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RATES OF CRUSTAL DEFORMATION IN EASTERN ANATOLIA

Doğu Anadolu'da Kıtasal Deformasyon Miktarları

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ABSTRACT

In this study, rates of crustal deformation of Eastern Anatolia was investigated by using the earthquakes located in the region between 35° N - 44° N latitude and 34° E - 46° E longitude. Eastern part of North Anatolian Fault Zone (NAFZ), Northeast Anatolian Fault Zone (NEAFZ), East Anatolian Fault Zone (EAFZ) and Çaldıran Fault Zone (CFZ) are selected as seismotectonic zones with high seismic activity. Fault plane solutions of 70 earthquakes occurred in investigated region with magnitude of 5.0 and higher are carried out.

Symmetric moment tensor method is applied to determine the crustal deformation type and to calculate deformation rates for defined seismotectonic zones in Eastern Anatolia by using the fault plane solution results. The results show that the deformation in the eastern part of NAFZ is taken up by extension on EW direction 28 mm/yr and as contraction an NS direction at a rate of 18 mm/yr. The average right-lateral displacement rate is about 33 mm/yr. In the EAFZ, the deformation is taken up as nearly NS contraction at a rate of 17.80 mm/yr and as nearly EW extension at a rate of about 7.5 mm/yr. The average left-lateral motion has a rate of about 3.5 mm/yr. The deformation rate in NEAFZ is 20 mm/yr with contraction in the NS direction and left-lateral displacement rate is 2.5 mm/yr justifying the left-lateral strike-slip fault mechanism. NS contraction rate CFZ is 40 mm/yr. Right-lateral deformation rate in CFZ having right-lateral strike-slip fault mechanism is calculated as 15 mm/yr. As a result of NS contraction in all zones, thickening rates are found as 0.16 mm/yr in eastern part of NAFZ, 0.12 mm/yr in NEAFZ, 0.40 mm/yr in EAFZ and 1.15 mm/yr in CFZ, respectively.

ÖZET

Bu çalışmada, 35° K - 44° K enlemleri ve 34° D - 46° D boylamları arasında kalan bölgede yer alan depremler kullanılarak Doğu Anadolu nun kıtasal deformasyon miktarları incelenmiştir. Deprem etkinliğinin yoğun olduğu sismotektonik zonlar, Kuzey Anadolu Fay Zonu nun doğusunda kalan bölge (KAFZ), Kuzeydoğu Anadolu Fay Zonu (KDAFZ), Doğu Anadolu Fay Zonu (DAFZ) ve Çaldıran Fay Zonu (CFZ) olarak belirlenmiştir. İnceleme alanında meydana gelmiş magnitüdü 5.0 ve daha büyük 70 depremin odak mekanizması çözümlemeleri yapılmıştır.

Belirlenen sismotektonik zonlarda kıtasal deformasyon biçimlerinin ve miktarlarının belirlenmesinde simetrik moment tensör yöntemi, Doğu Anadolu Bölgesi depremlerinin fay düzlemi çözümlerinden elde edilen parametreler kullanılarak uygulanmıştır. Sonuçlar göstermiştirki, Kuzey Anadolu Fay Zonunun doğusunda DB uzamanın miktarı 28 mm/yıl ve KG sıkışmanın miktarı 18 mm/yıl olarak bulunmuştur. Ortalama sağa yanal kayma miktarı 33 mm/yıl dır. Doğu Anadolu Fay Zonunda, KG sıkışmanın deformasyon miktarı 17.80 mm/yıl ve DB uzamanın miktarı 7.5 mm/yıl olmuştur. Ortalama sola yanal kayma miktarı 3.5 mm/yıl dır. Kuzeydoğu Anadolu Fay Zonunda, KG yönünde sıkışmanın deformasyon miktarı 20 mm/yıl ve sol yönlü doğrultu atımlı faylanma mekanizmalı bu zonun sola yanal kayma miktarı 2.5 mm/yıl olmuştur. Çaldıran Fay Zonunda, KG sıkışmanın deformasyon miktarı 40 mm/yıl dır. Sağ yönlü doğrultu atımlı faylanma mekanizmalı Çaldıran Fay Zonunda sağa yanal kayma miktarı 15 mm/yıl olarak hesaplanmıştır. Bütün zonlarda meydana gelen KG sıkışmanın neticesinde, kalınlaşma miktarları, Kuzey Anadolu Fay Zonunun doğusunda, 0.16 mm/yıl, Kuzeydoğu Anadolu Fay Zonunda, 0.12 mm/yıl, Doğu Anadolu Fay Zonunda, 0.40 mm/yıl, ve Çaldıran Fay Zonunda, 1.15 mm/yıl olarak bulunmuştur. Fay Zonunda, 1.15 mm/yıl olarak bulunmuştur

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INTRODUCTION

Northward motion of the Arabian plate relative to Eurasia causes lateral escape of the Anatolian block to the west (Ketin, 1948; McKenzie, 1972; Şengör, 1979) and the Northeast Anatolian block to the east. The North Anatolian fault and the East Anatolian fault constitute the northern and southern boundaries, respectively, of the westward moving Anatolian block. The motion of the Northeast Anatolian block is complicated by extensive internal deformation of the block along conjugate faults.

The North Anatolian Fault Zone is a 1500 km long seismically active right-lateral strike-slip fault that takes up the relative motion between the Anatolian block and Black Sea plate. This fault zone extends from the Karlıova triple junction as far as mainland Greece. Focal mechanisms for moderate and large earthquakes along this portion of the fault zone are mostly pure right-lateral strike-slip solutions (Canıtez and Üçer, 1967; McKenzie, 1972; Bağcı, 1994). Rates of slip along the North Anatolian Fault zone are estimated at 50-80 mm/yr from geological observations (Tokay, 1973; Seymen, 1975; Barka and Hancock, 1984).

Relative motion between the Anatolian Block and the Arabian plate is taken up by the left-lateral East Anatolian Fault Zone. This fault zone extends from the Karlıova triple junction (39.3° N, 41.1° E) to the Mediterranean. The East Anatolian Fault Zone is similar in many ways to the North Anatolian Fault Zone. It is characterized by a series of major discontinuities.

