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The June 6, 2000, Orta (Çankırı, Turkey) Earthquake: Sourced from a New Antithetic Sinistral Strike-slip Structure of the North Anatolian Fault System, the Dodurga Fault Zone

ALİ KOÇYİĞİT, BORA ROJAY, MUSTAFA CİHAN & ARDA ÖZACAR

Middle East Technical University, Faculty of Engineering, Department of Geological Engineering,
Tectonic Research Unit, TR-06531, Ankara - TURKEY
(e-mail: akoc@metu.edu.tr)

Abstract: The İsmetpaşa-Kargı section of the North Anatolian Fault System (NAFS) consists of six subfault zones, namely the Eskipazar, the Ulusu, the Tosya, the Çerkeş-Kurşunlu, the Devrez and the newly detected Dodurga fault zone (DFZ). Together these fault zones form a well-developed dextral strike-slip-faulting pattern, in which the DFZ is an antithetic secondary strike-slip component, indicated by focal-mechanism solutions of moderate and large earthquakes that have occurred in the İsmetpaşa-Kargı section of the NAFS.

The DFZ is a ~36-km-long, ~N-S-trending strike-slip structure located in the area between Saçak village in the north and Kösrelik village in the south. Pre-Upper Pliocene rocks are cut and tectonically offset for a distance of about 6 km. Upstream tributaries of the Devrez River are deviated in the shape of an "S" and are offset sinistrally up to 2.5 km. These values explain a 2.3 mm/yr rate of slip on the DFZ. In addition, several Plio-Quaternary pull-apart basins occur within the DFZ.

An intermediate-magnitude (Mw= 6.0), shallow-focus earthquake, the Orta earthquake, struck on Tuesday, June 6, 2000, at 5:42 (local time) in the Orta area, and resulted in two deaths and severe damage to a total of 4842 structures, almost all of rural-style construction. Most of severe damage was confined to a narrow area along the Dodurga fault; that is, the master strand of the DFZ. Isoseismal lines display an ellipsoidal pattern with a long axis that parallels the Dodurga fault. Both fore- and after-shocks of the June 6, 2000 Orta earthquake form a highly concentrated, N-S-trending distribution pattern that parallels the DFZ. Focal-mechanism solutions of the main shock carried out by various seismographic stations, except for DER-DDR station, indicate sinistral strike-slip faulting with a normal-slip component. Consequently, taken together these field observations and seismological data indicate that the Dodurga fault is an antithetic sinistral strike-slip structure included in the NAFS, and that the June 6, 2000 Orta earthquake resulted from its activation.

Key Words: North Anatolian Fault System, Antithetic Fault, Sinistral Strike-slip Fault, Orta Earthquake

Kuzey Anadolu Fay Sisteminde Tanımlanan Sol Yanal Atımlı Bir Fay Kuşağı: Dodurga Fay Kuşağı ve 6 Hairan 2000 Tarihli Orta (Çankarı-Türkiye) Depremi

Özet: Kuzey Anadolu Fay Sisteminin (KAFS) İsmetpaşa-Kargı bölümü Eskipazar, Ulusu, Tosya, Çerkeş-Kurşunlu, Devrez ve yeni tanımlanan Dodurga fay kuşağı (DKF) olmak üzere altı adet alt-fay kuşaklarından oluşur. Bu fay kuşaklarının tamamı iyi gelişmiş sağ yanal-atımlı fay deseni oluşturur ve bu sistem içerisinde DFK yanal atım bileşenli ikincil antitetik yapıyı temsil eder.

Yaklaşık 36 km uzunluğunda ve kuzey-güney uzanımlı bir yanal-atımlı fay olan DFK, kuzey de Saçak ve güneyde Kösrelik köyleri arasında yeralır. Üst Pliyosen öncesi kaya topluklarını kesen ve öteleyen fay kuşağı boyunca belilenen hareket 6 km kadardır. Devrez ırmağının memba dereleri "S" şekilli dönmüş ve sol yanal olarak 2.5 km' ye kadar atılmıştır. Bu değerler, DFZ üzerinde 2.3 mm/yr kayma miktarı verir. Bunlara ilaveten DFZ üzerinde birçok Pliyo-Kuvaterner çek-ayır havzalar gelişmiştir.

Orta ölçekli (Mw = 6.0) ve sığ odaklı, Orta depremi, 6 Haziran 2000 salı sabahı saat 5.42 (yerel zaman ile) Orta bölgesini vurdu. Deprem, iki ölüme ve çoğu ağır olmak üzere kırsal tarzda inşa edilmiş toplam 4852 yapının hasar görmesine neden oldu. Çoğunlukla hasar DFZ'nin ana kolu olan Dodurga fayı üzerinde dar bir kuşakta oluştu.

Eşdeğersismik eğrilerinin uzun ekseni Dodurga fayına parallel uzanan elipsoidal bir desen oluşturur. 6 Haziran 2000 Orta Depremin öncül ve ardçıl depremlerinin dağılımı kuzey-güney yönünde bir yoğunlaşma gösterip, Dodurga fay kuşağına paralellik sunarlar. DER-DDR dışında çeşitli sismograf istasyonlarında yapılan odak mekanizması çözümlemeleri normal bileşenli sol yanal-atımlı faylanma göstermektedir. Sonuç olarak, arazi jeolojisi gözlemleri ve sismik veriler birlikte Dodurga fayının KAFS'i içinde antitetik sol yanal-atımlı fay olduğunu ve 6 Haziran 2000 Orta depreminin bu fayın hareketlenmesi ile oluştuğunu ortaya koymaktadır.

Anahtar Sözcükler: Kuzey Anadolu Fay Sistemi, Antitetik Fay, Sol Yanal-atımlı Fay, Orta Depremi.

Introduction

An intermediate-magnitude (Mw= 6.0), shallow-focus (8-33 km) earthquake struck on Tuesday, June 6, 2000, at 5:42 (local time). This seismic event was felt over a wide region including many cities, counties and villages, such as Çankırı, Kastamonu, Zonguldak, Karabük, Bolu, Ankara, Kayseri, Çerkeş, Kurşunlu, Atkaracalar, Orta, Çubuk and Şabanözü, and caused severe damage to adobe structures in rural areas. Early morning on same day, the field epicenter of this seismic event was announced as Çerkeş county by a national seismographic station, Kandilli Observatory and Earthquake Research Institute, İstanbul-Turkey. Later, several national and international seismographic stations that recorded this event calculated its various seismic parameters (Table 1). Thus, based on instrumental data obtained from seismographic stations (Table 1), the field epicenter of this event was found to be somewhere in or near Orta county, 15-25 km SE of Çerkeş county. However, until the occurrence of this seismic event, there was no information about a fault mapped or reported from this area. Therefore, the source of this earthquake remained an unsolved geological problem for a short time. For this reason, we went to the Orta (Çankırı) area, visited all of the severely damaged settlements, and detected the structure that produced this seismic event, and mapped it in detail on a 1/25,000 scale topographic map. This structure, an approximately N-S-trending, left lateral strike-slip fault zone located ~5 km west of the Orta county (the largest settlement nearest to the field epicenter of the seismic event), we named the Dodurga fault zone. Accordingly, the seismic event is herein first named the June 6, 2000 Orta earthquake.

