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Research Article

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Comparison of earthquake activities occurring in the Van region with the Bouguer anomaly map

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Abstract Turkey's landforms were determined during the period when the Arabian Plate collided with the Anatolian Plate. This process, which started the new tectonic period of the Anatolian plate, took place approximately 12 million years ago, in the period called the middle Miocene. The Anatolian plate is a region that constantly compresses and creates earthquakes. The African plate subducting under the Anatolian plate along the Hellenic-Cyprus arc causes earthquakes in Eastern Anatolia, NAF (North Anatolian fault line), EAF (Eastern Anatolian fault line) and Western Anatolia (Aegean) regions. Another big plate pushing the Anatolian plate is the Arabian plate. The Arabian plate is constantly pushing the Anatolian plate towards the west. The Anatolian plate moves from the southeast to the west of the Arabian plate at a speed of 25 mm/year. The area where Anatolia meets the Arabian plate is the Eastern Anatolian fault line. The 558 km long fault extends from Bingöl Karlıova to the Gulf of İskendurun. Here it merges with the Ölüdeniz fault, which is a continuation of the East African fault line. Fault lines are areas where large earthquakes occur. Due to earthquakes in these regions, cities may be forced to relocate due to the natural and human factors they encounter. Türkiye has been constantly under the influence of earthquakes since ancient times. Therefore, some settlements have been destroyed and some have been displaced due to the effects of earthquakes until today. The Van earthquake, one of the earthquakes in the region, was an earthquake with a magnitude of Mw = 7.2 that affected Van - Erciş and its surroundings on October 23, 2011 at 13:41 local time. The earthquake caused damage in many villages connected to the center, especially in Erciş district, the largest district of Van. The epicenter of the earthquake was approximately 24 km from Van. It is around Tabanlı village (KRDAE) located in the north (38.9N/43.5E).

Keywords Van earthquake, Anatolian plate, Tectonic structure

Introduction

To the north of the Anatolian plate is the Eurasian plate, to the south is the Arabian plate and the African plate. The African plate moves northwestward at a speed of 18 mm/year and puts pressure on the Anatolian plate. This pressure causes Anatolia to move westward. The North Anatolian Fault Line determines the border of the Anatolian plate with the Eurasian plate. On this line, Anatolia moves westward at a speed of 25 mm/year. The area where Anatolia meets the Arabian plate is the Eastern Anatolian fault line. The 558 km long fault extends from Bingöl Karlıova to the Gulf of İskendurun. Here it merges with the Ölüdeniz fault, which is a continuation of the East African fault line. Fault lines are areas where large earthquakes occur. The Arabian plate meets Eurasia at the Mediterranean floor and a subduction line is formed here. It attracts Anatolia in this area along the Hellenic and Cyprus faults, where Africa dives under Eurasia. It is thought that this pulling movement is the reason for the southwestward opening in the West of Anatolia (Figure 1). When we look at the geological structure of Turkey, it is completely under the influence of the Alpine orogenic belt. It is possible to find rocks

from every period from the Paleozoic to the present day in our country. Faulting and epeirogenic movements began in our country with the Alpine orogeny, which intensified from the end of the Oligocene to the beginning of the Miocene. During this period, areas with a hard character collapsed under pressure by being torn apart by faults. While new fault lines were formed as a result of vertical faulting in the Pliocene, old faults in the field also became younger. During this period, as tension (in the west) and compression (in the east) occurred on Anatolia, it began to shift towards the west along the Northern and Western Anatolian fault lines. Many basins were formed in this process [1]. Many devastating earthquakes have occurred in Turkey and Earthquakes have caused thousands of people to lose their lives. Türkiye is basically located in two important fault zones. The first of these constitutes the North Anatolian Fault (NAF) line, which starts from Saros Bay, passes through the Marmara Sea, Izmit, Düzce, Bolu, Merzifon, Suluova, Erbaa, Niksar and Kelkit valley and extends to Varto (Muş). The second is the Eastern Anatolian Fault (EAF) line, which passes through the Red Sea and the Dead Sea from the south of our country, enters the country's borders from Antakya, passes through Kahramanmaraş, Pazarcık, Hazar Lake and Bingöl and joins the NAF in Varto. Apart from these, grabens extend east-west in the Aegean Region, and around Lake Van in Eastern Anatolia, There are many faults in Erzurum, Malazgirt, Pasinler and Horasan [1, 2, 3]. The Bitlis Suture Belt developed as a result of the collision of the Eurasian continent with the Arabian continent after the Bitlis ocean, which formed the Çüngüş basin, completed its closure in the late Middle Miocene [4, 5, 6]. As a result of this collision, the Eastern Anatolia Region began to have a new morphology, and a peneplain or a morphology close to peneplain was replaced by large tectonic structures and volcanic elevations [7]. In the region, as a result of N-S woolly compression and intense volcanic activity, a series of east-west trending down and fold belts have developed, and the areas between the uplifts are limited by strike-slip faults as a product of the compressional regime [7,8]. (Şaroğlu and Güner, 1981; Koçyiğit, 2005).

