



Seismic Activity and Tectonics of Sirnak Region in Turkey

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ABSTRACT

The Sirnak region is located in Turkey near the borders of Iraq and Syria on the Arabian Plate's northeastern border. Since the district includes Silopi Town Center, its seismic influence may affect our areas, making this area crucial to research. The International Seismological Center (ISC) moment tensor method is used to analyze the solutions of the focal mechanisms of four earthquakes within the study area. The seismic magnitude ranges from 4.8 to 5.8, but these solutions were not close to the proposed fault, so we relied mainly on morphotectonic analysis of satellite images using techniques (GIS), Landsat 8 and 9 to estimate the type of fault and determine its direction, which is of a strike-slip-lift type. As for the three seismic catalogs, ISC, European-Mediterranean Seismological Center (EMSC), and Kandilli Observatory and Earthquake Research Institute (KOERI), they are used for the purpose of obtaining seismic records about the Sirnak region for the past ten years (2010-2020) to study the seismic history of the region during this decade, which proved that there was a fault (Fig. 3) called the Şirnak Fault. It is an active and small fault, but it is not marked on maps. It is worth noting that the study area has many faults. However, the majority of the active faults in eastern Turkey are left-lateral or sinistral strike-slip faults that were identified following significant earthquakes, with few thrust fault lines, except for the Bitlis Suture Zone, the Silop, and the Cizre Faults.

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النشاط الزلزالي والتكتوني لمنطقة شرناق في تركيا

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المعلومات الارشفة	المخلص
تاريخ الاستلام: 24-يناير-2024	تقع منطقة شرناق في تركيا بالقرب من حدود العراق وسوريا على الحدود الشمالية الشرقية للصفحة العربية. وبما أن المنطقة تتكون من مركز مدينة سيلوبي، فإن تأثيرها الزلزالي قد يؤثر على مناطقنا، مما يجعل هذه المنطقة ذات أهمية كبيرة للبحث. تم استخدام طريقة موتر العزم من ISC لتحليل حلول الآلية البؤرية لأربعة زلازل ضمن منطقة الدراسة، يتراوح المقدار الزلزالي لها من (4.8 إلى 5.8) لكن هذه الحلول لم تكن قريبة من الصدع المقترح، لذلك تم الاعتماد بشكل اساسي على التحليل المورفوتكتوني لصور الأقمار الصناعية باستخدام تقنيات (GIS) لاندسات 8 و 9 لتقدير نوع الصدع وتحديد اتجاهه وهو من النوع الانزلاقي اليساري اما الكالوجات الثلاثة الزلزالية ISC، EMSC و KOERI فقد استخدمت لغرض الحصول على السجلات الزلزالية لمنطقة شرناق للسنوات العشر الماضية (2010-2020) لدراسة التاريخ الزلزالي للمنطقة خلال ذلك العقد من الزمن، والتي اثبتت أن الصدع تمت تسميته بصدع شرناق. وهو فائق نشط وصغير، لكنه غير محدد على الخرائط. ومن الجدير بالذكر أن منطقة الدراسة تمتلك صدوعاً كثيرة ومع ذلك، فإن غالبية الصدوع النشطة في شرقي تركيا هي فوالق انزلاقية تم تحديدها بعد أعقاب الزلازل الكبيرة التي حدثت، مع عدد قليل من صدوع الدفع باستثناء منطقة نطاق بيتليس، صدعي سيلوب وسيزر.
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Introduction