The Northeast Anatolian block, a wedge-shaped region located to the east of 39° E, is bounded by the Northeast Anatolian Fault to the north and by the North Anatolian Fault Zone to the south. East of 41.5° E this southern boundary disappears; it is no longer defined by surface morphology or seismological observations (Tchalenko, 1977). The Northeast Anatolian block differs from the Anatolian block to the west in that most of the strain is released along major boundary faults. Internal deformation in the Northeast Anatolian block occurs along the following structures; (1)north-northeast-south-southwest and/or northeast-southwest trending left-lateral strike-slip faults, (2)northwest-southwest trending right-lateral strike-slip faults, (3)east-west trending thrust and folds, and (4) north-south trending extension cracks (Arpat et al., 1977; Şengör, 1980; Şaroğlu and Güner, 1981, Şaroğlu, 1985).

SEISMICITY OF EASTERN ANATOLIA

Eastern Anatolia is located between the Eurasian, African and Arabian plates. It is squeezed and driven by the stresses exerted on it through the northward movements of the Arabian and African plates. Major tectonic elements of Turkey and adjacent areas are illustrated in Figure 1. The earthquake epicenters, covering the period 1900-1995, delineate the major fault zones and show the great activity and seismicity in Eastern Anatolia.

The North Anatolian Fault zone, which extends along the boundary between the Eurasian plate in the north and the

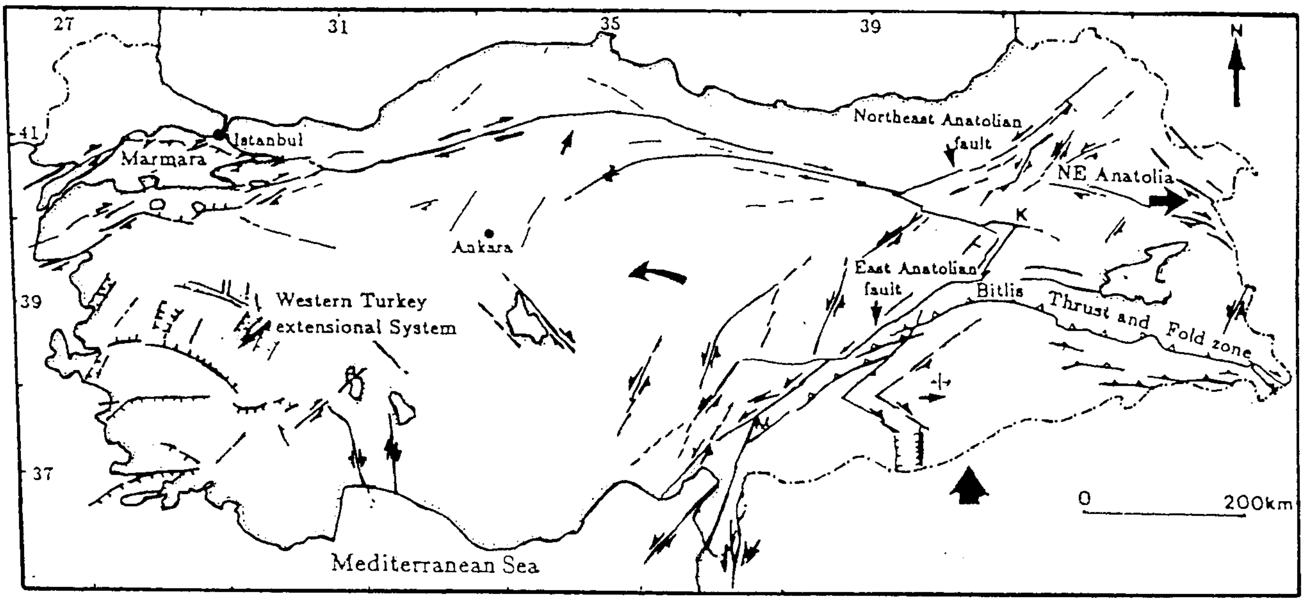


Fig 1. Major tectonic elements of Turkey and adjacent area (Barka and Kadinsky-Cade, 1988).
Şekil 1. Türkiye ve civarının esas tektonik elemanları (Barka ve Kadinsky-Cade, 1988).

Turkish plate in the south, is a major tectonic feature with a well defined fault trace, and an established history of seismicity (Ketin, 1968, 1976; Allen, 1969; Ambraseys, 1970; Dewey, 1976; Şengör, 1979; Toksöz et al., 1979). West of 31° E longitude the fault appears to break in two, or possibly three segments. In this region, the earthquake mechanisms show a north-south tension component in addition to the dominant right-lateral strike-slip component.

Another feature in the area is the Southeast Anatolian Thrust zone, also known as Bitlis Thrust zone. It is the collision zone of the Arabian platform with Eurasia (Baysal, 1977; Şengör and Canıtez, 1982). The thrust type source mechanisms of Lice earthquake (September 6, 1975) on this thrust belt support the convergence of the Arabian and Anatolian plates (Toksöz, 1979).

There are two important fault zones in Eastern Anatolia in addition to East Anatolian Fault zone: Northeast Anatolian Fault and Çaldıran Fault. They are characterized by moderate seismicity, but earthquake mechanisms are not well established. An earthquake on the Çaldıran Fault had a fault plane solution with right-lateral strike-slip fault mechanism. The Northeast Anatolian Fault zone, which extends in NE-SW direction, has same fault plane solutions. The source mechanism solutions and surface ruptures show that the main faulting took place on a left-lateral strike-slip fault.

