FRACTURE ANALYSIS OF ÇAYSİMAV SEGMENT (WEST ANATOLIA) AND ITS SURROUNDINGS USING REMOTE SENSING METHODS

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ABSTRACT

The Çaysimav segment constitutes one of the most important parts of the Sındırgı-Sinanpaşa Fault Zone, as one of the remarkable active fault zones in Western Anatolia. Numerous earthquakes (e.g., 1875-M: 6.1; 1928-Ms: 6.1; 1944-Ms: 6.0; March 28, 1970-Mw: 7.2; February 17, 2009-Mw: 5.3; May 19, 2011-Mw: 5.9; May 3, 2012-Mw: 5.8) have occurred along the segment both in historical and instrumental periods. The Çaysimav segment exhibits a distinct lineament between Izzettin and Yeşilköy settlements, which is approximately 67 km long and N65°-85°W striking. The lineaments represent by fault traces and related fractures with various lengths extending between 320 m and 14 km. Remote sensing studies reveal that all lithologies, basement rocks (e.g., metamorphites, sheared rocks, granitoids, ophiolitic melange rocks) and Neogene-Quaternary basin rocks (e.g., volcano-sedimentary units, clastic sediments, alluvial deposits), have been affected by fracturing processes intensively.

Lineament analysis was carried out using 10 m resolution digital elevations model data in Geomatica, ArcGIS, and RockWorks programs throughout the Çaysimav segment and its surrounding areas of lithologies cut by the segment. Numerous rose diagrams have been prepared from lineaments (5636 number) obtained from each lithology groups. The rose diagram analysis shows that the dominant orientations of the fracture lineaments in Quaternary units are ENE-WSW, E-W, and NNE-SSW directions. A limited number of fractures with WNW-ESE and NE-SW orientations exist as well. The fractures measured from Miocene-Pliocene volcano-sedimentary units and basement rocks are dominantly NW-SE oriented. These lithologies also have lineaments showing several direction maxima. Remarkably, some of the fracture orientations obtained from the basement rocks close to the Çaysimav segment can be correlated with orientations attained from Quaternary deposits.

All these data suggest the following conclusions: (1) Rose diagram patterns of fractures in Quaternary units are closely related to the formation and evaluation of the Çaysimav segment and represent the fractures associated with faulting. Lineaments with ENE-WSW, E-W, and WNW-ESE orientations correspond to the Çaysimav segment with normal fault zone characteristics. Limited NE-SW orientation is also present. (2)

Dominant NW-SE oriented fractures in other units within the study area are associated with the NE-SW direction regional extensional tectonics regime in Western Anatolia.

Keywords: Fault zone, Lineament analysis, Rose diagram, Remote sensing, Western Anatolia

INTRODUCTION

Turkey and its surroundings are located in a region affected by relative movements of Eurasia, African and Arabian Plates (Figure 1A). The west and southwest movement of the Anatolian Plate is provided by the North Anatolian Fault Zone (NAFZ) and the East Anatolian Fault Zone (EAFZ), which are among the most important fault zones in the world (Şengör et al., 1985; Çağlayan et al., 2019).