Silopi is a town in the Sirnak area of Turkey's southeastern Anatolia region, near the borders of Iraq and Syria. The region of Sirnak is situated between latitudes 36° 75' N - 37° 75' N and longitudes 42° 00' E - 43° 25' E, on the northeastern edge of the Arabian Plate. From a tectonic perspective, it is located in the Zagros fold-thrust belt, which connects Iraq's high folded and foothill zones (Fig. 1). One of the biggest areas of convergent deformation on Earth is the Zagros orogen (Allen et al., 2004). The tectonics of the area around these earthquakes govern the Eurasian Plate and Arabian Plate collision. The Bitlis Zagros Thrust fault existed when the collision happened, which also led the Anatolian block to rotate anticlockwise and move westward at a rate of 20–25 mm/yr. The tectonic activity of the area is demonstrated by the migration of the Arabian Plate toward the Eurasian Plate, which reached 20 mm/yr in an N-NW direction (McClusky et al., 2000). Many active faults in the area were affected by the collisional tectonic regime. North of the Arabian Plateau's Fold-and-Thrust Belt, the Bitlis Suture is a complicated continent-continent collisional boundary that stretches from southeast Turkey to Iran's Zagros Mountain ranges. The earthquakes happened in the seismically active eastern-southeastern area of Turkey, which is part of the Bitlis Suture Zone of the Alpine-Himalayan orogenic belt, one of the world's most seismically active areas. The Suture Zone is also known as the Fold Thrust Belt of Southern Anatolia. This zone has a width of more than 100 km in the N-S direction between Siirt-Hakkari-Cizre (Şengör et al., 1981).

The geological region in Sirnak is composed of many active faults, which are thrust, oblique, and right-lateral strike-slip fault systems that are parallel to each other. The Cizre fault is the most important in the south zone of the thrust system in Turkey. This fault is an active reverse fault along the N70°W direction. The Cizre fault and Southeast Anatolian overlap are the main tectonic structures of the Sirnak region. As a result of the Arabian and Eurasian Plates colliding, the N-S compressional regime governs the tectonics of the studied region. The extent of the Cizer fault in Turkey is 80 km, and the eastern part of this fault lies in Iraq. Because there is a ramp-fault structure developing in the southern part of the Southeastern Anatolian thrust zone, the fault turns into a high-angle fault at the surface. The characteristics of the fault could indicate that it is a part of the facet of the Southeastern Anatolia thrust-belt system in which the fault developed. The outer center of the earthquake (ML: 5.5) coincides with the fold-belt on the Cizre Fault facet. The active fault map of Turkey does not account for the association observed in all seismic occurrences, particularly in the southeast (Emre *et al.*, 2013). It is hypothesized that a basal thrust connects all of the structures in the Cizre–Silopi area. The relationships between the structures and the topography are depicted in (Fig. 2) (Gürol *et al.*, 2017).

Aim of the Study

This study aims to investigate the seismicity uniformity and faults that contribute to the seismic active faults that affect Iraq. Detailed information about the seismically active faults is important to update the seismic source zone in Iraq. There is seismic activity that has a specific direction and is related to an active fault, but this fault is not studied or named. Our mission in this study is to name this fault (Sirnak fault).

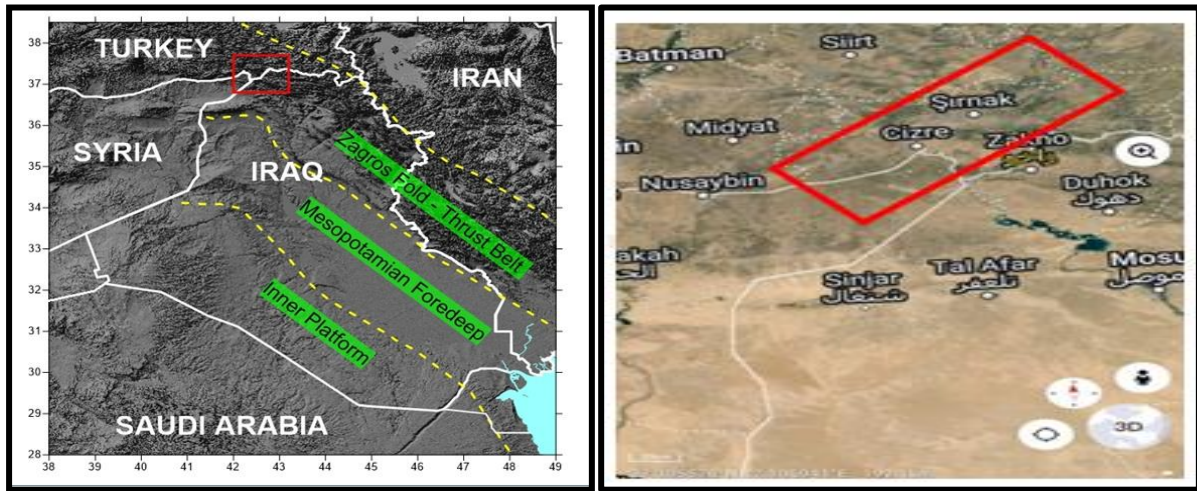


Fig. 1. Tectonic divide (dashed yellow lines) on the research area's location map, courtesy of Fouad (2010), Sissakian *et al.* (2017), and Karasozen *et al.* (2019). The study area is indicated by the red square. On the right is a Google Earth map showing the study area.