This paper aims: (1) to introduce a new structure, the Dodurga fault zone; (2) to explain its geometric-kinematic characteristics and relationships with the NAFS; and (3) to explain and document the origin of the June 6, 2000 Orta earthquake and the severe damage it caused to structures in the Orta area.

Regional Tectonic Setting

Turkey is located in the Mediterranean-Himalaya seismic zone, and approximately 90% of the country is under seismic hazard. The main structures that are responsible for high seismicity in Turkey and adjacent areas are the North Anatolian, East Anatolian and Dead Sea fault systems, and the Hellenic-west Cyprus arc (Figure 1). The Hellenic-west Cyprus arc is an active subduction zone along which the African plate has been subducting at a slip rate of 35 mm/yr northwards beneath the Turkish platelet (McKenzie 1972; Le Pichon & Angelier 1979; Meulenkamp *et al.* 1988; Kahle *et al.* 1998). The Dead Sea Fault System is a sinistral transform fault separating

Table 1. Various seismic parameters of the 2000 June 6 Orta (Çankırı) earthquake.

Date (yyyy/mm/dd)	Origin Time (GMT)	Location Lat°.N-Long°.E	Focal depth (km)	Magnitude	Seismic Moment (Mo)	Duration (second)	Fault Plane Mechanism Solution (strike/dip/rake)	Geographical Region	References*
2000/06/06	02:41:53.2	40.65 – 32.92	8	Mw= 6.0	1.25×10^{18} Nm	~ 6	1. 02°/46°/-29° 2. 111°/70°/-132°	Orta (Çankırı)	TT
2000/06/06	02:41:53.16	40.621 – 32.967	33	Ms= 6.1	-	-	1. 340°/26°/-53° 2. 122°/69°/-106°	Orta (Çankırı)	USGS-NEIC
2000/06/06	02:41:51.46	40.63 – 33.03	10.5	Md= 5.9	-	~ 10	1. 262°/88°/-139° 2. 170°/49°/-03°	Orta (Çankırı)	DER-DDR
2000/06/06	-	40.67 – 32.97	10	Md= 5.9	-	-	-	Çerkeş (Çankırı)	KOERI
2000/06/06	02:41:52.0	40.75 – 32.70	15	Mw= 6.0	1.11×10^{18} Nm	~ 5.4	1. 356°/39°/-47° 2. 126°/62°/-119°	Orta (Çerkeş)	HARVARD
2000/06/06	-	40.60 – 33.00	33	Ms= 6.1	-	-	1. 359.6°/47.6°/-46.8° 2. 125°/58°/-126°	Orta (Çankırı)	ERI

* TT: Tuncay Taymaz - İstanbul Technical University, Department of Geophysical Engineering, USGS-NEIC: The United States of Geological Survey – National Earthquake Information Center, DER-DDR: Department of Earthquake Research, General Directorate of Disaster Affairs, KOERI: Kandilli Observatory and Earthquake Research Institute, HARVARD: Harvard University Seismology Group, ERI: Tokyo University Earthquake Research Institute.

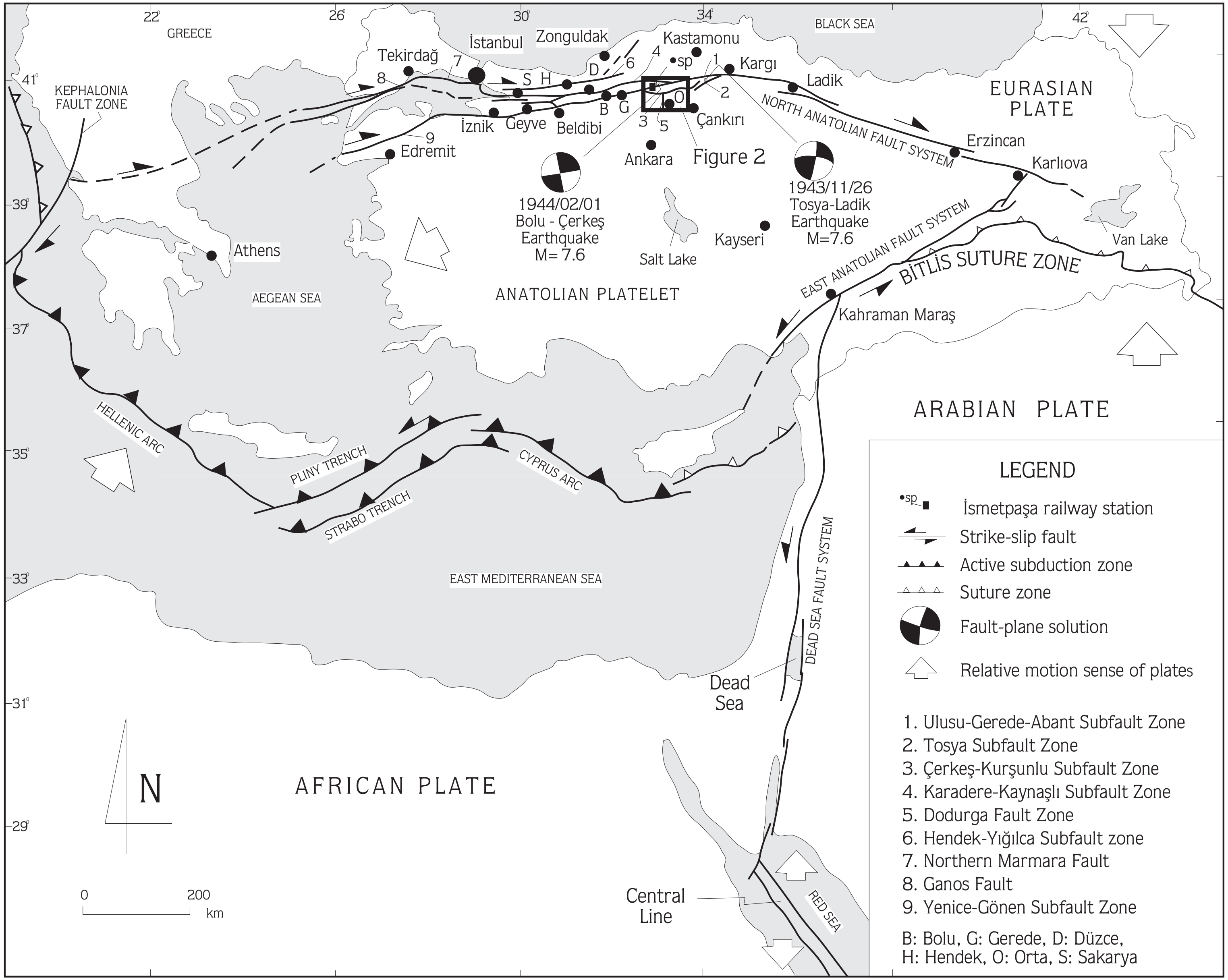

Figure 1. Simplified map showing the study area and major neotectonic structures of Turkey and adjacent areas (Focal-mechanism solutions were taken from Canıtez & Büyükaşıkoğlu 1984).