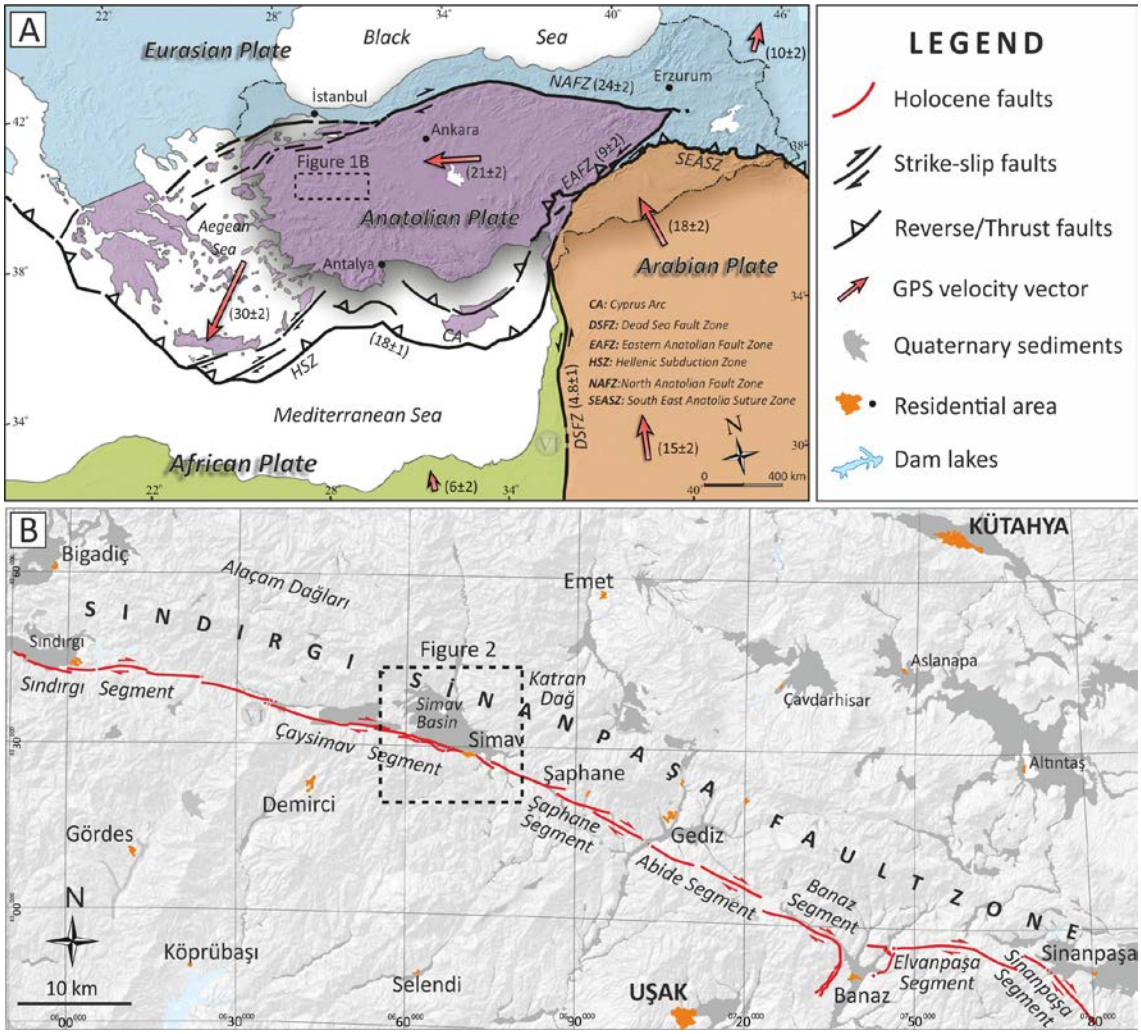

Figure 1 - (A) The map representing the tectonic features of Turkey and surroundings (Çağlayan et al., 2019), (B) The map shows the segments of Sındırgı - Sinanpaşa Fault Zone (simplified and redrawn from Emre et al., 2011.)

Western Turkey is one of the interesting areas including typical structures, such as detachment faults, metamorphic core complex and normal faults that occurred during regional Late Cenozoic's extensional regime (Işık et al., 2003; 2004; Seyitoğlu et al.,

2004; Seyitoğlu and Işık, 2015). The Sındırgı-Sinanpaşa Fault Zone is an important active fault zones in western Turkey, which was divided into seven segments (Figure 1B). The Çaysimav segment is distinctive in its structural and morphological characteristics.

TECTONIC SETTING

Sındırgı- Sinanpaşa Fault Zone extends for approximately 200 km length from Sındırgı (Balıkesir) in the northwest to the Sinanpaşa (Afyon) in the southeast. The orientation of it is approximately N60°W (Figure 2). Although the faulting characteristics of the fault zone are still controversial, the zone has been identified as a strike-slip fault in the Active Faults Map of Turkey (Emre et al., 2011). In the literature, characteristics of the zone have been proposed as a normal fault, or the fault that was initiated as a strike-slip fault then developed as a normal fault. The Çaysimav segment exhibits a distinct lineament between Izzettin and Yeşilköy settlement areas, which is approximately 67 km in length and has N65°-85°W striking. The segment consists of many parallel/sub-parallel fault strands in different lengths, varying from 320 meters to 14 kilometers. The southern part of the Simav Graben is restricted by the Çaysimav segment (Figure 2).