METHOD OF ANALYSIS

The analysis is based on Kostrov's (1974) formulation according to which, the average strain rate of seismic deformation in a region can be defined as:

$$\overset{*}{\varepsilon}_{ij} = 1 \;/ (2 / \mu VT) \{ \sum M_{ij} \} \tag{1}$$

where $\sum M_{ij}$ is the sum of symmetric moment tensors of N earthquakes in the seismogenic volume V of the deforming zone of rigidity μ in time T. This formula is applicable to the case in which the margins of the deforming zone are in the far-field and thus the method estimates the rate of irrotational strain due to slip on faults with a variety of orientations. The area studied is considered as a rectangular deforming region of thickness Z in the vertical (z) direction bounded by sides of lengths X and Y in the two horizontal directions x and y. A coordinate frame is used with the x=north, y=east and z=down directions positive.

The six elements of the seismic moment tensor for each fault plane solution, were obtained, using the relation

$$M_{ij} = M_0 (u_i n_j + u_j n_i) \tag{2}$$

where M_{ij} is the moment tensor, M_0 is the scalar moment, and u and n are unit vectors in the direction of the slip vector and the normal to the fault plane, respectively (Aki and Richards, 1980). Then, following the formulations developed in Jackson and McKenzie (1988), and using the abovementioned coordinate system the components of the rate of deformation were calculated directly from the moment tensors. The extent to which deformation is taken up by movement of material in the x direction is given by the following equation:

$$U_x^x = (1 / 2\,\mu l t T) \sum_{j=1}^{N} M_{11} \tag{3}$$

where μ=3x1011 dyne/cm^2, l is the length of the deforming zone, T is the time of observations, and t is the thickness of the seismogenic layer.

The extent to which deformation is taken up by movement of material in the y direction is calculated by M22, since

$$U_x^y = (1 / 2\,\mu T \alpha t) \sum_{j=1}^{N} M_{22} \tag{4}$$

where α is now the width of the deforming zone.

So, the rate of thickening in the seismogenic layer is given by the component of the moment tensor M33,

$$U_z^z = (1 / 2\,\mu T \alpha l) \sum_{j=1}^{N} M_{33} \tag{5}$$

As is stated in Jackson and McKenzie (1988) the off-diagonal terms of the moment tensor do not have simple physical meaning. But if the length, l, of the deforming zone is much greater than its width, α, then some components of the tensor do have physical sense. In this respect, the horizontal shear velocity is determined by the equation

$$U_y^x = (1 / \mu \tau t l) \sum_{j=1}^{N} M_{12} \tag{6}$$

Similarly, the gradients of the horizontal velocity in the vertical direction are given by the equations

$$U_z^x = (1 / \mu \alpha l T) \sum_{j=1}^{N} M_{13} \tag{7}$$

$$U_y^x = (1 / \mu \alpha l T) \sum_{j=1}^{N} M_{23} \tag{8}$$

REQUIRED DATA

The data used in this study consist of all the earthquakes with M ≥ 5.0 that occurred in the eastern Anatolia during the period 1900-1995. The catalogues of ISC (International Seismological Center) and ISS (International Seismological Summary) were used to identify the magnitude of earthquake data. For some earthquakes, Ms were not reported. In that case, the body wave Mb magnitudes were converted to Ms magnitude using the formula:

$$M_s = 1.46Mb - 2.29 \quad (9)$$

that was developed for earthquakes in Turkey (Can, 1982). The scalar moment data listed in Table 1 are used to determine the log-linear regression line betwen seismic moment and surface magnitude. The 17 known moment values are plotted in Figure 2 and the least-squares fit for the Log M_0, M_s data is:

$$\text{Log } M_0 = 1.36\ M_s + 15.20 \quad (10)$$

The fault plane solutions used are shown in Figure 3, using a lower hemisphere equal area projection. It can be seen that all the focal mechanisms along the entire length of the NAFZ indicate dextral strike-slip faulting. The pattern changes east of the junction of the fault with EAFZ, near Karlıova, and the fault plane solution of the Varto earthquake of 1966 shows mainly thrusting associated with dextral-lateral strike-slip.

The thickness of the seismogenic layer was assumed to be 15 km in all cases, based on previous work (Kiratzi , 1993).

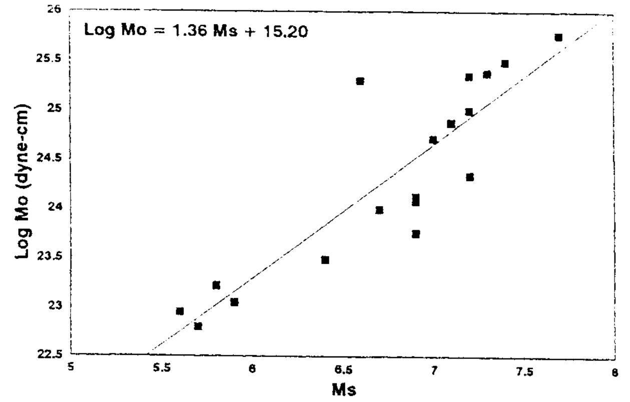


Fig. 2. Relationship between M_s and M_0 values for earthquakes in Eastern Anatolia.

Şekil 2. Doğu Anadolu da depremlerin $M_s$ve M_0 değerlerinin ilişkisi.

Table 1. M_0 values which are used to obtain Log M_0 = 1.36 M_s + 15.60.

Çizelge 1. Log M_0 = 1.36 M_s + 15.20 denkleminin bulunmasında kullanılan M_0 değerleri.

Date	M_S	M_0 (dyne-cm)	References
26.12.1939	7.7	5.80×10^{25}	Jackson and McKenzie (1988)
26.11.1943	7.3	2.40×10^{25}	Jackson and McKenzie (1988)
01.02.1944	7.4	3.10×10^{25}	Jackson and McKenzie (1988)
18.03.1953	7.2	1.00×10^{25}	Taymaz et al. (1991a)
14.06.1964	5.7	6.30×10^{24}	Taymaz et al. (1991b)
19.02.1968	7.2	2.24×10^{25}	Kriatzi et al (1991)
22.05.1971	6.9	5.80×10^{25}	Taymaz et al. (1991b)
27.03.1975	6.6	2.00×10^{25}	Taymaz et al. (1991a)
06.09.1975	6.7	1.00×10^{24}	Nabelek (1984)
19.12.1981	7.2	2.24×10^{24}	Kriatzi et al (1991)
27.12.1981	6.4	3.09×10^{23}	Kriatzi et al (1991)
18.01.1982	6.9	1.35×10^{24}	Kriatzi et al (1991)
05.07.1983	5.8	1.65×10^{23}	Ekstrom and England (1989)
06.08.1983	6.9	1.20×10^{24}	Ekstrom and England (1989)
05.05.1986	5.9	1.12×10^{23}	Taymaz et al. (1991b)
06.06.1986	5.6	9.00×10^{22}	Taymaz et al. (1991b)
13.03.1992	7.0	5.20×10^{24}	PDE USGS listings

