domain in which local stress permutations and geometrically controlled oblique components are superimposed on a regionally coherent tectonic pattern.

Comparison with previous regional studies also suggests that the Dodurga Fault occupies a transitional position between the deformation styles associated with the southern Marmara region and those characterizing the interior EFZ. Karabacak et al. (2022) showed that the Ulubat, Bursa, and İnegöl faults developed under a stress regime involving NW-SE compression and NE-SW extension, comparable to that affecting the southern branch of the North Anatolian Fault Zone. Likewise, Selçuk et al. (2016) proposed a stress regime involving NNW-SSE compression and ENE-WSW extension for the southeastern part of the İnönü-Eskişehir fault system. The stress orientations derived in this study broadly agree with those regional datasets and with the compilation shown in Figure 11. At the same time, the observed variation in the orientations of the principal stress axes along the Dodurga Fault may indicate local stress rotations related to fault geometry, segment interaction, and strain partitioning within the EFZ. Accordingly, the Dodurga Fault should not be considered an isolated structure, but rather an integral component of a distributed and geometrically complex deformation system in northwestern Anatolia.

The seismic implications of the Dodurga Fault are also noteworthy. Empirical scaling relationships of Wells and Coppersmith (1994) indicate that Segment 1 is capable of generating an earthquake of Mw 6.47, whereas Segment 2 could produce an event of Mw 6.97. If both segments were to rupture together, the total fault length would allow for

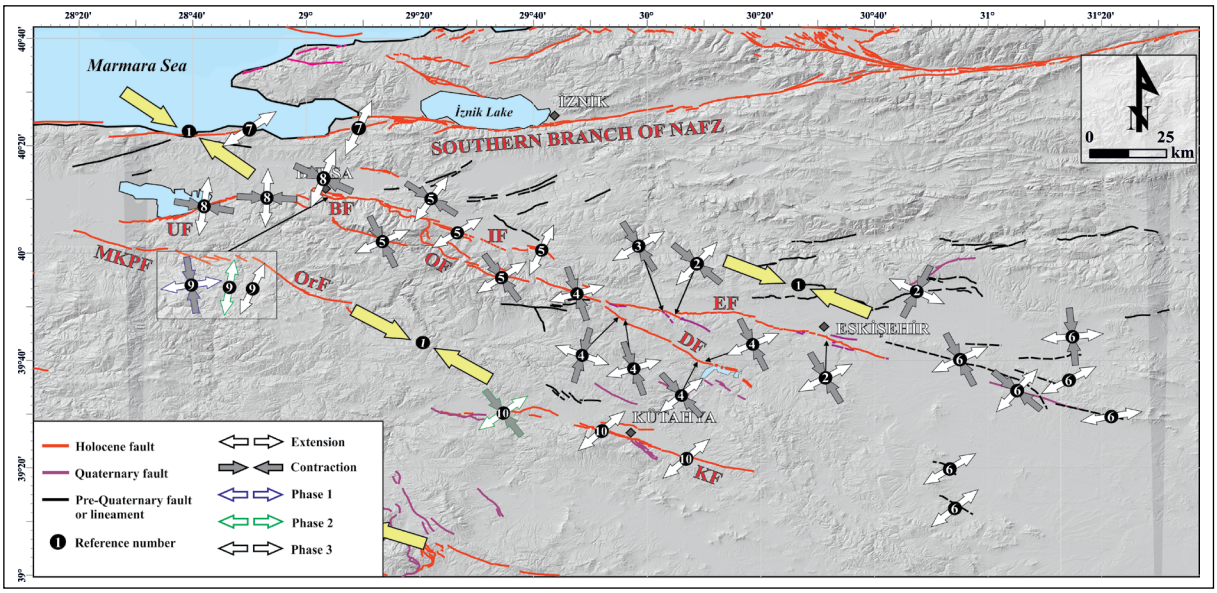


Figure 11- The distribution of stress orientations analyzed from the literature through geological studies and calculated in this study. Data numbers: 1-Heidbach et al. (2016); 2-Seyitoğlu et al. (2015); 3-Özden et al. (2015); 4- This study; 5-Alçiçek et al. (2023); 6- Selçuk et al. (2016); 7-Gürer et al. (2003); 8-Karabacak et al. (2022); 9- Çakır and Uzel (2023); 10-Akgün and Özden (2019). Abbreviations: EF-Eskişehir Fault; DF-Dodurga Fault; KF-Kütahya Fault; İF-İnegöl Fault; OF-Oylat Fault; BF-Bursa Fault; UF-Ulubat Fault; MKPF-Mustafa Kemal Paşa Fault; OrF-Orhaneli Fault.