the Arabian Plate in the east from the African Plate in the west. The African Plate is moving NNW at an average slip rate of 18 mm/yr (De Mets *et al.* 1994; Reilinger *et al.* 1997; Kahle *et al.* 1998). The dextral North Anatolian and sinistral East Anatolian fault systems are intracontinental transform faults, along which the wedge-shaped Anatolian platelet has been escaping west-southwestward since Late Pliocene (2.6 Ma) (McKenzie 1972; Tokay 1973; Hempton 1987; Şaroğlu 1988; Koçyiğit & Beyhan 1998). Average rates of slip along the NAFS and the EAFS are estimated at 10 mm/yr and 6 mm/yr, respectively, based on field observations (Tokay 1973; Tatar 1978; Barka & Hancock 1984; Barka & Gülen 1988; Şaroğlu 1988; Koçyiğit 1988, 1989, 1990) while they appear to be 26 mm/yr and 15 mm/yr, respectively, based on Global Positioning System (GPS) and seismological data (McKenzie 1972; Canıtez 1973; North 1974; Kasapoğlu & Toksöz 1983; Taymaz *et al.* 1991; De Mets *et al.* 1994; Reilinger *et al.* 1997; Stein *et al.* 1997; Kahle *et al.* 1998, 2000; McClusky *et al.* 2000).

Tectonic Setting of the Study Area

The NAFS is an approximately 1500-km-long and 10-100-km-wide dextral shear zone trending first NW, and then E–W, and finally SW between Karlıova in the east and the northern Aegean Sea in the west (Figure 1). The NAFS displays two common distribution patterns or geometries along its length: (1) splay-type geometry, and (2) anastomasing-type geometry. The splay type is well-developed in both the Erzincan-Çerkeş and the Marmara sections of the NAFS. In the area between Erzincan in the east and Çerkeş in the west, a number of fault zones, fault sets and isolated faults of varying sizes branch as splay structures from the master strand of the NAFS. These structures first trend E-W for some distance (up to 40 km), and then bend southward and trend ~NE-NNE, traversing the Anatolian platelet for several hundreds kilometers, cutting across and deforming it. Well-defined examples of splay structures are the Ovacık-Malatya, Central Anatolian, Almus, Yağmurlu-Ezinepazarı (or "Sungurlu"), Merzifon-Laçin, Taşova-Çorum and the Kızılırmak fault zones or splay fault zones (Koçyiğit 1989, 1990, 1991a, 1991b, 1996; Şengör & Barka 1992; Özçelik 1994; Kaymakçı & Koçyiğit 1995; Bozkurt & Koçyiğit 1995, 1996; Koçyiğit & Beyhan 1998, 1999; Kaymakçı 2000; Westaway 2001).

In the second pattern or geometry of the NAFS, the master strand (Y-shear) first bifurcates into several subfault zones, fault sets and isolated faults of varying sizes, and then they rejoin and rebifurcate several times, leaving behind a series of lensoidal highlands (pressure ridges) such as Armutlu Peninsula, Almacık Mountain, Bolu Mountains, Arkotdağ, Ilgaz Mountains and Karadağ, and lowlands (basins) whose long axes parallel the general trend of the master strand of the NAFS. This pattern is the most diagnostic characteristic of the Kargı-East Marmara section of the NAFS. Examples of subfault zones, fault sets and isolated faults having anastomosing geometry along the NAFS in its Kargı-East Marmara section are, from E to W, the Ulusu-Gerede-Abant, Tosya, Çerkeş-Kurşunlu, Karadere-Kaynaşlı-Mengen-Eskipazar and the Hendek-Yığılca subfault zones (Figures 1 & 2). These zones have been mapped previously and introduced into the geological literature (Öztürk 1968; Tokay *et al.* 1973; Tokay 1973; Öztürk *et al.* 1984; Şaroğlu *et al.* 1987; Barka & Kadinsky-Cade 1988; Andrieux *et al.* 1995; Koçyiğit *et al.* 1999). Thus, usage of the term "North Anatolian fault system" is preferred to the term "North Anatolian fault zone" due to its aforementioned complicated geometry.

One of newly detected splay faults of the NAFS is the Dodurga fault zone, (DFZ) located south of the İsmetpaşa-Kargı section of the NAFS (Figure 2). It branches from the E-W–trending Çerkeş-Kurşunlu subfault zone and then runs South for a distance of ~36 km. The master strand of the Dodurga fault zone became active and produced the June 6, 2000 Orta (Çankırı, Turkey) earthquake of Mw= 6.0. The present paper deals with the various characteristics, including the geometry, kinematics, size, age, and displacement of the Dodurga fault zone, the Mw= 6.0 earthquake, and its damage to various structures.

Dodurga Fault Zone (DFZ)

The Orta area was first studied by Türkecan *et al.* (1991), who identified various rocks of dissimilar facies and age, and mapped them separately at a 1/25,000 scale. These rocks are from, oldest to youngest: an Upper Cretaceous marine sedimentary sequence, Miocene volcanic rocks, a Miocene continental sedimentary sequence, Pliocene basalts and a Plio-Quaternary continental sedimentary sequence. Türkecan *et al.* (1991)