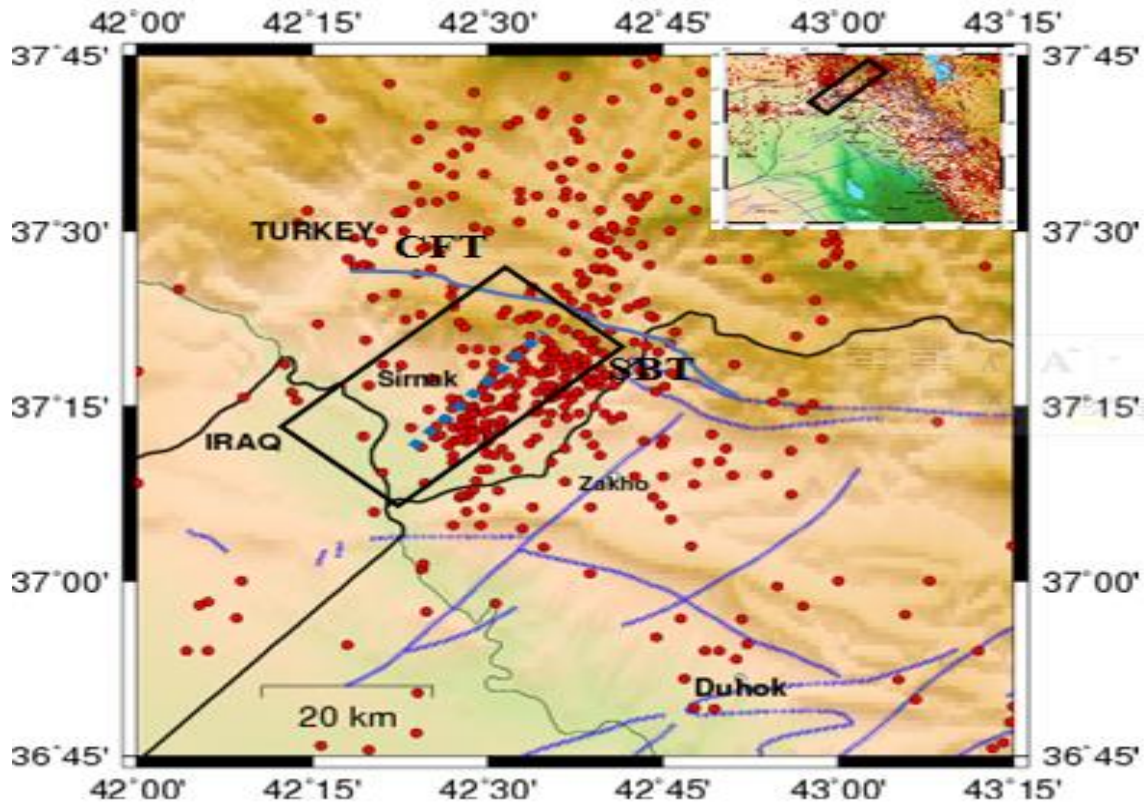


Fig. 2. Map of faults, the study area is indicated by the black square. The expected fault is indicated by the dotted blue line (CFT), representing the Silopi Blind Thrust Fault (SBT) and the Cizre Thrust Fault.

Materials and Methods

The region was first studied using three catalogs from the International Seismological Center (ISC), the European-Mediterranean Seismological Center (EMSC), and the Kandilli Observatory and Earthquake Research Institute (KOERI). These catalogs have shown a linear feature in the center of the Sirnak region near the Iraqi-Turkish-Syrian boundaries. It is necessary to study the seismicity and focus on the linear features in this area. Seismic data from four times were collected from the International Seismological Center (ISC) and utilized to find focal mechanism solutions for selected events. It is difficult to study the area without focal mechanism solutions due to the lack of solutions for the area in the seismic agencies.