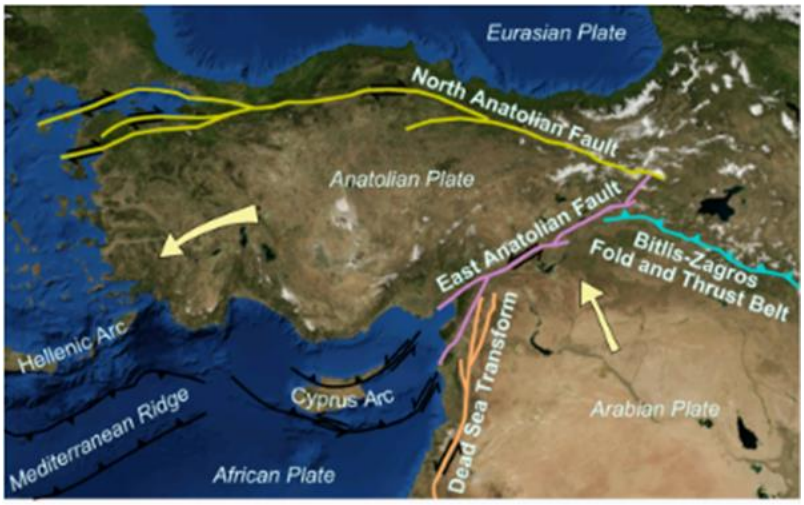

Figure 1: Turkey's active tectonic lines [9].

Geology of the region

Many rock groups of different ages, from the Paleozoic to the present day, crop out over large areas in the Van Lake Basin (Figure 2). From the south of the basin towards the west, mostly metamorphic rocks belonging to the Bitlis Massif surface [10,11, 12, 13]. The most observed rock group within the basin is the Volcanic units, which are observed in most parts of the Eastern Anatolia Region. The lavas and volcaniclastic products produced by many volcanoes such as Nemrut in the west, Süphan, Etrusk, Meydan, Girekol in the north, and Tendürek in the northwest, at different times from the Miocene to the present day, are widely distributed in the region [14, 15, 16]. In the southeast and east of the basin, there are ophiolitic units and clastic sediments belonging to the Yüksekova Complex, settled in the Upper Cretaceous-Paleocene interval. Mainly marine clastics and carbonates were deposited on these units in the Eocene-Miocene interval, and with the closure of the basins starting from the late Miocene, a completely continental environment dominated the region. In the region, Lower-Middle Miocene aged units crop out as the end products of the marine environment [17]. In the east and northeast of the basin, lake and river products deposited since the Pliocene surface on the volcanic units

in some places. Water level changes in Lake Van at the end of the Pleistocene caused the lake, river and delta sediments to be widely spread. During the same period, a widely distributed travertine unit was formed in the eastern part of the basin, around the Edremit district of Van [17]. Hillside debris and unattached fluvial sediments currently crop out in limited areas on all these units. The units observed along the fault where the main rupture took place are mostly Pliocene and Quaternary aged clastics in the SW direction, while Oligocene aged marine clastics dominate towards the NE [6].