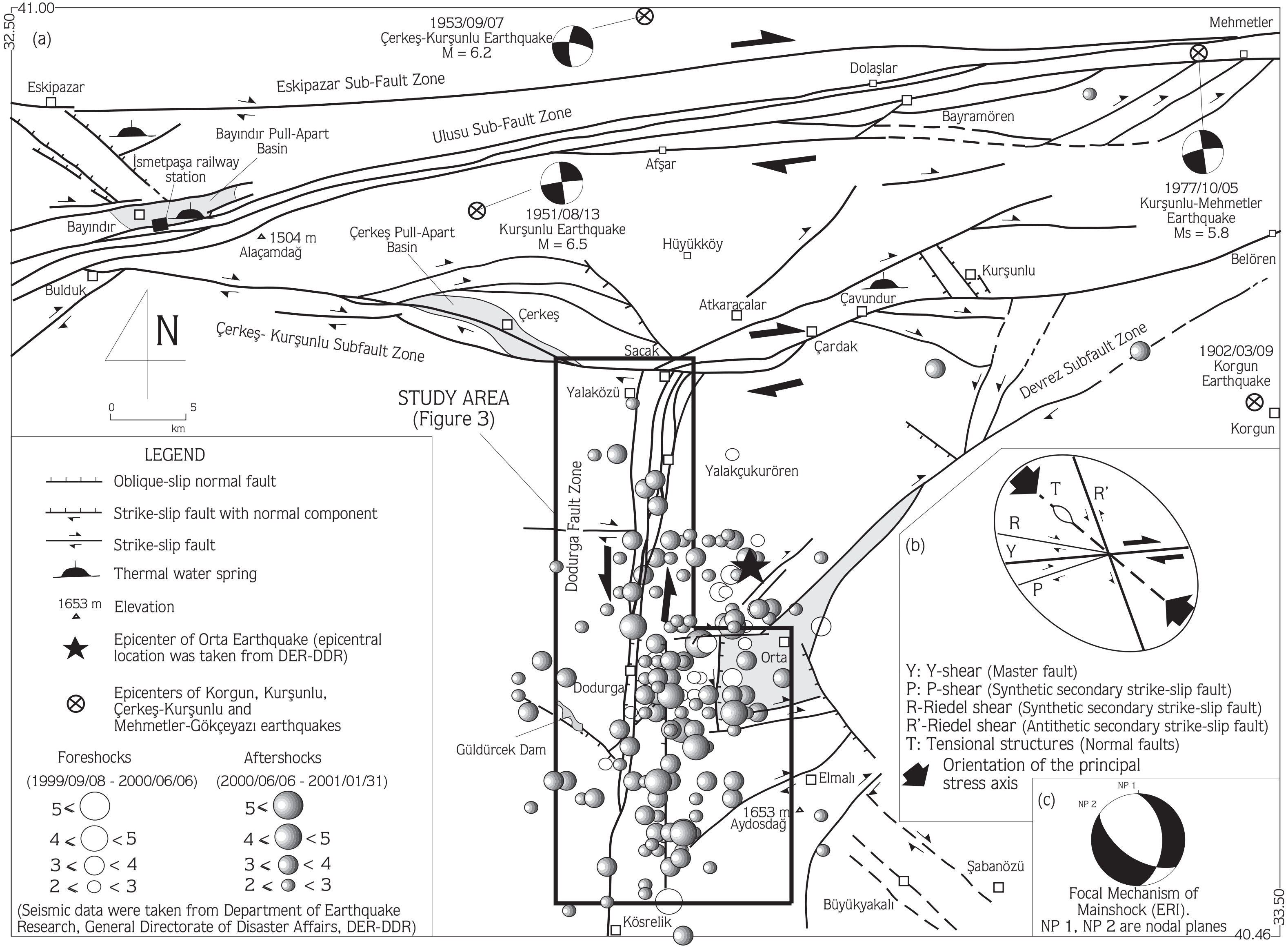

Figure 2. (a) Seismotectonic map of the area around Çerkeş, Orta, Kurşunlu, Korgun and Bayramören counties (focal-mechanism solutions were taken from Canıtez & Üçer 1967; Jackson & McKenzie 1984) (see Figure 1 for location). (b) Pattern of dextral strike-slip faulting. (c) Focal-mechanism solution of the June 6, 2000 Orta (Çankırı) earthquake. NP1 fits well with the Dodurga fault.

have also observed and mapped a few short (0.5 to 3-km-long), N-S- to NNW-trending isolated faults. However, a continuous fault or fault set longer than 5 km is not shown on their map. On June 6, 2000, a short time after the occurrence of the Orta earthquake, we visited the Orta area; there we detected a large fault zone and prepared a detailed neotectonic map (Figure 3) via geological field mapping carried out in the same area. This neotectonic structure is here first named the Dodurga fault zone (DFZ).

The DFZ is an 4 to 7-km-wide, 36-km-long and approximately N-S trending sinistral strike-slip fault zone. This zone is located in the area between Saçak village in the north, Kösrelik village in the south (outside the study area) and Orta County in the east (Figures 2a & 3). The DFZ consists of a number of parallel to sub-parallel, ~1 to 36 km long, N-S–, NNW– and NNE-trending, closely-spaced sinistral strike-slip faults with considerable normal-slip components as indicated by several Plio-Quaternary pull-apart basins bounded by these faults (Figure 3). Some of the larger faults comprising the DFZ are, from E to W, the Kayılar fault, the Buhya fault set, the Hasanhacı fault set, the Söğütözü fault, the Büğren fault, the Dodurga fault and the Yalaközü fault set (Figure 3).

The Kayılar fault is about 7-km-long, NNW-trending sinistral strike-slip fault. It occurs in three segments and controls the eastern side of the Karalık stream valley (Figure 3). The Buhya fault set is located around Buhya village in the southern part of the study area, and consists of seven 1- to 5-km-long, closely-spaced, N-S– to NNE–trending sinistral strike-slip fault segments. These faults control the Buhya pull-apart basin (Figure 3). The Hasanhacı fault set is located between Gökçeören village in the south and Salur village in the north, and consists of seven 1- to 3.5-km-long, NNE–trending sinistral strike-slip faults with considerable normal-slip components. Two longer segments of the Hasanhacı fault set control the western margin of the Orta pull-apart basin and sinistrally displace the Uludere stream course up to 0.5 km, north of Hasanhacı village (Figure 3). The Söğütözü fault, located 3 km east of Dodurga village, is an approximately 15-km-long, N-S–trending sinistral strike-slip fault. This fault controls both the Söğütözü and İçin streams and offsets them sinistrally up to 1 km (Figure 3). The Büğren fault splays off the Söğütözü fault near the Gökçeviran plateau in the south, and then runs NW up