an earthquake of approximately Mw 7.16. These values should be regarded as first-order estimates of seismogenic potential rather than deterministic forecasts; nevertheless, they highlight the capacity of the Dodurga Fault to generate damaging earthquakes. This inference is especially important given the fault's proximity to Eskişehir and the broader urbanized corridor influenced by the EFZ.

The geomorphic offsets documented in this study also provide a preliminary basis for discussing long-term deformation along the fault. The largest measured offsets reach 7.0 ± 0.7 km on Segment 1 and 6.2 ± 0.2 km on Segment 2, values comparable to the Quaternary right-lateral offsets of up to 6 km previously reported by Şaroğlu et al. (2005). If these displacements are assumed to represent cumulative Quaternary deformation, they imply a slip rate of 2.69 ± 0.27 mm/yr. Alternatively, if the relevant drainage development is linked to the onset of the neotectonic regime in western Anatolia at ca. 5 Ma (Angelier et al., 1981; Hancock and Barka, 1987; Seyitoğlu and Scott, 1991; Bozkurt, 2001; Sözbilir, 2001, 2005; Bozkurt and Sözbilir, 2004, 2006; Özkaymak and Sözbilir, 2008; Uzel and Sözbilir, 2008; Özkaymak et al., 2011) the average geomorphological slip rate decreases to 1.4 ± 0.14 mm/yr. These estimates are necessarily approximate because they depend on the age assigned to the displaced geomorphic markers. They should therefore be treated as first-order geomorphic constraints rather than definitive fault-slip rates. Even so, they indicate that the Dodurga Fault has accommodated substantial cumulative strike-slip deformation and is likely to represent a major kinematic component of the EFZ.

This inference can be compared with the regional block-model results of Seyitoğlu et al. (2022), who proposed strike-slip and normal-faulting components west of the Dodurga Fault, between the Dodurga and Eskişehir faults, and near the Eskişehir Fault. Although those modeled values do not directly correspond to slip rates on individual faults, they suggest that deformation across the EFZ is partitioned and distributed between adjacent structures. In contrast, trench-based paleoseismological studies on the Eskişehir Fault indicate a lower long-term slip rate of 0.50 ± 0.02 mm/yr (Elma et al., 2025*b*). When considered together with recurrence intervals reported for neighbouring faults to the west, approximately 2000 years for the Bursa Fault and 2500 years for the İnegöl Fault (Karabacak and Sançar, 2025), and the longer

recurrence interval of about 3000 years on the western segment of the Eskişehir Fault (Elma et al., 2025*a*), the available evidence suggests that deformation may be partitioned unevenly along and across the EFZ. In this framework, the Dodurga Fault may accommodate an important share of the dextral component of regional strain, although this interpretation remains to be tested by direct paleoseismological and geochronological data from the fault itself.

Overall, the Dodurga Fault emerges from this study as a major active strike-slip structure that plays a significant role in the kinematics of the EFZ and in the broader neotectonic evolution of northwestern Anatolia. Its mapped segmentation, persistent dextral geomorphic signature, and along-strike variation in stress regime provide new insight into the structural organization of the EFZ. At the same time, the absence of direct paleoseismological constraints on the timing of past surface ruptures remains a major limitation for seismic hazard assessment. Future trench-based investigations, supported by chronological control on displaced geomorphic markers, are needed to determine the fault's recurrence behaviour, constrain its slip rate more robustly, and assess whether its segments tend to rupture independently or as part of larger multi-segment earthquakes.