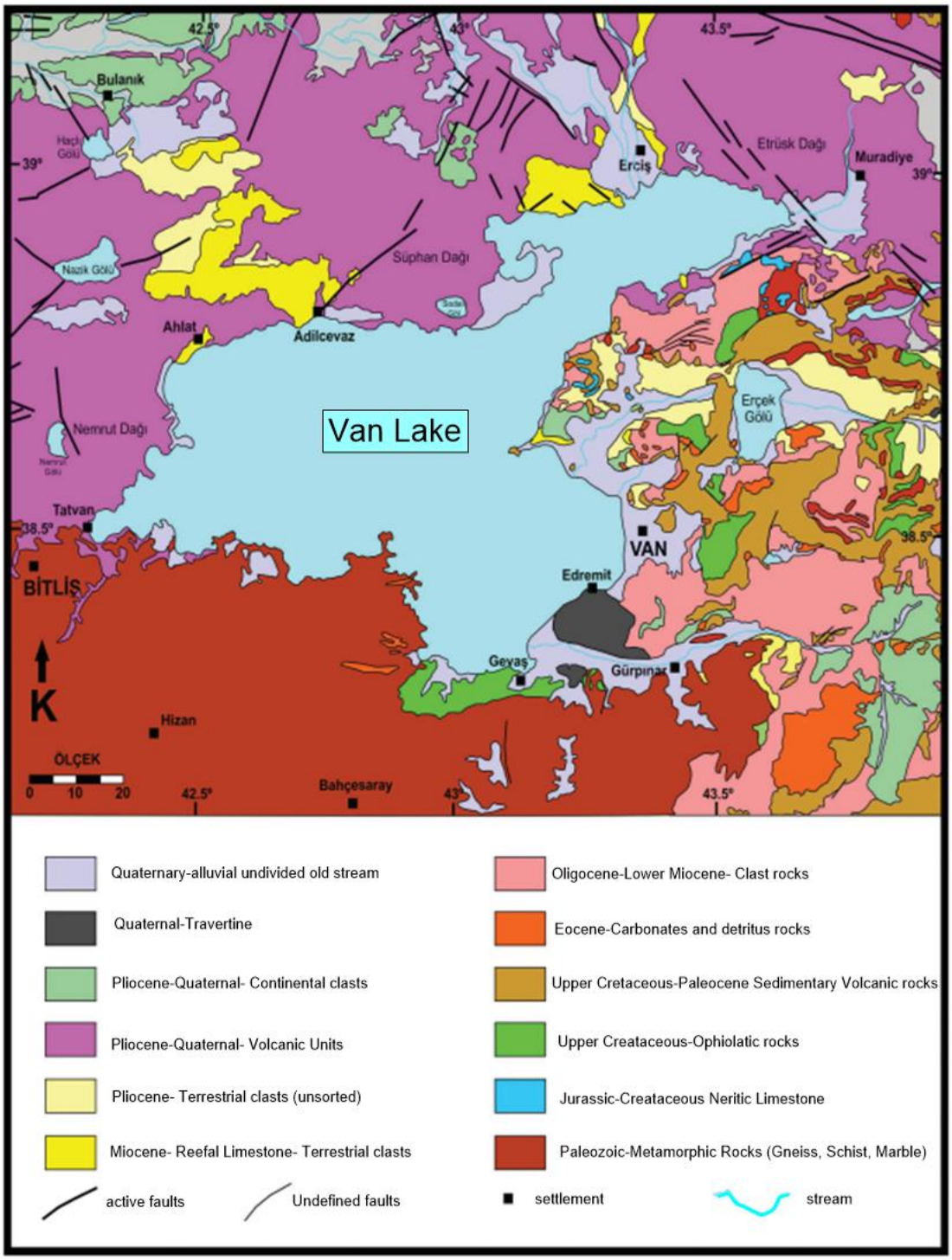

Figure 2: Geological Map of Lake Van Basin [18].

Evaluation of Van earthquake and its aftershocks

The Van (Mw= 7.2) Tabanlı-Van earthquake, which occurred at 13:41 local time on 23 October 2011, started at 38.75 East - 43.36 North coordinates given by Kandilli Observatory and moved towards the Northeast and Southwest (Figure 3). The earthquake occurred as a result of a rupture of approximately 60 km x 20 km in size, which showed the characteristics of a reverse fault. Aftershock locations also confirm this finding. The average displacement on this fault plane at a depth of approximately 10 -15 km is 2 m. No fault rupture was observed on the surface. Fault rupture took about 50 seconds. is up to The fracture direction of the fault is approximately 250 degrees to the north and the slope of the fault is approximately 35 degrees. Although the earthquake was felt in a wide area, the most significant damage and loss of life occurred in Erciş district.