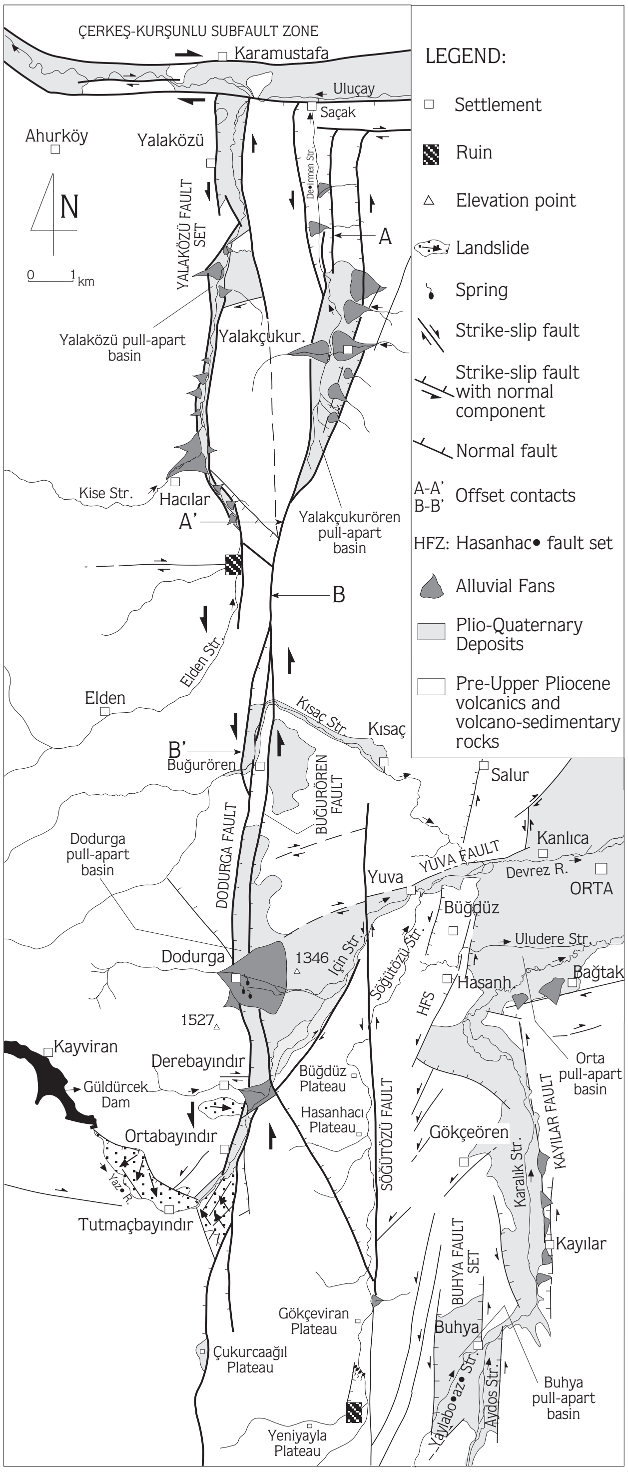

Figure 3. Neotectonic map of the Dodurga fault zone (see Figure 2 for location).

to the east of Derebayındır village, where it bends northward and continues for 10 km in the same direction. Finally, this fault meets the Dodurga fault

(Figure 3). The Büğren fault has a length of ~16 km and displays a concave-eastward outcrop pattern. In addition, the Büğren fault is a transfer structure between the Söğütözü and the Dodurga faults and has a considerable normal-slip component as indicated by the Plio-Quaternary depressions located in its eastern block (Figures 3). The Yalaközü fault set is located in the north of the study area, and consists of a few relatively long (~9 km) and several short (1-3 km), closely spaced, N-S–, NNW– and NNE–trending, linear to curvilinear fault segments (Figure 3). These faults control both the Elden and Kise streams and the Yalaközü Plio-Quaternary pull-apart basin, which resulted from the subsidence of a block bounded by two major faults of the Yalaközü fault set, also a sinistral strike-slip structure with a considerable normal-slip component as indicated by the Yalaközü pull-apart basin.

The Dodurga fault is the master structure comprising the DFZ. This fault is located in the area between Saçak village in the north and Kösrelik village (outside of the study area) in the south. The Dodurga fault is an approximately 36-km-long, N-S–trending sinistral strike-slip fault with a well-developed curvilinear and anastomosing outcrop pattern (Figure 3). In the area around Yalakçukurören village, the Dodurga fault divides into several sub-branches, resulting in a very young (Plio-Quaternary) pull-apart basin due to the subsidence of a wedge-like block bounded by the sinistral strike-slip faults (Figure 3). Farther north around Saçak village, each of the basin-bounding faults bends eastward and meets the E-W–trending Çerkeş-Kurşunlu dextral strike-slip subfault zone. However, farther south (outside of the study area), the Dodurga fault continues for about 6 km on the same trend, as indicated by both the morphotectonic features and the linear distribution of aftershocks of the June 6, 2000 Orta earthquake.

Age and Total Displacement

Within the Dodurga fault zone, steeply dipping and folded rocks of dissimilar age and facies are cut across and tectonically juxtaposed. In the area between Büğren village in the south and Yalakçukurören village in the north, Miocene volcanic rocks, a Miocene continental sedimentary sequence and Pliocene basalts are cut and displaced sinistrally by the Dodurga fault, up to ~6 km and ~4 km, respectively (A-A' and B-B' in Figure 3). In addition, a number of streams, that comprise the upstream part of the E-W–flowing Devrez River, are bent into a concave-northward pattern, and then offset up to 2.5 km as they approach and pass across the Dodurga and Büğren faults around Büğren, Tutmaçbayındır and Ortabayındır villages. Three well-developed examples of such a drainage system are the Yazı River, İçin stream and Kısaç stream (Figure 3). In the area between Büğren village in the north and Derebayındır village in the south, both the Dodurga and Büğren faults display a concave-eastward outcrop pattern, in which their eastern blocks have been downthrown (up to 180 m), and produce two small Plio-Quaternary pull-apart basins with long axes that parallel the general trend of the DFZ (Figure 3).

Briefly, the existence and activity of the DFZ is indicated by a series of well-developed and very young (most probably Late Pliocene-Quaternary) morphotectonic features such as sudden breaks in slope, anastomosing outcrop patterns, fault-parallel pressure ridges, pull-apart basins, ruins of ancient settlements, fault-parallel aligned alluvial fans, active landslides, S-shaped bent and offset drainage systems (Figure 3). This was substantiated also by the June 6, 2000 Orta earthquake and its fore- and after-shocks aligned parallel to the DFZ (Figure 2a). Sedimentary infill of the pull-apart basins which developed under the influence of the DFZ is loose to poorly lithified, undeformed and rests along an angular unconformity on the erosional surface of the pre-Upper Pliocene deformed (folded) rocks. The Dodurga (Orta) area is located near the Çankırı and Ankara regions, experiencing the same tectonic regime (strike-slip neotectonic regime), as indicated by minor but frequent seismic activity (Figure 1). In both the Ankara and Çankırı regions, a number of isolated, 1- to 20-km-long, N-S– and NNE–trending faults, fault sets and strike-slip basins have also been previously detected and reported by Koçyiğit (1991a), Koçyiğit *et al.* (1995), Kaymakçı (2000), Kaymakçı *et al.* (2000). According to those authors, these structures are sinistral strike-slip faults with a considerable normal-slip components. These structures are younger than Late Pliocene-Early Quaternary since they cut across and displace the Lower Miocene-lowermost Pliocene rocks, fold axes and thrust faults developed in them, and their undeformed (nearly flatlying) cover rocks of Late Pliocene-Early Quaternary age. Therefore, the age of the pull-apart basins and their margin-bounding faults is estimated as Late Pliocene or Early Quaternary.