5. Conclusions

This study provides a detailed geological, geomorphological, and kinematic characterization of the Dodurga Fault, an active structure within the EFZ in northwestern Anatolia. The main conclusions are as follows:

- The Dodurga Fault is an active NW-SE-trending right-lateral strike-slip fault with a total mapped length of approximately 63 km. Based on its surface geometry, the fault can be subdivided into two principal geometric segments: a 16-km-long western segment (Segment 1) and a 47-km-long eastern segment (Segment 2).

- Geological and geomorphological observations demonstrate that the fault has exerted a strong control on the recent landscape. Linear fault traces, fault scarps, structural boundaries, elongated ridge development, and right-lateral offsets observed in drainage systems collectively indicate persistent surface expression and active deformation along the fault.

- Kinematic data obtained from six localities along the fault confirm that the Dodurga Fault is dominantly right-lateral in character. Paleostress inversion results further show that the recent deformation phase is governed by a regional stress regime characterized by approximately N-S to NNW-SSE contraction and E-W to ENE-WSW extension, although local variations from compressional/transpressional to transtensional conditions occur along strike.

- Empirical fault-scaling relationships indicate that Segment 1 may be capable of producing an earthquake of Mw 6.47, whereas Segment 2 may generate an event of Mw 6.97. In the case of multi-segment rupture, the Dodurga Fault could potentially produce an earthquake of about Mw 7.16. These estimates highlight the significance of the Dodurga Fault as an important seismic source for Eskişehir and its surroundings.

Overall, the Dodurga Fault emerges as a major active component of the EFZ and a key structure in the neotectonic deformation of northwestern Anatolia. Its geometry, kinematics, and inferred seismogenic potential underline the need for future paleoseismological investigations aimed at constraining its long-term slip rate, recurrence behaviour, and most recent surface-rupturing events. Such data are essential for improving regional seismic hazard assessment and for supporting urban resilience and risk mitigation studies in the Eskişehir region

Acknowledgment

This study was supported by the TÜBİTAK-KAMAG project numbered 123G010 (project coordinator: Prof. Dr. Volkan Karabacak), conducted as part of the "Identifying Paleoseismological Characteristics of the Active Faults of Türkiye (P/SISMO-TURK). The geological, geomorphological, and kinematic field observations related to faulting constitute part of the first author's ongoing PhD dissertation at the Graduate School of Natural and Applied Sciences, Eskişehir Osmangazi University. We are grateful to Şule Gürboğa, and the anonymous

reviewers for their indispensable comments and suggestions. The authors thank Res. Assist. Burak Demiral (Eskişehir Osmangazi University) and Mirza Agha Safarov (Eskişehir Osmangazi University) for their support during the fieldwork.

References

Akgün, E., Özden, S. 2019. Plio-Quaternary stress states along the Kütahya Fault and surroundings, NW Turkey. Turkish Journal of Earth Sciences 28 (5), 671-686.

Aktuğ, B., Parmaksız, E., Kurt, M., Lenk, O., Kılıçoğlu, A., Gürdal, M.A., Özdemir, S. 2013. Deformation of Central Anatolia: GPS Implications. Journal of Geodynamics 67, 78-96.

Alçiçek, M. C., Karabacak, V., Okay, A. I., Kaya, T. T. 2023. İnegöl Havzası'nın Stratigrafisi ve Tektono-Sedimanter Gelişimi (KB Anadolu), (Proje no: 119Y208). TÜBİTAK 1001 Projesi Final Raporu.

Angelier, J. 1990. Inversion of Field Data in Fault Tectonics to Obtain the Regional Stress—III. A New Rapid Direct Inversion Method by Analytical Means. Geophysical Journal International 103, 363-376.

Angelier, J., Dumont, J.F., Karamanderesi, İ.H., Poisson, A., Şimşek, Ş., Uysal, Ş. 1981. Analyses of fault mechanisms and expansion of southwestern Anatolia since the Late Miocene. Tectonophysics 79, 11-19.

Bozkurt, E. 2001. Neotectonics of Turkey-a synthesis. Geodinamica Acta 14, 3-30.