Many methods can determine the focal mechanism solution, which depend on the radiation pattern of the seismic waves (Abdulnaby, 2013). It describes the orientation of the fault and the slip direction. In the Sirnak area, the fault type was estimated using the moment tensor approach and which is responsible for the seismic activity. Herrmann and Ammon's (2002) Computer Programming in Seismology (CPS) V. 3.30 was utilized for estimating the focal mechanism solution. In this study, the periods for these times range from 1950 to 2024. However, these events were not related to the expected fault, as they were surrounding the study area, so data from remote sensing and from the United States Geological Survey (USGS) were used to study the structural geology of a specific area. The arc-second elevation map belonging to the Shuttle Radar Topography Mission is the recovered data that aided this research. To interpret and study the details of the structural geology of the Sirnak area, GIS techniques are used. ArcGIS V.10.4.1 software has been used to implement the data, e.g., color composite bands (753) from Landsat 8 and 9 (USGS, 2023).

Results and discussions

Seismic History

The dispersion of the earthquakes' epicenters from the International Seismological Center (ISC) strongly documents events found in more than 1330 earthquakes from 1940 to 2020 in the study area of Southeastern Anatolia. On June 14, 2012, and August 5, 2012, the main earthquakes struck the area. These earthquakes were followed by many other aftershocks, with an interval of minutes between each one. The Kandilli Observatory AFAD, the National Seismological Observation Network, and the Earthquake Research Institute determined the earthquakes' magnitudes. A 4.0-magnitude earthquake struck the same location two minutes before these earthquakes. Following these earthquakes, 14 further earthquakes with magnitudes ranging from 2.3 to 3.8 were recorded in the first five hours, suggesting that the E-W thrusting is another significant neotectonic structure in the Northeast of Syria that is capable of causing significant seismic events. Three seismic agencies' worth of data were gathered and used in this investigation. These are from the International Seismological Center (ISC), the European-Mediterranean Seismological Center (EMSC), and the Kandilli Observatory Earthquake Research Institute (KOERI). As shown in Figure 3, the linear feature in the center of the research area is obvious. The earthquakes that formed this feature need more study because of the lack of information about them and the absence of studies on these earthquakes. Ali (2018) collected nearly 161 earthquakes recorded at Şirnak station between 1912 and 2013, which is situated 40 kilometers closer to the epicenter of this earthquake, having a magnitude of >3.0 . On June 14, 2012, at 05:52:54 local time, an earthquake with a magnitude of $M_w=5.2$ occurred. With a focal depth of 11.3 km, the epicentral locations of the earthquake were found at coordinates 37.21N, and 42.48E. You may also feel the tremor in Mardin, Siirt, and Diyarbakır. The magnitude is under five M_w , although the area is active. It does not provide a good solution for the focal mechanism in the same path as the earthquakes (Fig. 3d).