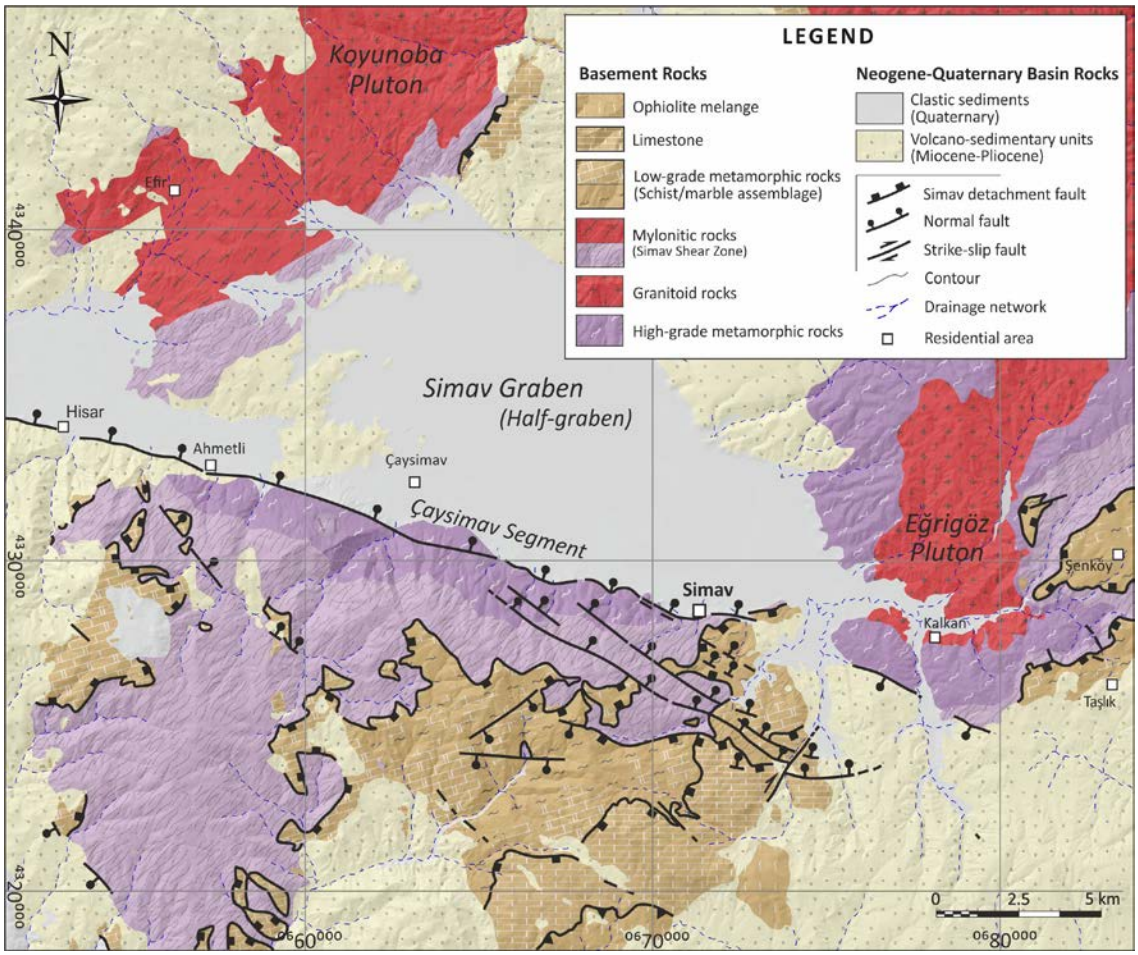

Figure 2 - Geological map of Simav and its surroundings (redrawn from Isik, 2004)

Numerous earthquakes (e.g., 1875-M: 6.1; 1928-Ms: 6.1; 1944-Ms: 6.0; March 28, 1970-Mw: 7.2; February 17, 2009-Mw: 5.3; May 19, 2011-Mw: 5.9; May 3, 2012-Mw: 5.8) have occurred along the segment both in historical and instrumental periods.