Bozkurt, E., Sözbilir, H. 2004. Tectonic evolution of the Gediz Graben: field evidence for an episodic, two-stage extension in western Turkey. Geological Magazine 141, 63-79.

Bozkurt, E., Sözbilir, H. 2006. Evolution of the large-scale active Manisa Fault, southwest Turkey: implications on fault development and regional tectonics. Geodinamica Acta 19, 427-453.

Çakır, E., Uzel, B. 2023. Strain partitioning between extensional and transcurrent systems: Field relationship and kinematic of the North Anatolian Fault Zone in the Bursa Basin, NW Turkey. Journal of Asian Earth Sciences 251. 105669.

Duman, T. Y., Çan, T., Emre, Ö., Kadirioğlu, F.T., Başarır Baştürk, N., Kılıç, T., Arslan, S., Özalp, S., Kartal, R.F., Kalafat, D., Karakaya, F., Eroğlu Azak, T., Özel, N.M., Ergintav, S., Akkar, S., Altınok, Y., Tekin, S., Cingöz, A., Kurt, A.İ. 2017. Türkiye Sismotektonik Haritası. Maden Tetkik ve Arama Genel Müdürlüğü, Özel Yayınlar Serisi-34, Ankara, Türkiye.

Duman, T. Y., Çan, T., Emre, Ö., Kadirioğlu, F. T., Başarır Baştürk, N., Kılıç, T., Arslan, S., Özalp, S., Kartal, R. F., Kalafat, D., Karakaya, F., Eroğlu Azak T., Özel, N. M. Ergintav, S., Akkar, S., Altınok, Y., Tekin, S., Cingöz, A., Kurt, A. İ. 2018. Seismotectonics Database of Turkey. Bulletin of Earthquake Engineering, 16(8), 3277−3316.

Elma, İ., Özçelik, B., Karabacak, V., Özkaymak, Ç., Sümer, Ö. 2024. Eskişehir Fayının İnönü-Oklubalı Segmentine Ait İlk Paleosismolojik Bulgular. Türk Deprem Araştırma Dergisi 6(2), 349-368.

Elma, İ., Safarov, M.A., Karabacak, V., Özkaymak, Ç., Sümer, Ö. 2025*a*. Paleosismolojik Veriler Işığında Eskişehir Fayı'nın Batı Segmentinin Deprem Davranışı / Earthquake Behaviour of the Western Segment of the Eskişehir Fault in Light of Paleoseismological Data. Türkiye Jeoloji Bülteni 68(3), 333-356.

Elma, İ., Safarov, M. A., Karabacak, V., Özkaymak, Ç. Sümer, Ö. 2025*b*. Eskişehir Fayı'nın Uzun Dönem Kayma Hızı ve Paleosismolojisi. 77.Türkiye Jeoloji Kurultayı, Bildiri Özleri Kitabı, 334, 14-18 Nisan 2025, Maden Tetkik ve Arama Genel Müdürlüğü, Ankara.

Elma, İ., Karabacak, V., Özkaymak, Ç., Sümer, Ö., Özcan, D. M. 2025*c*. Dodurga Fayı'nın Fay Geometrisi ve Segmentasyonu, Eskişehir Fay Zonu, KB Anadolu. ATAG 28. Çalıştayı, Bildiri Özleri Kitabı, 56-57, 5-7 Kasım 2025, Aydın, Türkiye

Emre, Ö., Duman, T. Y., Özalp, S., Elmacı, H., Olgun, Ş., Şaroğlu, F. 2013. 1/250.000 ölçekli Türkiye Diri Fay Haritası. Maden Tetkik ve Arama Genel Müdürlüğü Özel Yayınlar Serisi Ankara, Türkiye.

Emre, Ö., Duman, T. Y., Özalp, S., Şaroğlu, F., Olgun, Ş., Elmacı, H., Çan, T. 2018. Active Fault Database of Turkey. Bulletin of Earthquake Engineering 16, 3229–3275.

Gözler, M. Z., Cevher, F., Küçükayman, A. 1985. Eskişehir civarının jeolojisi ve sıcak su kaynakları. Türkiye Jeoloji Kurumu Bülteni 21, 39-54.