Offset formation boundaries and drainage systems reveal that the total sinistral displacement accumulated on faults of the DFZ ranges between 0.5 km and 6 km since Late Pliocene (~2.6 Ma). From these values, it can be concluded that the maximum rate of slip on the DFZ has been 2.3 mm/yr since the Late Pliocene. In the same way, almost all faults of the DFZ have a considerable normal-slip component. The one that has a greater normal-slip component (180 m) than others is the master strand of the DFZ, namely the Dodurga fault. The ratio of the normal-slip component to the sinistral strike-slip component (180 m / 6000 m) is ~1/33 at the ground surface, consistent with that observed on the NAFS.

Mechanism of the Dodurga Fault Zone

As has been explained in foregoing sections, the İsmetpaşa-Kargı section of the NAFS displays a well-developed pattern of a dextral strike-slip faulting (cf. Wilcox *et al.* 1973; Sylvester 1988). In this pattern, originally the E-W–trending elements are dextral Y-shears or master faults, the WNW– and WSW–trending elements are synthetic secondary dextral strike-slip faults (Y, R and P in Figure 2b), the NW–trending elements are extensional structures such as dikes and oblique-slip normal faults (T in Figure 2b), and the NNW–trending elements (R' in Figure 2b) are the antithetic secondary sinistral strike-slip faults. In this context, the DFZ, as a whole, is an antithetic secondary sinistral strike-slip structure rotated clockwise up to 15° (Figure 2a) (Gürsoy *et al.* 1997) due to the simple shear character of the NAFS since the Late Pliocene. The antithetic sinistral strike-slip character and considerable normal-slip component of the master fault, namely the Dodurga fault of the DFZ are also proved by both the aforementioned morphotectonic structures (sinistrally offset drainage systems, formation boundaries and pull-apart basins) and focal-mechanism solutions of the mainshock of the June 6, 2000 Orta earthquake carried out by various stations (Table 1, Figure 2c). Based on both the geologic data (Koçyiğit 1991a; Andrieux *et al.* 1995) and various focal-mechanism solutions of five intermediate- and high-magnitude earthquakes (M= 5.8-7.6) that have occurred in this region, the operation direction of the principal stress that caused faulting and the June 6, 2000 Orta earthquake was approximately NW-SE (McKenzie 1969, 1972; Nowroozi 1972; Jackson & McKenzie 1984; Canıtez & Büyükaşıkoğlu 1984; McClusky *et al.* 2000) (Figures 1 & 2).

Seismicity of the İsmetpaşa-Kargı Section of the NAFS

One of the more geologically complicated parts of the NAFS is the İsmetpaşa-Kargı section (Figure 1). Most of the İsmetpaşa-Kargı section was first examined and mapped at a 1/25,000 scale by Tokay *et al.* (1973). According to those authors, the İsmetpaşa-Kargı section of the NAFS consists of six subfault zones, namely the Eskipazar, the Ulusu, the Tosya, the Çerkeş-Kurşunlu, the Devrez and the Dodurga fault zones (Figures 1 & 2). The Ulusu fault zone is the master strand of the NAFS while the Dodurga and the Devrez fault zones are its splays (Figure 2). In general, these fault zones range from 1 to 7 km in width and from 40 to 160 km in length. In addition, except for the Dodurga fault zone, all of the rest are right lateral strike-slip faults.

Seismicity of the İsmetpaşa-Kargı section has been very high in both historical periods and recent times. In the period 109 A.D. to 1900, four historical earthquakes with intensities varying from V to IX took place in the İsmetpaşa-Kargı section (including Çerkeş, Orta, Kurşunlu, Kargın, Ilgaz and Tosya counties) of the NAFS (Soysal *et al.* 1981; Ambraseys & Finkel 1995; Ambraseys & Jackson 1998); namely, the 109, 1668.08.17, 1845 and 1881.09.28 earthquakes. These seismic events could not be recorded and well-documented owing to lack of well-educated people and technology in those days. However, it has been reported that loss of life and heavy damage to various structures was very high (Ambraseys & Finkel 1995). In addition to these, recent paleoseismic studies, carried out in the İsmetpaşa-Kargı section of the NAFS, have identified five paleoearthquakes, namely the 830, 399, and 92 B.C. events, and the 1035 and 1668 A.D. events (Özaksoy *et al.* 1998; Özaksoy 2000).

In the 19th century, six destructive earthquakes occurred in the İsmetpaşa-Kargı section of the NAFS. These seismic events are the 1902.03.09 Korgun (Io= IX), the 1943.11.26 Tosya-Ladik (M= 7.6), the 1944.02.01 Bolu-Çerkeş (M= 7.6), the 1951.08.13 Kurşunlu (M= 6.5), the 1953.09.07 Çerkeş-Kurşunlu (M= 6.4), and the 1977.10.05 Mehmetler-Gökçeyazı (Ilgaz) (Ms= 5.8) earthquakes (Ergin *et al.* 1967; Ambraseys 1970; Alsan *et al.* 1975; Ambraseys & Finkel 1987).

The epicenters of the1902, 1943, 1944, 1951, 1953 and 1977 events were located within the İsmetpaşa-Kargı section of the NAFS (Figures 1 & 2). These events ruptured most parts of the Ulusu, Çerkeş-Kurşunlu and Tosya fault zones and led to development of ground ruptures. These were examined in the field and mapped at a 1/25,000 scale in places (Taşman 1944; Blumental 1945; Pınar 1953; Öztürk 1968; Ketin 1969; Tokay *et al*. 1973). Lengths of ground ruptures resulting from 1943, 1944 and 1951 earthquakes have been reported as 265 km, 190 km and 40 km, respectively (Blumental 1945; Ambraseys 1970). The 1902 event could not be recorded well, but focal-mechanism solutions for the other five events have clearly shown that these earthquakes have been sourced from dextral strike-slip faulting with minor normal and thrust components (Canıtez & Üçer 1967; Canıtez & Büyükaşıkoğlu 1984; Jackson & McKenzie 1984). Other than the major subfault zones described briefly in foregoing sentences, there may be some other ill-defined or undefined faults in the İsmetpaşa-Kargı section of the NAFS, and as such may still retain their high seismicity. In this context, the Dodurga fault zone has been a very recent example.