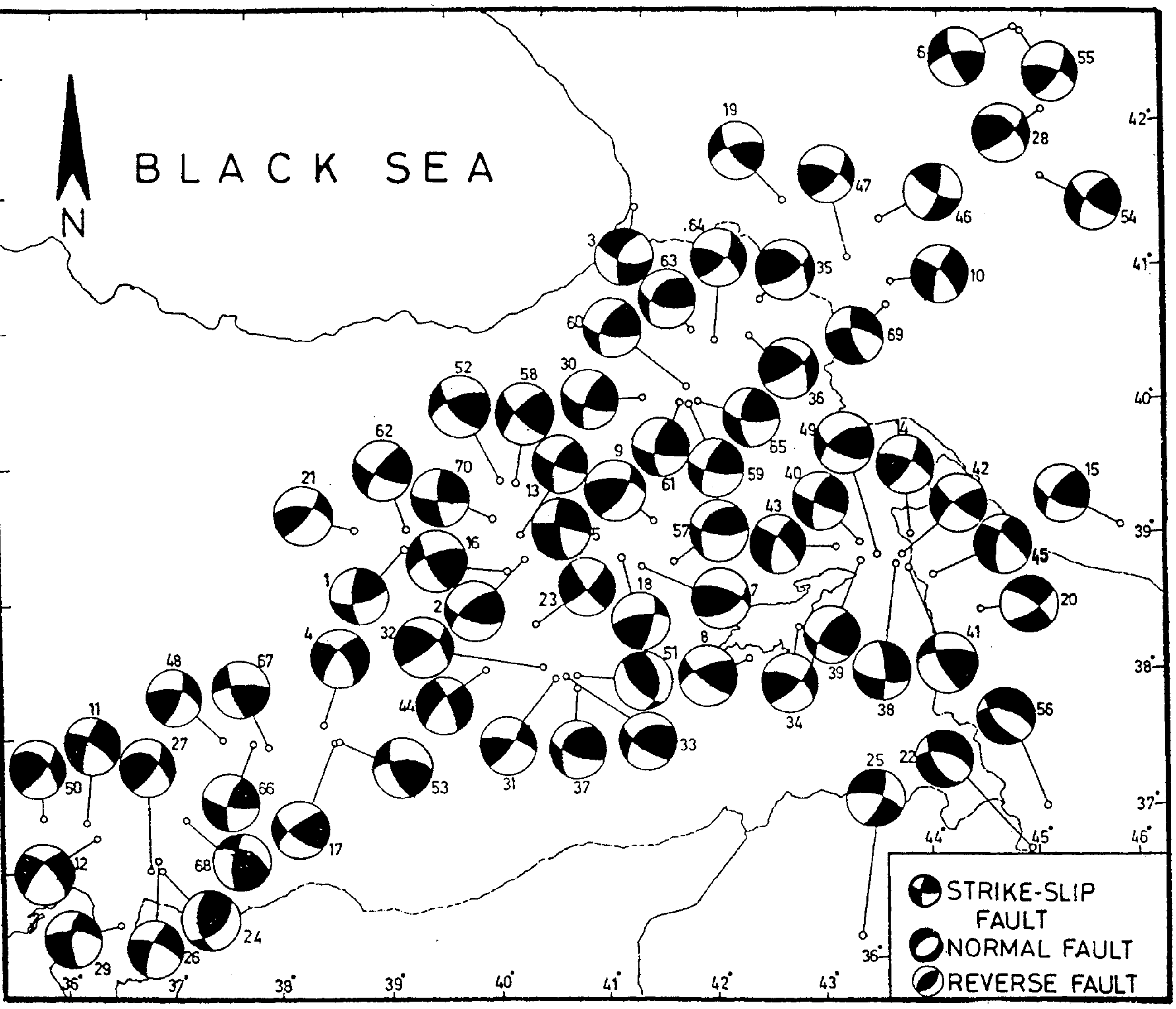


Fig. 3. Diagrams of the fault plane solutions for Eastern Anatolia (Bağcı, 1994).
Şekil 3. Doğu Anadolu da incelenen depremlerin fay düzlemi çözümleri haritası (Bağcı, 1994).

DEFORMATION RATES

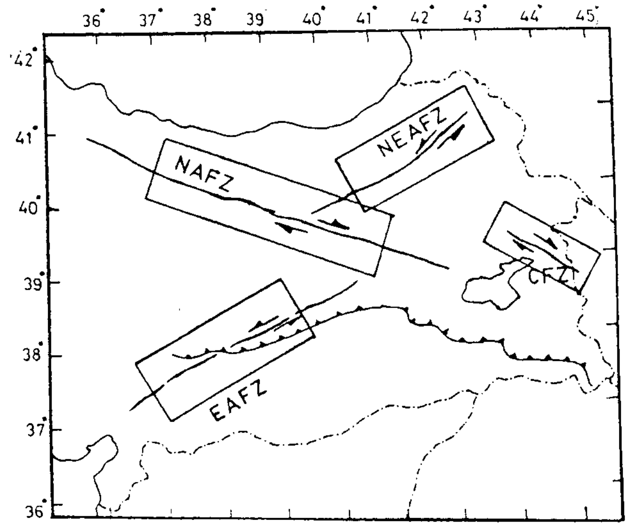
North Anatolian Fault zone, Northeast Anatolian Fault zone, East Anatolian Fault zone and Çaldıran Fault zone are determined as deforming zones in Eastern Anatolia as shown in Figure 4.