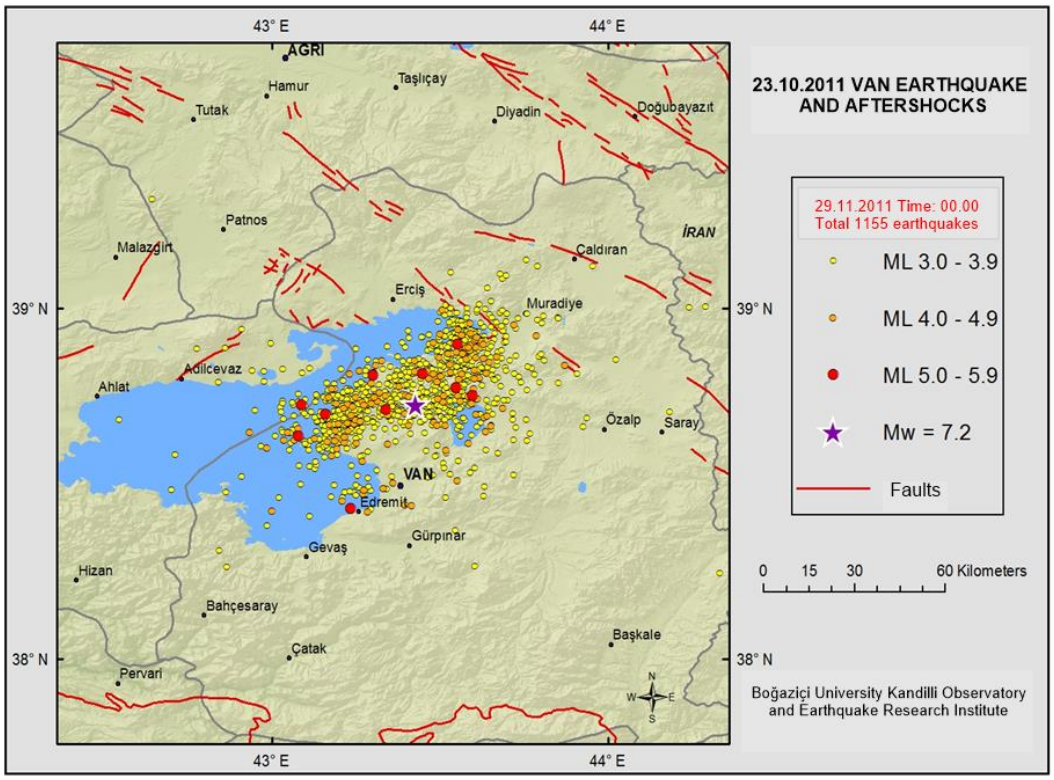

Figure 3: Aftershocks that occurred as a result of the Van earthquake

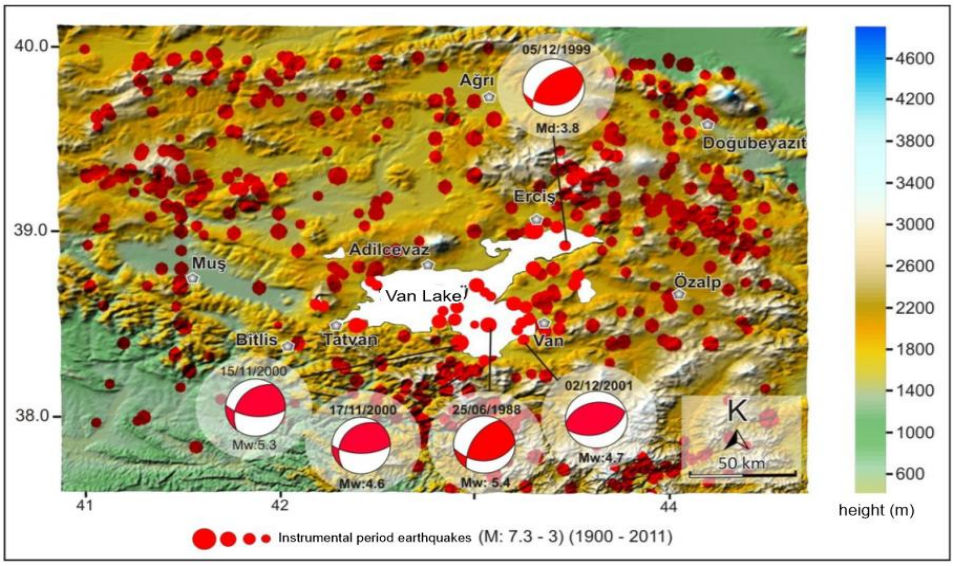

Figure 4: Instrumental period earthquakes occurring in the Van Lake Basin and its immediate surroundings and focal mechanisms of some earthquakes that have occurred in recent years (Kandilli, Usgs, Tübitak, Emsc, [19]).