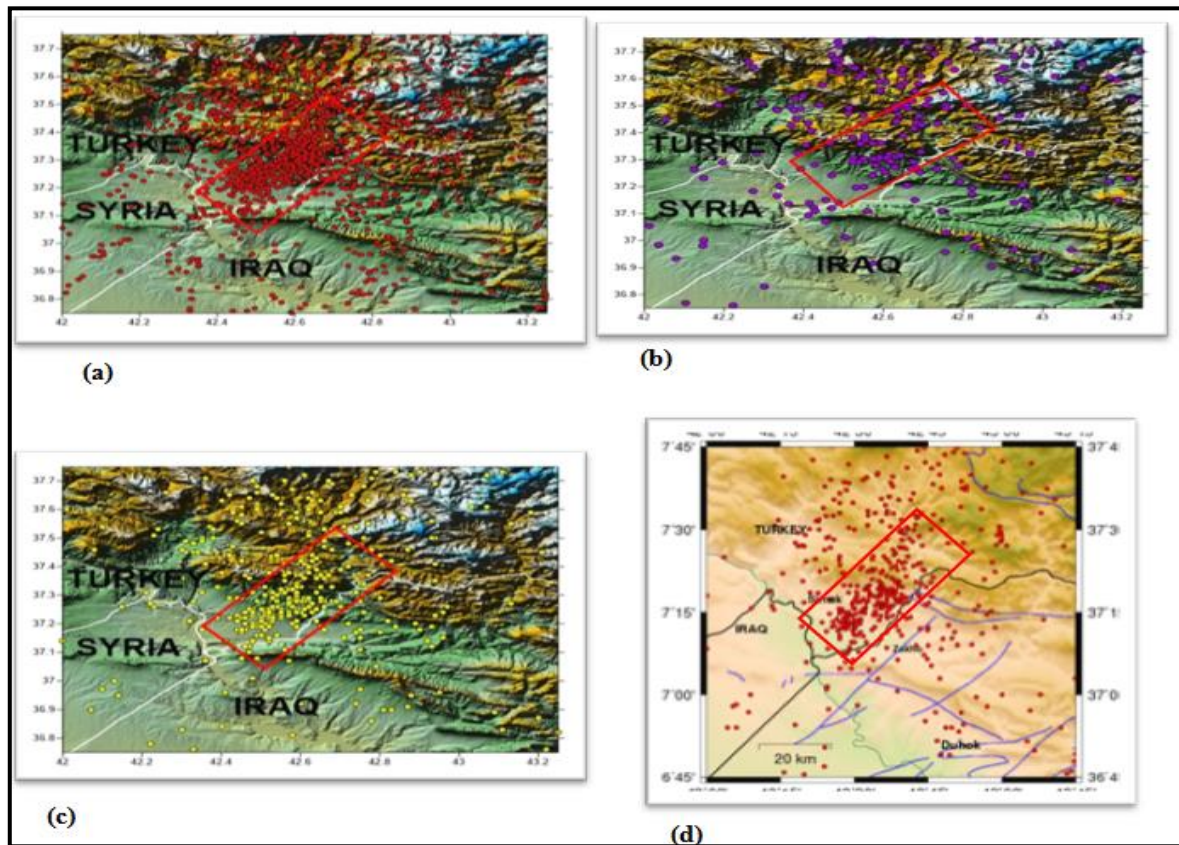


Fig. 3. The pattern of distribution of the seismic activity within the studied region between 2010 and 2020 (a) according to the International Seismological Center (ISC), (b) the Earthquake Research Institute and the Kandilli Observatory, (c) the Mediterranean-European Seismological Center (EMSC), (d) according to the European-Mediterranean Seismological Center (EMSC) for the period between 1913-2012.

Remote Sensing

GIS techniques are used to interpret and study the details of the structural geology of the Sirnak area. ArcGIS V.10.4.1 software has been used to implement the data, e.g., color composite bands (753) from Landsat 8 and 9 (USGS, 2023). As can be observed, a fault trace with a NE-SW trend is shown in the center of the study area. This fault has not been previously described due to the perpendicular direction to the boundary between tectonic plates, so that fault has a strike-slip movement (Fig. 4). There is some complexity to this strike-slip fault. Overlapping in the middle of this fault appears, which gives more information about what type that fault it is. The authors assume this to present a pull-apart basin within the fault; this type of structure occurs at different lengths, ranging from millimeters to plate boundaries (Atmaoui *et al.*, 2006). The most common mechanism for this type of fault is overlapping between two strike-slip basement faults (Aydin and Nur, 1982; Atmaoui *et al.*, 2006).

Pull-apart basins form as a result of the interaction between strike-slip faults and the regional stress field. When two segments of a strike-slip fault offset each other, the displacement creates a region of extensional (tensional) stress perpendicular to the fault plane (Fig. 4). This tensional stress causes the rocks to stretch and the crust to thin, leading to the formation of a basin-shaped depression. However, pull-apart basins are bounded by two segments of a strike-slip fault known as the restraining bend and the releasing bend. The restraining bend experiences greater friction and impedes fault motion, while the releasing bend allows for relatively freer movement. The basin forms between these two bends as the rocks are pulled apart.