The June 6, 2000 Orta Earthquake

In at least the 19th century, the Dodurga fault zone may have remained as a seismic gap - even if it had not been detected - because its previous unknown situation does not change the reality of a possible seismic gap. Starting September 8, 1999, minor seismic events with magnitudes ranging between 2.4 and 4 began to occur (Figure 4) with an approximately N-S distribution pattern (Figure 2a). The N-S–trending linear distribution of foreshocks that occurred in the period 1990-1999 were ascribed to the activation of a reverse fault, namely the "Atkaracalar reverse fault", that was detected in a trench located farther north outside of the Dodurga fault zone (Özaksoy 2000). Until the time (June 6, 2000) of the main shock, 27 earthquakes were reported (Department of Earthquake Research, General Directorate of Disaster Affairs). The main shock, with a magnitude of 5.9 to 6.1, struck on Tuesday, June 6, 2000 at 5:42 (local time), and moved the Dodurga fault zone of the NAFS (Figures 2a & 4). The June 6, 2000 Orta earthquake was felt in the cities of Ankara, Bolu, Zonguldak, Kastamonu, Çankırı and Kayseri, 80-300 km away from Orta county (Figure 1). The destructive effects of this earthquake were confined mainly to villages (Dodurga, Büğren, Elden, Derebayındır, Ortabayındır, Tuğmaçbayındır, Kısaç, Yuva, Salur, Büğdüz, Kanlıca) located in a narrow and approximately N-S–trending zone delimited by the Dodurga fault zone in the western part of Dodurga county (Figure 3). The June 6, 2000 Orta earthquake resulted in two deaths, moderate to severe damage to a total of 4842 structures of mostly rural-style construction (unreinforced, poor-quality, single- to two-story stone and/or adobe-masonry structures with mud mortar). Some moderate damage to isolated concrete and adobe structures has also been reported from settlements such as Büyükyakalı, Şabanözü and Çubuk, far from Orta county (Figures 2 & 5).

Based on the type and amount of damage and the modified Mercalli's Scale, an isoseismal map was prepared for the June 6, 2000 Orta earthquake (Figure 5). Isoseismal lines are labeled with roman numerals. The maximum intensity value determined for this earthquake was VII, and that was confined to a narrow, lazy ellipsoidal area including the aforementioned and severely damaged villages (Figures 3 & 5). In general, isoseismal lines display an ellipsoidal distribution pattern with a NNE-SSW–trending long axis paralleling the master fault of the Dodurga fault zone, implying that this fault was the source of the June 6, 2000 Orta earthquake.

From Table 1, it is seen that there are clear differences in both focal depths (8-33 km) and instrumental locations (coordinates) of the epicenter of the June 6, 2000 Orta earthquake. However, the values of focal-mechanism solutions found by various seismographic stations, except for the DER-DDR station, are very similar. When locations of field epicenters and focal mechanisms are evaluated in the light of field observations (field mapping of faults, their distributions, trends, geometries, etc.), high concentration and the distribution pattern of both fore- and after-shocks (Figure 2a), and location and shape of the greatest intensity line (Figure 5), the field epicentral location of the DER-DDR station and the focal mechanism of ERI (Table 1, Figure 2c) are more favourable than those of remaining stations.

The number of aftershocks (M= 2.1-5) in the first 20-day period was 67, and aftershocks continue to occur at present (Figures 2a & 4). Ground rupture did not develop during the Orta earthquake. However, some open cracks with uneven distribution patterns occurred within mostly soft, infilling ground material and unconsolidated slope screes as a result of ground shaking.

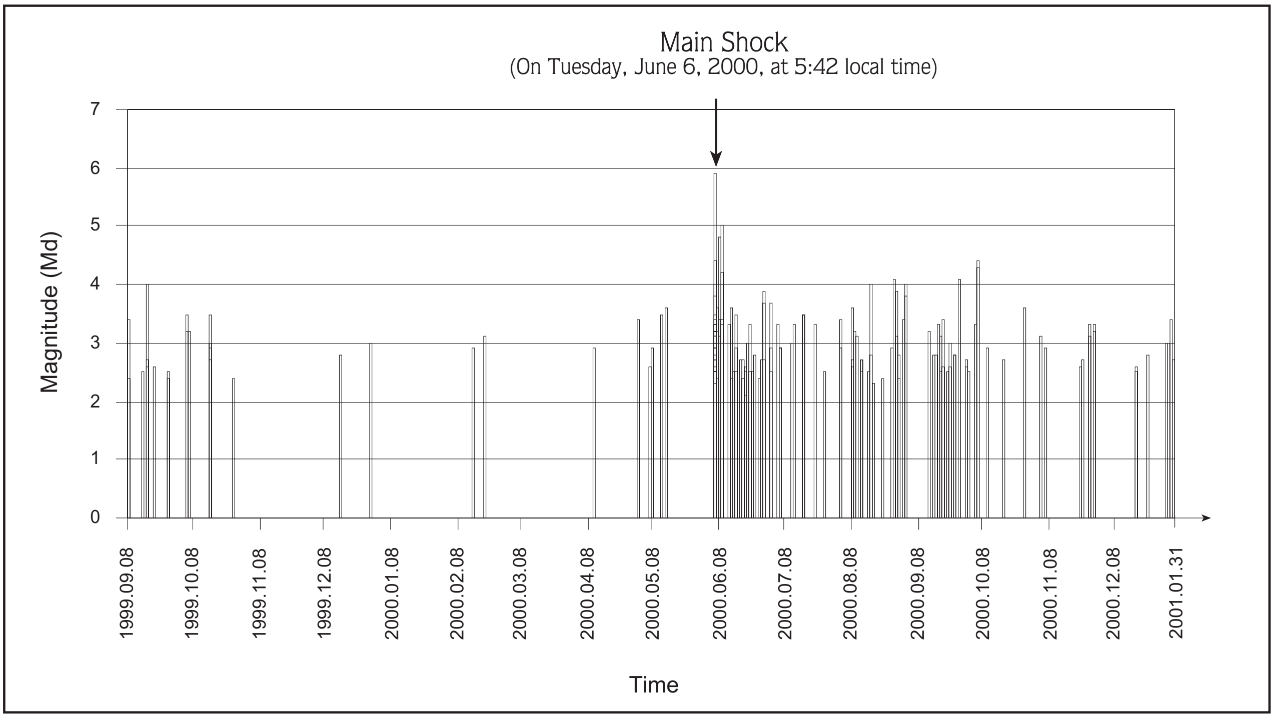

Figure 4. Histogram showing foreshocks, mainshock (Orta earthquake) and aftershocks in the period 1999.09.08 and 2001.01.31. (Seismic data were taken from Department of Earthquake Research, General Directorate of Disaster Affairs: DER-DDR)

In addition, several large-scale, ancient landslides in the southern half of the Dodurga fault zone were activated and became threats to nearby settlements, such as Derebayındır and Tutmaçbayındır villages (Figure 3).