Seismicity of the Region

Historical Period

Figure 4 shows the epicenter points of the earthquakes that occurred in the Van Lake Basin and its immediate surroundings in the historical period. The Van region was affected by many earthquakes in the V-X intensity range between 1101 and 1900. Along with the Van earthquakes of 1101, 1894 and 1900, the epicenter of the earthquakes of magnitude IX in 1111 and magnitude VII-VIII earthquakes, which occurred in the early 17th century and was reported to last for 4-5 years as a series of earthquakes, is given as Van city center (Figure 4). It was not possible to obtain detailed information about these earthquakes. However, it is stated in the sources that the earthquakes that occurred in Ahlat, Adilcevaz, Tatvan and Nemrut regions were also effective in the Van region. These earthquakes, which occurred in 1439 and 1441, are associated with the volcanic activities of the Nemrut Crater, located in the southwest of Lake Van. It is known that lava flowed from Nemrut Crater on these dates [20, 21]. It is also known that earthquakes with magnitudes VI and VIII, which occurred in Güzelsu (Hoşap) and its surroundings, southeast of Van city center, in the 16th and 17th centuries, also caused damage in the cities of Van and Erciş. It is said that the earthquake that occurred in 1648 destroyed villages in a large area extending from Van to Gevaş, Hoşap and Albağ [22]. It was emphasized that this earthquake, whose aftershocks lasted for about three months, also triggered landslides.

Instrumental Period

According to instrumental period records, many earthquakes with magnitudes ranging from 3 to 7.3 occurred in the Van Lake Basin and its immediate surroundings. The right-lateral strike-slip Çaldıran Fault in the northeast of Lake Van produced a 7.3 (USGS) magnitude earthquake in 1976, creating a 55 km long surface rupture; The Çaldıran earthquake represents the largest seismic activity in the region during the instrumental period. The focal mechanism results of the earthquakes that occurred in Van city center and its immediate surroundings in 1988, 1999, 2000, 2001 and 2003 mostly point to dip-slip reverse faulting (Redpuma, Kandilli, Emsc; Usgs, Tübitak). The magnitude of the earthquake that occurred in Lake Van, west of Van city center on June 25, 1988, was recorded as 5.4 (Kandilli) [19]. Focal mechanism analysis of this earthquake indicates reverse faulting with a left-lateral component (Kandilli). The focal mechanism analysis of a small-scale earthquake (Md = 3.8) that occurred in the south of Erciş and within Lake Van on 5.12.1999 indicates a NE-trending reverse fault with a left lateral component, similar to the earthquake that occurred in 1988 (Tübitak) [19]. In November 2000, earthquakes concentrated in Gevaş and its immediate vicinity occurred along a certain line. The magnitude of the earthquake that occurred on 02.12.2001 near Edremit district was determined as 4.7 by Redpuma, while according to Kandilli data, it was announced as 4.5 [19]. It is seen that the direction of the thrust component plane that created this earthquake near Edremit is close to the direction of thrust faults that are frequently encountered in the region [23]. The earthquake, which occurred at a depth of 18 km (Redpuma), did not cause any loss of life or property in the region, but damage in the form of cracks occurred in some buildings built on loose ground. While the magnitude of the earthquake that occurred on 15.11.2000 near Gevaş district was determined as 5.3 by Redpuma, it was announced as 5.7 according to Koeri data [19]. When the focal mechanism analysis of this earthquake is examined, it is seen that the movement in the region is strike-slip with a dominant thrust component (Figure 4). The earthquake, which occurred at a depth of 27 km (Redpuma), did not cause any loss of life or property in the region, but damage in the form of cracks occurred in some buildings built on loose ground. 2 days after this earthquake dated 15.11.2000, which occurred near the Gevaş district, the 4.6 (Redpuma, Koeri) magnitude earthquake, which was thought to be an aftershock of this earthquake, occurred approximately 8 km south of the main earthquake [23]. It is seen that the movement mechanism of this earthquake, which occurred at a depth of 18 km, is approximately the same as the main earthquake (Figure 4) [19].