Gürer, Ö. F., Kaymakçı, N., Çakır, Ş., Özburan, M. 2003. Neotectonics of the southeast Marmara region, NW Anatolia, Turkey. Journal of Asian Earth Sciences 21, 1041-1051.

Hancock, P. L., Barka, A. A. 1987. Kinematic indicators on active normal faults in western Turkey. Journal of Structural Geology 9, 419427.

Heidbach, O., Custodio, S., Kingdon, A., Mariucci, M.T., Montone, P., Müller, B., Pierdominici, S., Rajabi, M., Reinecker, J., Reiter, K., Tingay, M., Williams, J., Ziegler, M. 2016. Stress Map of the

Mediterranean and Central Europe 2016. GFZ Data Services.

Karabacak, V., Sançar, T. 2025. Bursa İli Yerleşim Alanlarının Deprem Tehlikesi: Ulubat, Bursa ve İnegöl Diri Faylarının Paleosismolojik Özellikleri / Earthquake Hazard in Urban Areas of Bursa Province: Paleosismological Properties of the Ulubat, Bursa and İnegöl Active Faults. Türkiye Jeoloji Bülteni 68(2), 151-176.

Karabacak, V., Sançar, T., Yıldırım, G., Uysal, T. 2022. When did the North Anatolian fault reach southern Marmara, Turkey, Geology 50, 432-436.

Karabacak, V., Özkaymak, Ç., Sümer, Ö. 2024. Eskişehir Fayı ve Dodurga Fayının Paleosismolojik Özelliklerinin Belirlenmesi, 123G010 no.lu TÜBİTAK Projesi 1. Gelişme Raporu.

Karabacak, V., Elma, İ., Doğan, G.G., Özkaymak, Ç., Sümer, Ö., Yayan, K. 2025. Dodurga Fayı deprem tehlikesi ve Eskişehir ili için olası afet senaryoları: Kentsel dirençlilik anlamında mühendislik yapılarının mekânsal planlamasına bir örnek. MTA Yerbilimleri ve Madencilik Dergisi 8, 1-12

Küçükayman, A., Genç, S., Gök, L., Kar, H., Ateş, M. 1987. Bozüyük-Tavşanlı- Kütahya Arasının Jeolojisi. Maden Tetkik Arama Genel Müdürlügü, Rapor No: 8356.

Le Pichon, X., Angelier, J. 1979. The Hellenic arc and trench system: a key to the neotectonic evolution of the eastern Mediterranean area. Tectonophysics 60, 1-42.

McKenzie, D. 1972. Active Tectonics of Mediterranean Region, Geophys. J. R. Astro. Soc. 30, 109-185.

Okay, A. I. 1984. Distribution and characteristics of the northwest Turkish blueschists. In: The Geological Evolution of the Eastern Mediterranean (ed. J.E. Dixon ve A.H.F. Robertson). Geological Society Special Publication, 17, 455-466.

Okay, A. I. 2011. Tavşanlı Zonu: Anatolid-Torid Blok'nun Dalma-Batmaya uğramış kuzey ucu. Maden Tetkik ve Arama Genel Müdürlüğü Dergisi 142, 195-226, 2022.

Özden, S., Gündoğdu, E., Bekler, T. 2015. Interactions between Eurasian/African and Arabian plates: Eskişehir Fault, NW Turkey. Journal of African Earth Sciences 111, 349-362.

Özkaymak, Ç., Sözbilir, H. 2008. Stratigraphic and Structural Evidence for Fault Reactivation: The Active Manisa Fault Zone, Western Anatolia. Turkish Journal of Earth Sciences 17 (3), 615-635.

Özkaymak, Ç., Sözbilir, H., Uzel, B., Akyüz, H. S. 2011. Geological and Palaeoseismological Evidence for Late Pleistocene−Holocene Activity on the Manisa Fault Zone, Western Anatolia. Turkish Journal of Earth Sciences 20 (4), 449-474.