Source of the June 6, 2000 Orta Earthquake

The attitudes of first nodal planes and the characters of faulting obtained from focal-mechanism solutions of the various seismographic stations, except for the DER-DDR station, fit well with those of the DFZ (Table 1, Figure 2). In addition, in the Orta area, the longest (36 km) active fault is the Dodurga fault, the master strand of the DFZ. Most of sinistral strike-slip (~6 km), activated landslides and severe damage to structures were also concentrated along the Dodurga fault. All of these data reveal that the June 6, 2000 Orta earthquake originated from activation of the Dodurga fault (Figures 2a & 3). This conclusion has been corroborated by the field studies of Emre *et al.* (2000).

Discussion and Conclusions

Some small seismic events began to occur in and adjacent to the Orta area in 1990, and continued until the mainshock, namely the June 6, 2000, Mw= 6.0 Orta earthquake. The N-S–trending linear distribution of these foreshocks was previously ascribed to the activation of a N-S–trending high-angle thrust fault, the "Atkaracalar reverse fault", observed in a trench located farther north and outside of the study area (Özaksoy 1990). That interpretation is incorrect because: (1) there is no a N-S–trending reverse fault running from Atkaracalar in the north to the west of Orta county in the south; (2) focal-mechanism solutions of the mainshock yield sinistral strike-slip faulting with a normal-slip component for the source of the June 6, 2000 Orta earthquake; and (3) there has been no damage to structures in Atkaracalar area. In the same way, Demirtaş *et al.* (2000) interpreted the source of the Orta earthquake as a dextral strike-slip fault, the "Orta Fault" that strikes ENE and dips NNW. This interpretation is also incorrect because it is in conflict with the N-S–trending linear distribution of both fore- and after-shocks and results obtained from focal-mechanism solutions of the mainshock carried out by five national and international seismographic stations (Table 1, Figures 2a & 2c).

In contrast to the aforementioned interpretations, we detected – via detailed field geological mapping in the

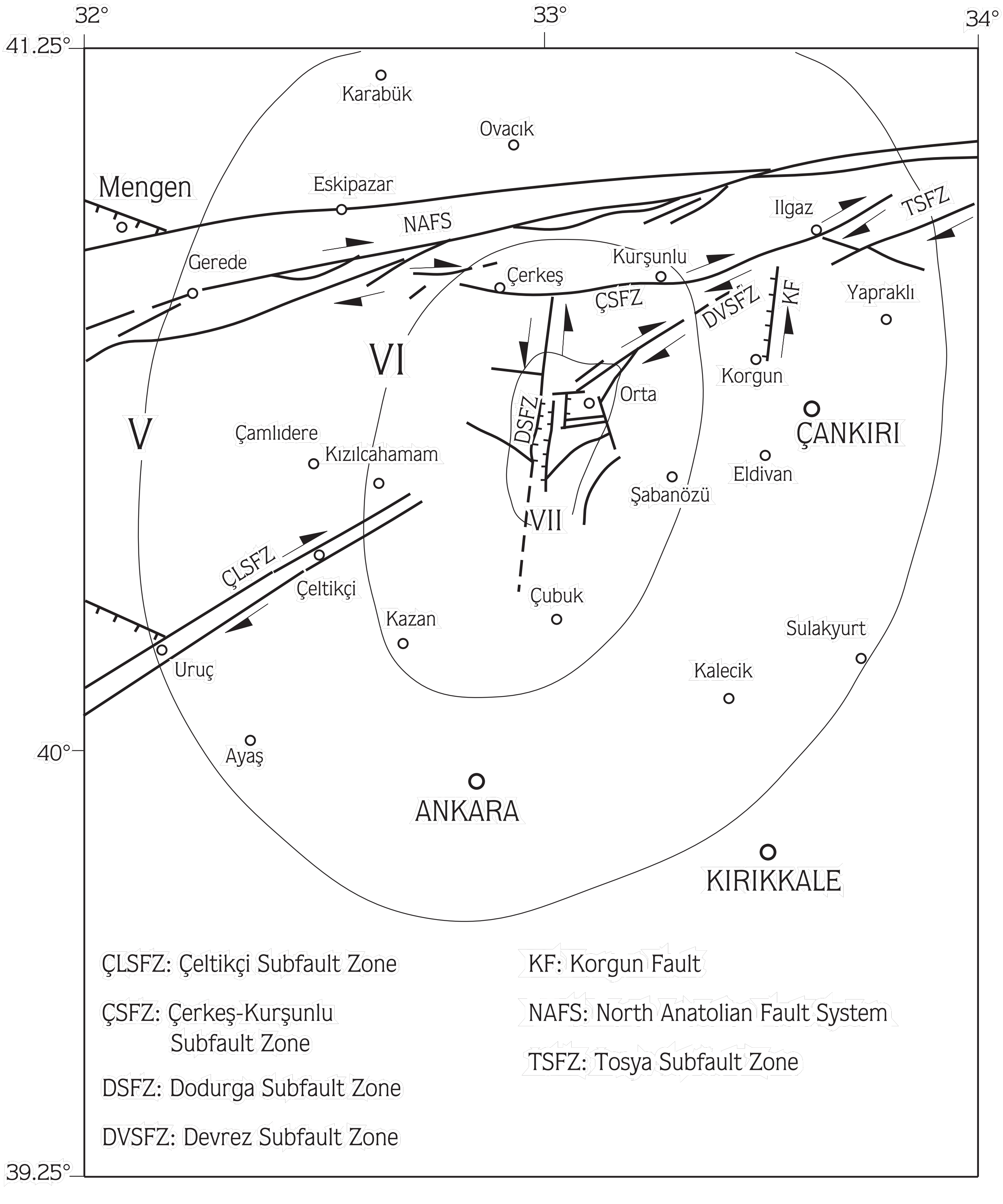

Figure 5. Isoseismal map for the June 6, 2000 Orta (Çankırı) earthquake.

Orta area – an approximately 36-km-long, 4- to 7-km-wide and N-S–trending sinistral strike-slip fault zone with a considerable normal-slip component . This structure is here first named the Dodurga fault zone (DFZ). It consists of numerous 1- to 36-km-long, closely-spaced, N-S–, NNE–, and NNW–trending isolated faults. Sinistrally offset (up to 6 km) formation boundaries, "S"-shaped deviated and sinistrally offset (up to 2.5 km) drainage systems, fault-parallel-aligned active landslides and Plio-Quaternary pull-apart basins reveal that the DFZ is an active sinistral strike-slip structure along which the rate of slip is 2.3 mm/yr. This is also proved by focal-mechanism solutions of various seismographic stations (Table 1, Figures 2a & 2c), the N-S–trending linear distribution of both fore- and after-shocks, and the high concentration of severe damage to structures within the DFZ.

Consequently, all of these geological field observations and seismological data indicate that the June 6, 2000 Orta earthquake occurred because of the Dodurga fault, the master strand of the DFZ.

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