North Anatolian Fault Zone

The North Anatolian Fault zone is seismically active right-lateral strike-slip fault that takes up the relative motion between the Anatolian block and Black Sea plate.The fault plane solutions of earthquakes used in the calculations are listed in Table 2. The fault plane solutions used are shown in Figure 5, using a lower hemisphere equal area projection. The total dimension of the deformed volume of North Anatolian Fault zone in the NS and EW directions is about 40 km and 300 km respectively. Using a seismogenic layer of 15 km the following strain rate tensor is calculated for the time span observations, 1939-1982.

$$\begin{bmatrix} -60.27 & 54.86 & 16.35 \\ 54.86 & 46.30 & 8.19 \\ 16.35 & 8.19 & 14.01 \end{bmatrix} \times 10^{-9} / \mathrm{yr} \qquad (11)$$

It is observed that the dominant components of the tensor are e^*_{11} and e^*_{22} corresponding to 18.08 mm/yr of contraction in the NS direction and 28.0 mm/yr of extension in the EW direction. The tensor also revelas that the average



NAFZ : **NORTH ANATOLIAN FAULT ZONE**
NEAFZ : **NORTHEAST ANATOLIAN FAULT ZONE**
EAFZ : **EAST ANATOLIAN FAULT ZONE**
CFZ : **ÇALDIRAN FAULT ZONE**

Fig. 4. Location of studied deforming zones.
Şekil 4. Çalışılan deformasyon zonlarının bulduru haritası.

right-lateral shear motion in the EW direction is 33.0 mm/y The thickening of the seismogenic layer corresponds to approximately 0.16 mm/yr.

Northeast Anatolian Fault Zone

The Northeast Anatolian block, a wedge-shaped region located to the east of 39° E, is bounded by the Northeast Anatolian fault to the north and by the North Anatolain Fault zone to the south. The fault plane solutions of earthquakes located on the Northeast Anatolian Fault Zone used in the calculations are listed in Table 3. The fault plane solutions of the earthquakes located in NEAFZ used are shown in Figure 6. The length and the width of the deforming zone are 300 km in the EW direction and 40 km in the NS directions, respectively, then the strain rate tensor is

$$\begin{bmatrix} -66.94 & 29.44 & -33.52 \\ 29.44 & 59.26 & 23.52 \\ -33.52 & 23.52 & 7.73 \end{bmatrix} \text{X } 10^{-9} / \text{yr} \qquad (12)$$

It is observed that the dominant components of the tensor are again e^*_{11} and e^*_{22} corresponding to 20.0 mm/yr of contraction in the NS direction and 2.40 mm/yr of extension in the EW direction. The tensor also reveals that the average right-lateral shear motion in the EW direction is 2.50 mm/yr. The thickening of the seismogenic layer corresponds to approximately 0.12 mm/yr.

East Anatolian Fault Zone

Relative motion between the Anatolian Block and the Arabian plate is taken up by the left-lateral East Anatolian Fault Zone. East Anatolian Fault Zone is similar in many ways to the North Anatolian Fault Zone. The fault plane solutions of earthquakes located in EAFZ used in the calculations are listed in Table 4. The fault plane solutions of earthquakes used are shown in Figure 7. The length and the width of the deforming zone are 400 km and 40 km, respectively, then the strain rate tensor is:

Table 2. Earthquakes of the period 1939-1992, occurred in North Anatolian Fault Zone.
Çizelge 2. 1939-1992 yılları arasında Kuzey Anadolu Fay Zonunda olan depremler.

Date	Strike	Dip	Rake	M (dyne-cm)	References
26.12.1939	117.4	77.3	157.6	5.80×10^{25}	Bağcı (1994)
20.12.1942	118.0	90.0	180.0	0.45×10^{27}	Jackson and McKenzie (1988)
31.08.1965	286.9	75.6	-165.0	0.15×10^{23}	present study
07.03.1966	296.4	79.9	-157.7	0.19×10^{23}	present study
27.04.1966	295.8	78.4	-157.5	0.79×10^{22}	present study
19.08.1966	45.0	58.0	150.0	0.16×10^{27}	Stewart and Kanamori (1982)
26.07.1967	103.7	88.8	156.5	0.10×10^{24}	present study
10.09.1969	104.7	89.3	121.4	0.19×10^{23}	present study
03.09.1970	297.2	76.6	-146.6	0.79×10^{22}	present study
12.01.1976	127.8	85.5	113.5	0.79×10^{22}	present study
18.11.1983	291.7	61.9	-108.8	0.79×10^{22}	present study
20.05.1989	296.5	77.3	-143.2	0.79×10^{22}	present study
13.03.1992	304.0	84.0	-163.0	0.52×10^{25}	PDE USGS listings
15.03.1992	326.0	77.0	159.0	0.80×10^{23}	PDE USGS listings