Gravity map

When the Bouguer anomaly map of Lake Van is examined, it is seen that Samandag in the northern part of the lake and Erciş in the western part are close to -110 mgal values (Figure 5). It is seen that values reach approximately -110, -120 in the eastern part of Tatvan. It is seen that gravity values reach very low values towards the eastern part of Van province (Figure 5). The regional anomaly map of the Bouger gravity anomaly map was obtained and the discontinuity boundaries were determined by applying the first vertical derivative

method to the regional anomaly map (Figure 6). Significant earthquakes in the region were added to the first vertical derivative map of regional gravity [25].When the Bouguer anomaly map of Lake Van is examined, it is seen that Samandag in the northern part of the lake and Erciş in the western part are close to -110 mgal values (Figure 5). It is seen that values reach approximately -110, -120 in the eastern part of Tatvan. It is seen that gravity values reach very low values towards the eastern part of Van province (Figure 5). The regional anomaly map of the Bouger gravity anomaly map was obtained and the discontinuity boundaries were determined by applying the first vertical derivative method to the regional anomaly map (Figure 6). Significant earthquakes in the region were added to the first vertical derivative map of regional gravity [25].

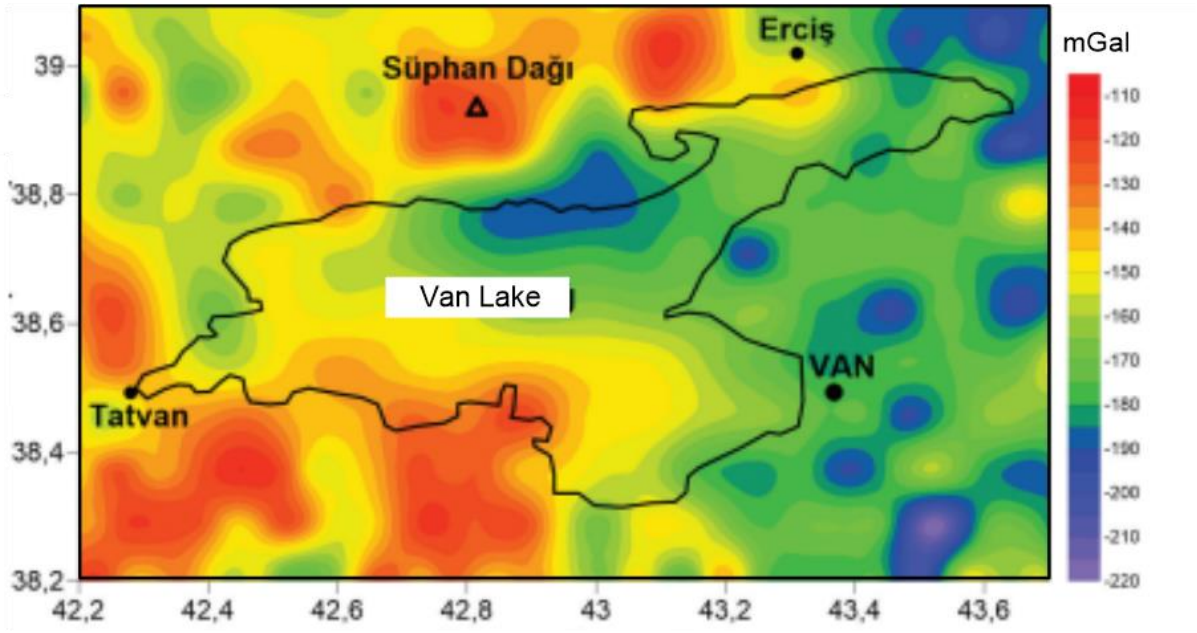

Figure 5: Bouguer anomaly map of Van Region [24].