The study area comprises of different rock types. The rock types of the region are mainly metamorphic rocks and granitoid intrusions deformed by extension Oligocene time, and low-grade metamorphites and non-metamorphic rocks, which the Simav detachment fault and associated shear zone separate these rocks (Işık et al., 2001). These rocks can be divided into two main groups, basement rocks and basin rocks (Işık, 2004) (Figure 2). The basement rocks consist of metamorphic rocks (both high-grade and low-grade), limestones, ophiolitic rocks, and granitoid rocks. The basin units comprise Miocene-Pliocene sedimentary and volcanic rocks, and Quaternary deposits (Figure 2). Quaternary units widely deposit on the hanging-wall of the Çaysimav segment. The existence of hot springs and travertine formations in the hanging-wall of the segment indicates that the segment is active. Our remote sensing studies reveal that all lithologies taking place both hanging-wall and footwall of the Çaysimav segment include variable fractures with different orientations.

FRACTURE ANALYSIS

Fractures are discontinuities in displacement and mechanical properties where rocks or minerals are broken, and reduction or loss of cohesion characterizes most fractures (Fossen, 2010). Fracture analysis is used to determine the direction of the fractures, the fracture density, and identifying the number of tectonic phases that affect an area. Lineament analysis was carried out throughout the Çaysimav segment and its surrounding areas using 10 m resolution digital elevations model (DEM) data in Geomatica 2017, ArcGIS 10.4, and RockWorks 16 software. Fracture analysis was performed using a combination of various remote sensing methods throughout the Çaysimav segment, both on the basement and basin rocks and separately for hanging-wall and footwall blocks (Figure 3). 10 rose diagrams were drawn for a total of 5636 lineaments which were determined in different lithologies both on the hanging wall and footwall (Figure 3). The fracture density map shows the concentration of fractures mostly in the basement rocks units in the southwestern and northeastern parts of the study area. On the other hand, observations reveal that fractures in the basin rocks show less density than in the basement rocks, where the lowest density was observed in the Quaternary units of the Simav Graben and near its surroundings.

Analyzing rose diagrams related to rocks of the footwall block of the Çaysimav segment demonstrates that fractures in high-grade metamorphic rocks are predominantly in N-S and NW-SE directions. In contrast, the dominant directions of fractures in mylonitic rocks are NW-SE. Furthermore, fractures exhibit N-S, NNW-SSE, and E-W general directions in low-grade metamorphic rocks (Schist/marble units), NW-SE, and very few NE-SW directions in limestones, and NNE-SSW and WNW-ESE dominant directions in ophiolitic melange units (Figure 3).

Rose diagrams of basin rocks in the footwall block indicate dominant NW-SE, NE-SW, and very few E-W directions.

The analysis of the rose diagram of fractures developed in basement rocks of the hanging-wall shows that dominant fracture directions in mylonitic rocks are NW-SE

and very few NE-SW, while in the granitoid rocks, fractures exhibit NW-SE general directions. Likewise, fractures developed in Miocene-Pliocene units in the hanging-wall block were observed in dominant NW-SE and very few in NE-SW directions.

Rose diagrams show that the dominant direction of the fractures in Quaternary units are ENE-WSW, E-W, and NNE-SSW, where a limited number of WNW-ESE and NE-SW oriented fractures were observed as well (Figure 3).