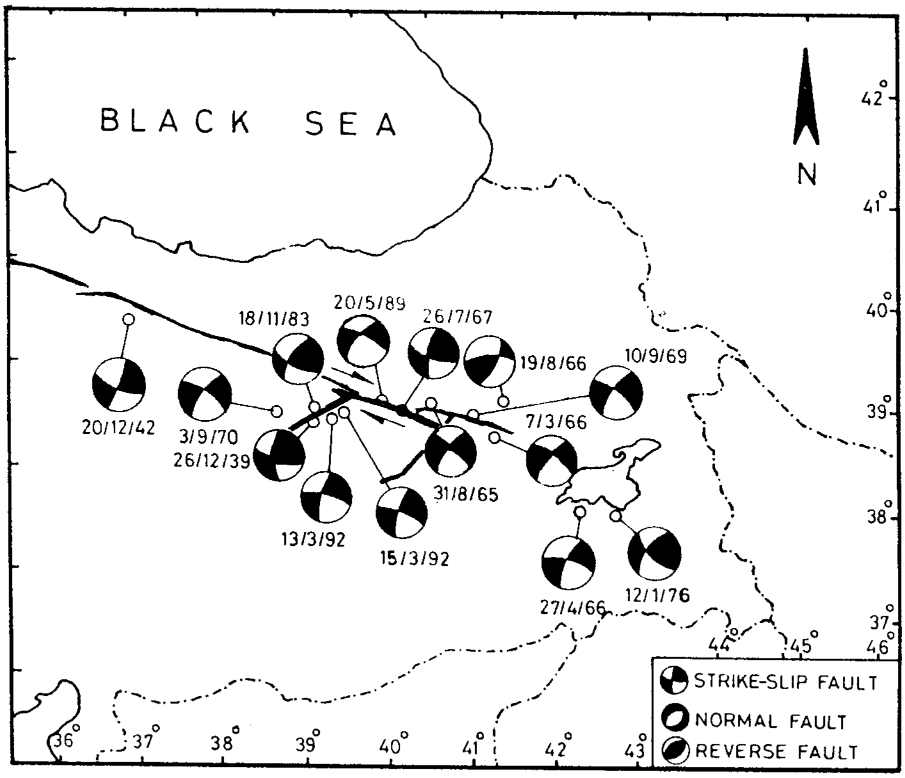


Fig. 5. Fault plane solutions of the earthquakes located in North Anatolian Fault Zone.
Şekil 5. Kuzey Anadolu Fay Zonunda olan depremlerin fay düzlemi çözümleri haritası.

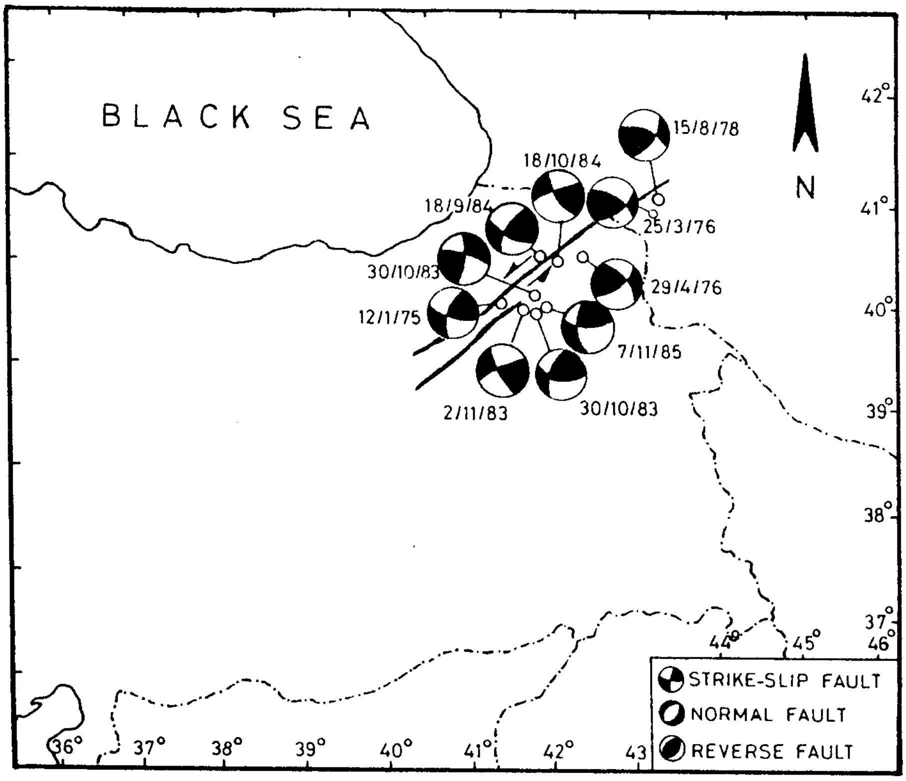


Fig. 6. Fault plane solutions of the earthquakes located in Northeast Anatolian Fault Zone.
Şekil 6. Kuzeydoğu Anadolu Fay Zonunda olan depremlerin fay düzlemi çözümleri haritası.

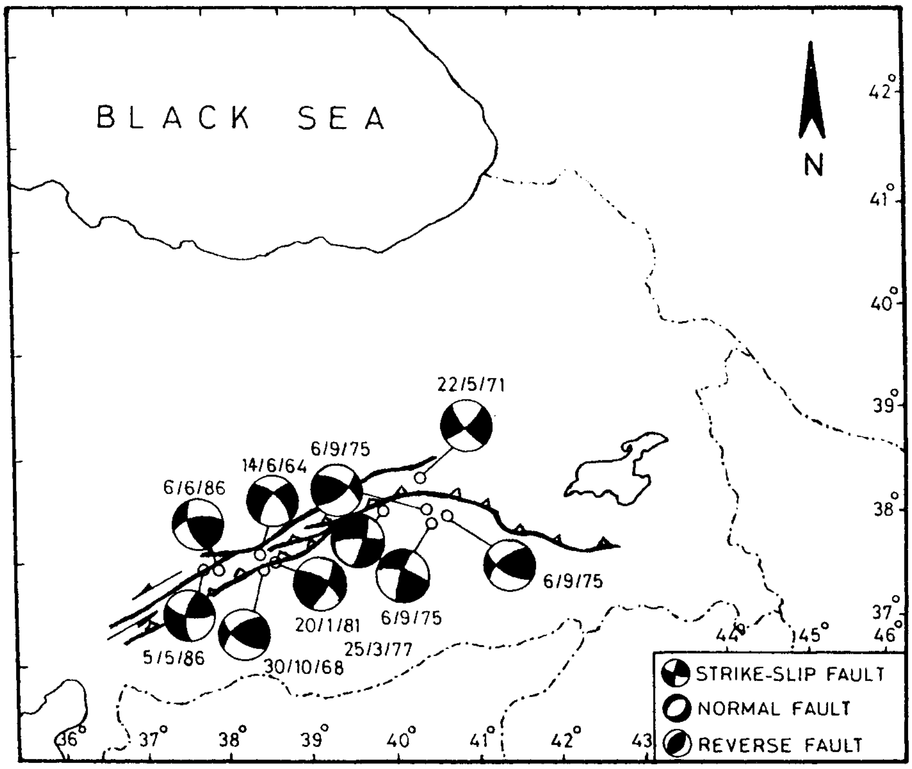


Fig. 7. Fault plane solutions of the earthquakes located in East Anatolian Fault Zone.
Şekil 7. Doğu Anadolu Fay Zonunda olan depremlerin fay düzlemi çözümleri haritası.