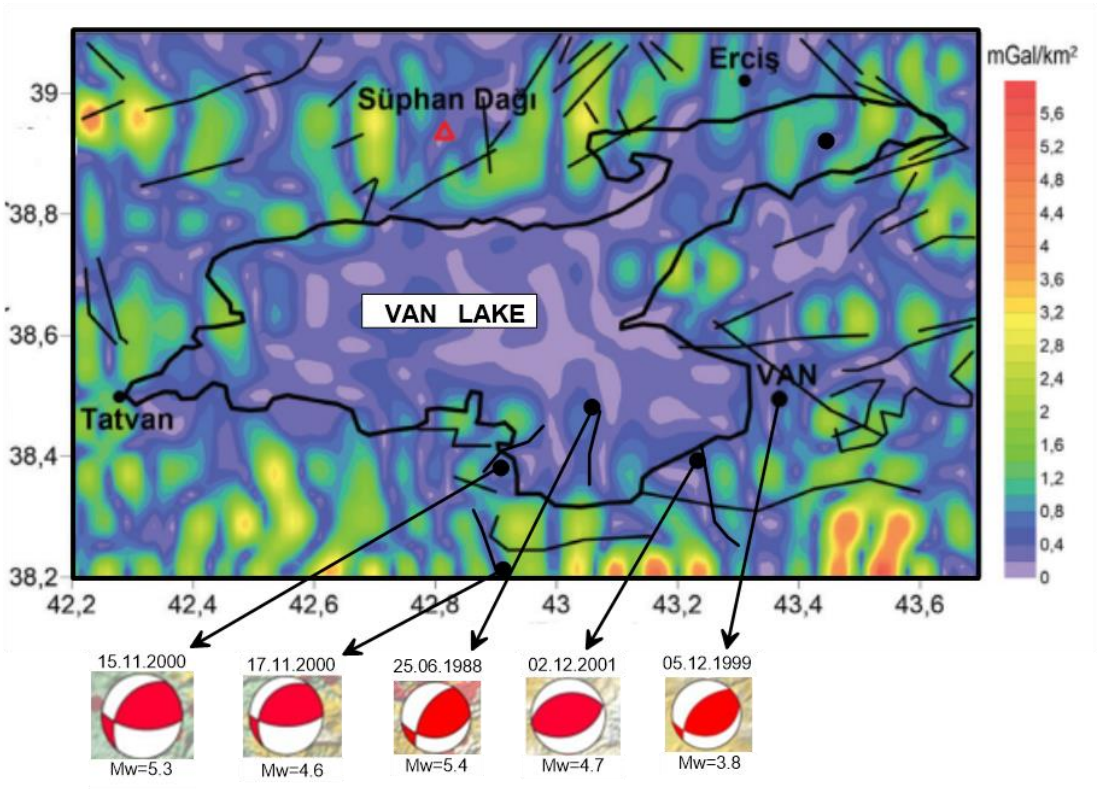

Figure 6: *First vertical derivative map of regional gravity [24].*

Conclusion

The focal mechanism results of the earthquakes that occurred in Van city center and its immediate surroundings in 1988, 1999, 2000 and 2001 mostly point to dip-slip reverse faulting. The magnitude of the earthquake that occurred on June 25, 1988, in Lake Van, west of Van city center, was recorded as 5.4. Focal mechanism analysis of this earthquake indicates reverse faulting with a left-lateral component [19]. The focal mechanism analysis of a small-scale earthquake (Md: 3.8) that occurred in the south of Erciş and within Lake Van on 5.12.1999 indicates a NE-trending reverse fault with a left-lateral component, similar to the earthquake that occurred in 1988 [19]. In November 2000, earthquakes concentrated in Gevaş and its immediate vicinity occurred along a certain line. The magnitude of the earthquake that occurred on 2.12.2001 near Edremit district was announced as 4.5, according to Kandilli data. When the focal mechanism analysis of this earthquake is examined, it is seen that the movement in the region has almost a pure thrust component [19]. It is seen that the direction of the thrust component plane that created this earthquake near Edremit is close to the direction of thrust faults that are frequently encountered in the region [23]. The earthquake, which occurred at a depth of 18 km, did not cause any loss of life or property in the region, but damage in the form of cracks occurred in some buildings built on loose ground. The magnitude of the earthquake that occurred on 15.11.2000 near the Gevaş district was announced as 5.7 according to Koeri data. When the focal mechanism analysis of this earthquake is examined, it is seen that the movement in the region is strike-slip with a dominant thrust component [19]. Gevaş 2 days after this earthquake dated 15.11.2000, which occurred near the district, the 4.6 magnitude earthquake, which was thought to be an aftershock of this earthquake, occurred approximately 8 km south of the main earthquake [23]. It is seen that the movement mechanism of this earthquake, which occurred at a depth of 18 km, is approximately the same as the main earthquake (Figure 6). Vertical derivative gravity data of the region was used by [24] to determine the discontinuity boundaries in the region (Figure 6). The boundaries of the main tectonic units in the study area have been revealed [24].

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