Pavlides, S., Caputo, R. 2004. Magnitude versus faults'surface parameters: Quantitative relationships from the Aegean. Tectonophysics 380, 159- 188.

Reilinger, R., McClusky, S., Vernant, P., Lawrence, S., Ergintav, S., Çakmak, R., Özener, H., Kadirov, F., Guliev, I., Stepanyan, R., Nadariya, M., Hahubia, G., Mahmoud, S., Sakr, K., ArRajehi, A., Paradissis, D., Al-Aydrus, A., Prilepin, M., Guseva, T., Evren, E., Dmitrotsa, A., Filikov, S. V., Gomez, F., Al-Ghazzi, R., Karam, G. 2006. GPS constraints on continental deformation in the Africa-Arabia-Eurasia continental collision zone and implications for the dynamics of plate interactions. Journal of Geophysical Research 111, B05411.

Selçuk, A. S., Gökten, Y. E., Aktuğ, B. 2016. The Stress State of The Region around Inonu-Eskisehir active fault system (Turkey); kinematic analysis accompanied with GPS Data. Journal of Indian Geophysical Union 20(6), 527-535.

Servais, M. 1982. Collision et suture téthysienne en Anatolie Centrale, étude structurale et métamorphique (HP-BT) de la zone nord Kütahya. Ph.D. Thesis, Universite de Paris-Sud, Centre d'Orsay, 374.

Seyitoğlu, G., Scott, B. 1991. Late Cenozoic crustal extension and basin formation in west Turkey. Geological Magazine 128, 155-166.

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

Seyitoğlu, G., Aktuğ, B., Esat, K., Kaypak, B. 2022. Neotectonics of Turkey (Türkiye) and surrounding regions: a new perspective with block modelling. Geologica Acta 20(4), 1-21.

Sözbilir, H. 2001. Geometry of macroscopic structures with their relations to the extensional tectonics: field evidence from the Gediz detachment, Western Turkey. Turkish Journal of Earth Sciences 10, 51-67.

Sözbilir, H. 2005. Oligo-Miocene extension in the Lycian orogen: evidence from the Lycian molasse basin, SW Turkey. Geodinamica Acta 18, 257-284.

Şaroğlu, F., Emre, Ö., Boray, A. 1987. Türkiye'nin Diri Fayları ve Depremsellikleri. Maden Tetkik ve Arama Genel Müdürlüğü, Ankara.

Şaroğlu, F., Emre, Ö., Doğan, A., Yıldırım, C. Ç. 2005. Eskişehir Fay Zonu ve Deprem Potansiyeli. Eskişehir Fay Zonu ve İlişkili Sistemlerin Depremselliği Çalıştayı, Osmangazi Üniversitesi, 28-30 Nisan 2005, Eskişehir, Bildiri Özleri Kitapçığı.

Sümer, Ö., Karabacak, V. 2024. Archaeoseismology: Earthquake traces studies in ancient settlements; a chronological evaluation from the World focusing on Türkiye. Bulletin of the Mineral Research and Exploration 174, 99-128.

Şengör, A. M. C. 1980. Türkiye'nin Neotektoniğinin Esasları: TJK Konferanslar Dizisi, 2,40. Ankara.

Şengör, A. M. C., Kidd, W. S. F. 1979. Post-collisional tectonics of the Turkish-Iranian plateau and a comparison with Tibet. Tectonophysics 55, 361-376.

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

Şengör, A. M. C., Görür, N., Şaroğlu, F. 1985. Strike-Slip Faulting and Related Basin Formation in Zones of Tectonic Escape: Turkey as a case Study: Strike-Slip Deformation. Basin Formation, and Sedimentation. Edited by Biddle, K.T, and Mineralogists Special Publication, 37, 227-264.

Uzel, B., Sözbilir, H. 2008. A First Record of a Strike-slip Basin in Western Anatolia and Its Tectonic Implication: The Cumaovası Basin. Turkish Journal of Earth Sciences 17 (3), 559-591.

Wells, D. L., Coppersmith, K. J. 1994. New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement, Bulletin of the Seismological Society of America 84(4), 974-1002.