Table 3. Earthquakes of the period 1975-1985, occurred in Northeast Anatolian Fault Zone.
Çizelge 3. 1975-1985 yılları arasında Kuzeydoğu Anadolu Fay Zonunda olan depremler.

Date	Strike	Dip	Rake	M (dyne-cm)	References
12.01.1975	205	82	4	0.79×10^{22}	present study
30.10.1983	215	64	7	0.80×10^{26}	Eyidoğan (1987)
30.10.1983	240	87	349	0.12×10^{25}	Eyidoğan (1987)
02.11.1983	272	65	55	0.79×10^{22}	present study
18.09.1984	204	81	11	0.14×10^{25}	Eyidoğan (1987)
18.10.1984	261	58	54	0.80×10^{24}	Eyidoğan (1987)
07.11.1985	227	47	28	0.14×10^{23}	present study

Table 4. Earthquakes of the period 1964-1986, occurred in East Anatolian Fault Zone.
Çizelge 4. 1964-1986 yılları arasında Doğu Anadolu Fay Zonunda olan depremler.

Date	Strike	Dip	Rake	M (dyne-cm)	References
14.06.1964	227	29	-28	6.30×10^{24}	Taymaz et al. (1991b)
30.10.1968	234	55	-28	0.25×10^{24}	present study
22.05.1971	231	82	3	0.58×10^{26}	Taymaz et al. (1991b)
06.09.1975	270	50	50	0.10×10^{27}	Nabelek (1984)
06.09.1975	257	55	35	2.55×10^{22}	present study
06.09.1975	280	52	42	1.87×10^{22}	present study
25.03.1977	258	52	-56	0.98×10^{24}	present study
20.01.1981	254	56	31	1.87×10^{22}	present study
05.05.1986	273	49	31	0.11×10^{26}	Taymaz et al. (1991b)
06.06.1986	275	27	30	0.90×10^{26}	Taymaz et al. (1991b)

$$\begin{bmatrix} -44.51. & -23.39 & 6.53 \\ -23.39 & 18.50 & 21.40 \\ 6.53 & 21.40 & 25.95 \end{bmatrix} \text{X } 10^{-9} / \text{yr} \qquad (13)$$

It is observed that the dominant components of the tensor are e^*_{11} and e^*_{22} corresponding to 17.80 mm/yr of contraction in the NS direction and 7.50 mm/yr of extraction in the EW direction. The tensor also reveals that the average left-lateral shear motion in the EW direction is 3.50 mm/yr. The thickening of the seismogenic layer corresponds to approximately 0.40 mm/yr.

Çaldıran Fault Zone

Çaldıran fault is approximately 50 km long. It contains an 18 (bend near Çaldıran which seperates the fault two sections. The fault plane solutions of earthquakes used in the calculations are listed in Table 5. Fault plane solutions of the earthquakes located in CFZ used are shown in Figure 8. The length of the deforming area is 120 km and its width is 4 km. The strain rate tensor was calculated to be as follows:

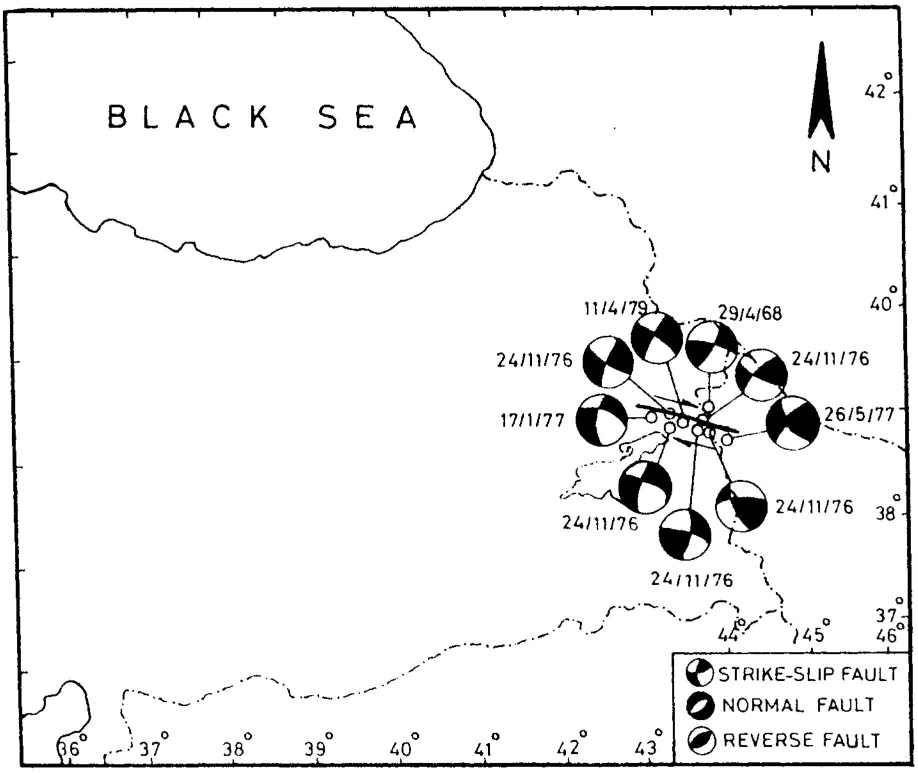


Fig. 8. Fault plane solutions of the earthquakes located in Çaldıran Fault Zone.
Şekil 8. Çaldıran Fay Zonunda olan depremlerin fay düzlemi çözümleri haritası.

Table 5. Earthquakes of the period 1968-1979, occurred in Çaldıran Fault Zone.
Çizelge 5. 1968-1979 yılları arasında Çaldıran Fay Zonunda olan depremler.