Strike-slip faults are commonly associated with plate boundaries and are classified as either dextral (right-lateral) or sinistral (left-lateral) according to the direction of movement when facing the fault. Therefore, the Sirnak Fault has a left-lateral (sinistral) movement as shown in Figure 4, which is derived from Landsat 8 and 9: 742. The tectonic implication of the presence of the pull-apart basins along strike-slip faults indicates the occurrence of significant horizontal crustal movement. They are commonly associated with transform plate boundaries; therefore, the study of pull-apart basins helps geologists to understand the kinematics and dynamics of strike-slip fault systems, as well as the broader tectonic processes occurring in the Earth's lithosphere.

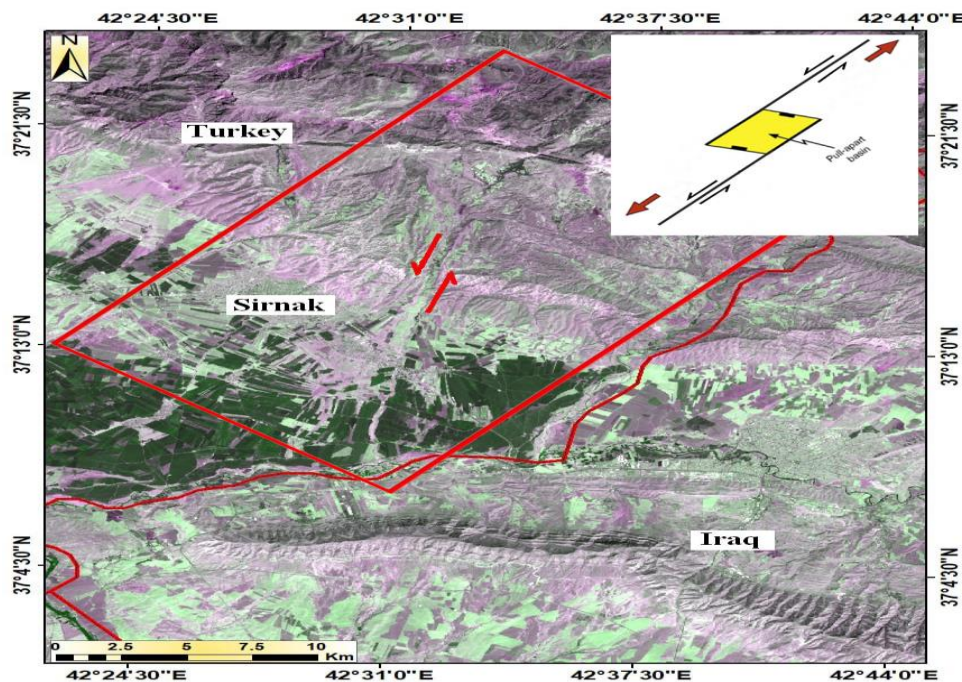


Fig. 4. Type and direction of the Sirnak Fault. The red half arrows represent strike-slip fault movement direction (left-lateral or sinistral) using Landsat 8 and 9: 753 (USGS, 2023).

Focal Mechanism Solutions

Seismic data from four events for the period from 1950 to 2024 are used to determine the focal mechanism solutions of the Sirnak region (Fig. 5). The strike-slip solution is considered the main solution as a result of two earthquakes located near the study area. There are also some solution-oriented results.