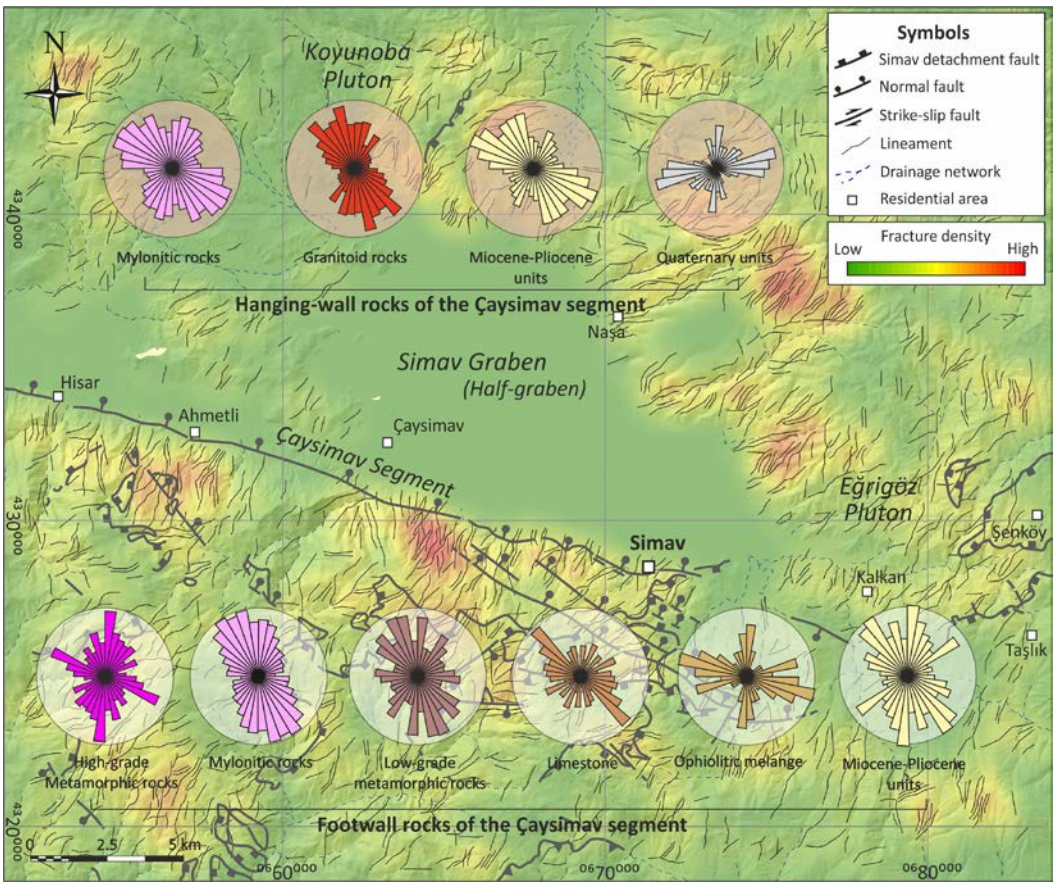

Figure 3 - Fracture density map of the Çaysimav segment. The colors in the rose diagram represent the lithologies in the geological map. Digital elevation model (DEM) was extracted from 1:25.000 topographic maps

CONCLUSIONS

Several rose diagrams considering lineaments (5636 number) were obtained from rocks in the study area separately. The analysis of the rose diagrams shows that the dominant directions of the fractures in Quaternary units are ENE-WSW, E-W, and NNE-SSW, where a limited number of fractures with WNW-ESE and NE-SW directions were observed as well. The fractures in Miocene-Pliocene volcano-sedimentary units and basement rocks are dominantly in the NW-SE direction. These lithologies include lineaments representing several directions also. The consistency of fracture directions obtained from basement rocks close to the Çaysimav segment with those observed in the Quaternary units is remarkable.

Evaluation of the rose diagrams revealed that: (1) Fractures developed in the Quaternary units are related to the formation and development of the Çaysimav segment and are consistent with Riedel fractures associated with the faulting. Accordingly, fractures with ENE-WSW, NE-SW, and E-W directions are associated with the main fault and R-fractures, while WNW-ESE direction fractures are formed in limited areas, representing P fractures. NNE-SSW direction fractures indicate R' fractures, also. (2) Fractures with dominant direction of NW-SE in other units are associated with the NE-SW oriented extension regime occurring on a regional scale in Western Anatolia.

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