Date	Strike	Dip	Rake	M (dyne-cm)	References
29.04.1968	298	80	-146	2.5×10^{22}	present study
24.11.1976	163	90	152	8.24×10^{23}	present study
24.11.1976	137	70	143	1.02×10^{24}	present study
24.11.1976	282	62	-141	7.94×10^{21}	present study
24.11.1976	154	58	143	7.94×10^{21}	present study
24.11.1976	245	57	121	7.94×10^{21}	present study
17.01.1977	293	62	-146	1.92×10^{22}	present study
26.05.1977	170	64	149	1.90×10^{22}	present study
11.04.1979	284	62	-151	7.94×10^{21}	present study

$$\begin{bmatrix} -2.49 & -1.91 & 3.49 \\ -1.91 & 1.73 & 1.59 \\ 3.49 & 1.59 & 0.76 \end{bmatrix} X\ 10^{-9} / yr \qquad (14)$$

It is seen that the dominant components are e^*_{11} and e^*_{22} which corresponds to about 40.0 mm/yr for NS contraction and 7.00 mm/yr for the EW extension. The results also show left-lateral shear in the EW direction corresponding to about 15.0 mm/yr and thickening of the seismogenic layer, at a rate of only 1.15 mm/yr.

DISCUSSION AND CONCLUSIONS

The analysis in this study is based on information on the seismicity parameters of the area and on the moment tensors of well-studied earthquakes. Deformation rates for four different seismotectonic zones are given in Table 6. The results of this study, which are broadly illustrated in Figure 9, are consistent with the tectonics of studied area and can be summarized as follows:

The calculated strain rate tensors indicate that the dominant mode of deformation in the North Anatolian Fault zone is associated with NS contraction at a rate of about 18 mm/

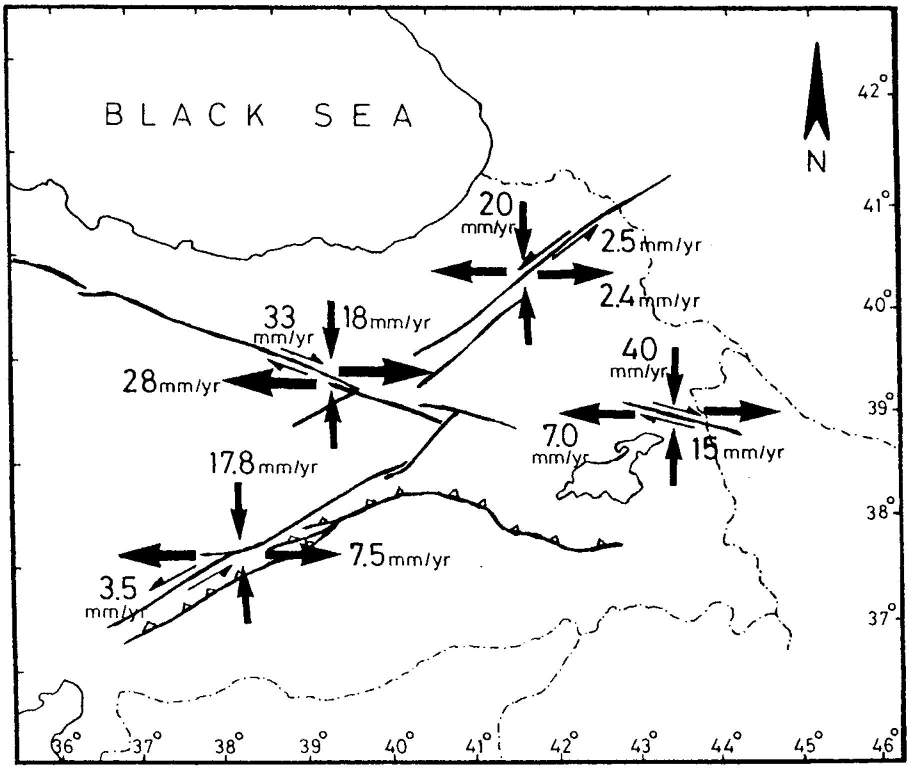


Fig. 9. Schematic illustration of the deformation rates of the studied zones.
Şekil 9. Çalışılan zonlardaki deformasyon miktarlarının şematik gösterimi.

Table 6. Calculated deformation rates.
Çizelge 6. Hesaplanan deformasyon miktarları.

Deformation Zone	North Anatolian Fault Zone	Northeast Anatolian Fault Zone	East Anatolian Fault Zone	Çaldıran Fault Zone
NS contraction rate, mm/yr	18.00	20.00	17.80	40.00
EW extension rate, mm/yr	28.00	2.40	7.50	7.0
Left-lateral displacement rate, mm/yr	-	2.50	3.50	-
Right-lateral displacement rate, mm/yr	33.00	-	-	15.00
Thickening rate, mm/yr	0.16	0.12	0.40	1.15

yr and EW extension at a rate of 28 mm/yr. The average right-lateral displacement is about 33 mm/yr. This is consistent with right-lateral strike-slip fault mechanism of North Anatolian Fault. The Northeast Anatolian Fault zone exhibits the same pattern of deformation. That is NS contraction at a rate of 20 mm/yr. EW extension is at a rate of about 2.4 mm/yr. The left-lateral shear motion is estimated to have a rate of 2.5 mm/yr. This is also consistent with the left-lateral strike-slip fault mechanism. In EAFZ, the deformation is taken up as nearly NS contraction at a rate of 17.80 mm/yr and as nearly EW extension at a rate of about 7.5 mm/yr. The average left-lateral motion has a rate of about 3.5 mm/yr. In Çaldıran Fault Zone, NS contraction at a rate of 40 mm/yr and EW extension at a rate of 7.0 mm/yr are obtained. Right-lateral deformation rate in Çaldıran Fault Zone having right-lateral strike-slip fault mechanism is calculated as 15.0 mm/yr. As a result of NS compression in all zones, thickening rates are found as 0.16 mm/yr in eastern part of NAFZ, 0.12 mm/yr in NEAFZ, 0.40 mm/yr in EAFZ and 1.15 mm/yr in CFZ, respectively.

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