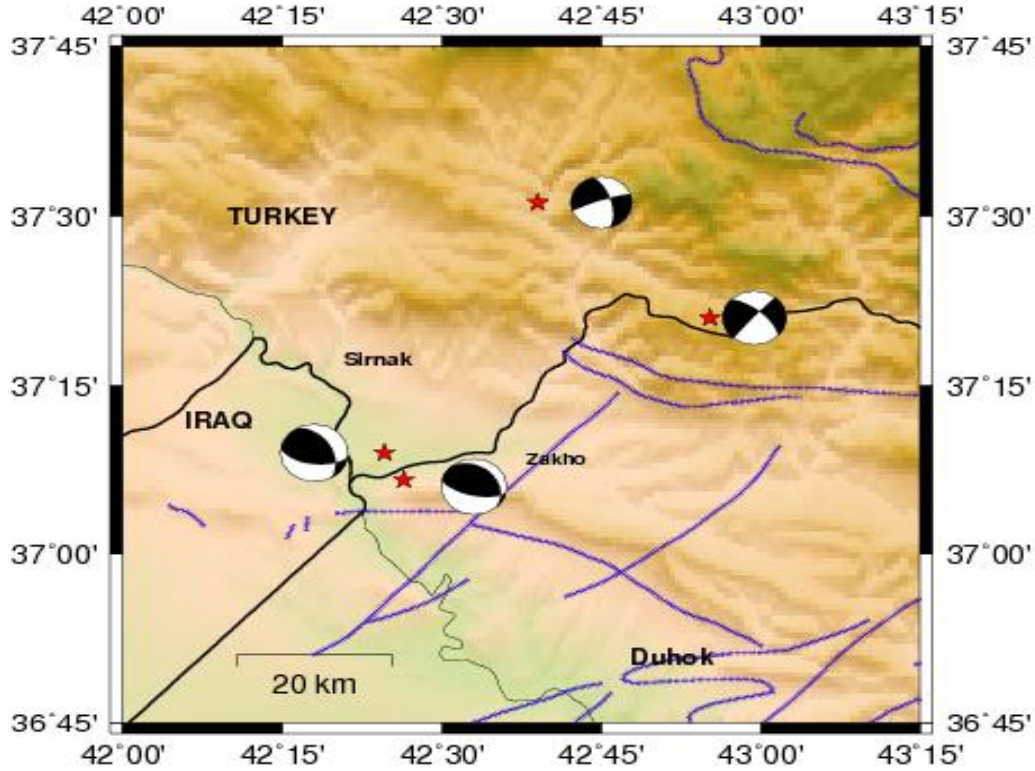


Fig. 5. Focal mechanism solutions of earthquakes in the Sirnak region by ISC based on Table (1).

Table 1: The focus mechanism solutions and source parameters of the chosen local events.

Date	O. Time UTC	Lat	Lon	Mw	Depth	Plane 1			Plane 1		
						S	D	R	S	D	R
2003-10-23	17:24:01	37.5210	42.6560	4.8	15.0	251.00	83	-27.00	344	64.00	-172
2012-06-14	05:52:53.6	37.2159	42.4833	5.2	11.3	110.88	67.01	80.48	314.12	24.79	111.30
2012-06-14	05:52:53.60	37.1100	42.4400	5.8	12.0	103.00	65.00	73.00	318.00.00	30.00	121
2012-08-05	20:37:23.40	37.3500	42.9200	5.1	22.5	221.00	87.00	-23.00	312	67.00	-177

O. Time (UTC) is origin time, D is the dip, S is strike, R is raking angle, Mw is reported magnitude moment, Lat is degree latitude, with Lon is longitude in degree.

Conclusion

The Sirnak region is among Turkey's seismically most active areas. In this paper, four focal mechanism solutions were collected by the International Seismological Center (ISC) from 1950 to 2024. It is difficult to study the region without focal mechanism solutions due to the lack of solutions for the region from seismic agencies. The strike-slip resolution can be considered the main consequence of two earthquakes. There are also some solution-oriented ones. Therefore, we relied mainly on the morphotectonic analysis of the study area. It is confirmed that there is a small fault. This fault had not been described before and was not marked on maps. It is named the Sirnak Fault, as the direction of this fault is determined. From a satellite view, it is a sinuous strike-slip fault associated with the break-up basin. But since its direction is perpendicular to the boundary between the tectonic plates, it can be said to have a sliding motion.

Based on the ISC, EMSC, and KOERI earthquake catalogs, the authors studied the distribution of earthquakes in the Sirnak area for the period between 2010 and 2020. Through the seismic history of the past years, the seismic activity of this fault has been proven. In

general, the seismic activity in the Sirnak region is the result of the collision between the Eurasian and Arabian plates.

There are many faults in the study area, but the most active is the Cizre fault in the south zone of the thrust system in Turkey. The southeast Anatolian overlap is the main tectonic structure of the Sirnak region, and faults in the eastern borders of Turkey extend to 80 km in length, which is within the borders of Iraq.

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