CHAPTER 3

GEOLOGY OF THE ASARSUYU CATCHMENT

3.1. Geology

3.1.1. Regional Geology and Previous Works

The study area is located in northern Central Anatolia, within the North Anatolian Fault Zone (NAFZ), and it is mainly comprised of Paleozoic metamorphic/intrusive basement and its covering Mesozoic and Tertiary flyschoidal deposits (Figure 3.1) in the Pontide Tectonic unit of Ketin 1966.

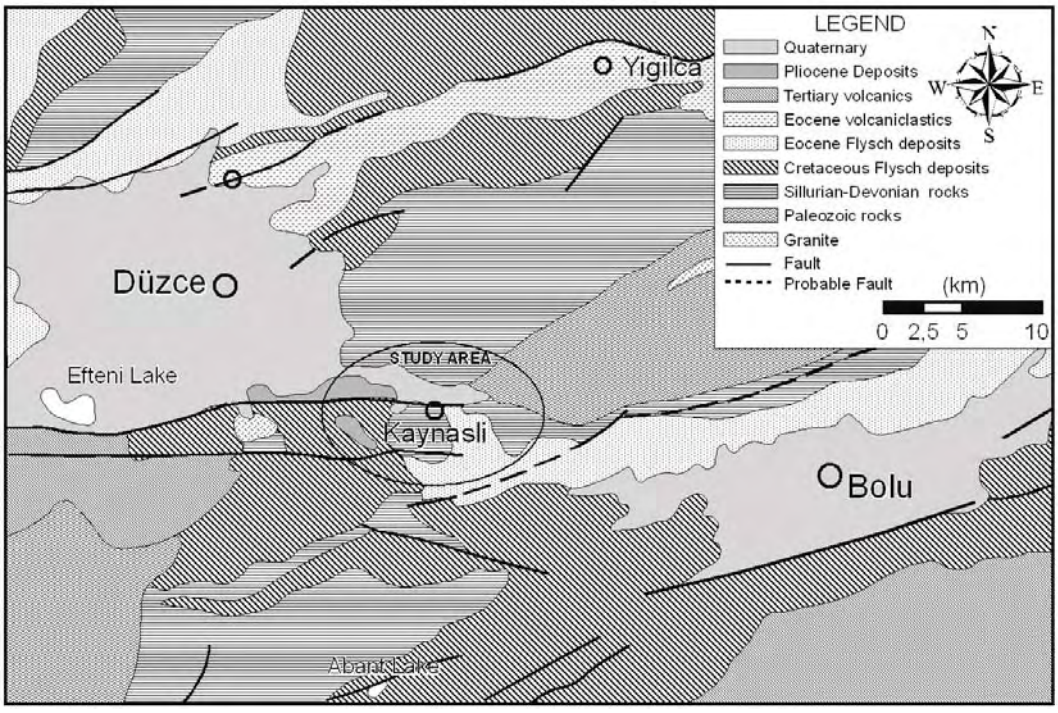

Figure 3.1. Regional geological map of the study area and its environs (modified from Tokay,1964).

The study area is hosting the main state highway connecting the capital city Ankara to the biggest metropolitan area İstanbul. The presence of the Anatolian highway and the problems associated with the construction of Bolu Tunnels attracted the attention of the scientists and hence a number of studies had been carried out concerning the geology, NAFZ and engineering geological problems of this region. Hereforth, a brief summary will be given about the previous works of the study area in table form (Table 3.1). The citations would be made in the appropriate parts in the following sections with detailed explanations when needed.

Table 3.1. Previous studies performed in the study area and its near vicinity

Research Field	Researcher	Research Area	Remarks
Geology	Blumenthal (1948)	Regional	First definitions of tectonic units
	Ketin (1955)	Akçakoca-Düzce	First sub-division of Paleozoic Massifs
	Uysallı (1959)	Bolu-Merkeşler	Coal Resources
	Abdülselamoğlu (1959)	Mudurnu-Göynük	Definition of Paleozoic and mesozoic formations
	Ketin (1967)	Bolu-Gerede-Mengen-Yıgılca	Paleozoic Units
	Batum (1968)	Northern Slopes of Asarsuyu Valley	First defined the age of the conglometares that overlie Bolu massif as Sillurian
	Gözübol (1978)	Mudurnu-Dokurcun-Abant	Geology/NAFZ
	Görmüş (1980)	Yığılca	Stratigraphy/Tectonics
	Yılmaz *et al.* (1981)	Abant-Dokurcun	Geological evolution, relations of metamorphic rocks and the ophiolitic rocks in area.
	Görmüş (1982a)	Yığılca	Stratigraphy
	Görmüş (1982b)	Yığılca	Tectonic and evolutionary model
	Kaya (1982)	Ereğli-Yığılca-Bolu-Mengen	Stratigraphy-Tectonics
	Kaya & Dizer (1981-1982a)	Mengen	Coal Resources
	Kaya & Dizer (1981-1982b)	North Bolu	Stratigraphy of Mesozoic and Tertiary sequences
	Cerit (1983)	Mengen	Geology
	Serdar & Demir (1983)	Bolu-Mengen-Devrek	Petroleum Resources
	Öztürk *et al.* (1984)	Abant-Yeniçağa	Stratigraphy of north and south of NAFZ

Table 3.1. (continued)

Geology	Aydın *et al.* (1987)	Çamdağ-Sünnicedağ	Complete stratigraphic outline.
	Kaya *et al.* (1986)	Yığılca	Stratigraphy of Mesozoic and Tertiary sequences
	Cerit (1990)	Bolu Massif	Geology and tectonics
	Erendil *et al.* (1991)	Bolu Massif	Economical resources
	Yalçın & Cerit (1991)	Bolu Massif	Investigated the metamorphism by using clay mineralogy
	Koral *et al.* (1994)	Asarsuyu	Microfabric study in Paleozoic rocks
	Gedik & Alkaş (1996)	Bolu Region	Carbondioxide potential
	Sözen *et al.* (1996)	Düzce and Devrek	Geochemistry/Economical resources
	Güler (1999)	Bakacak	Geology of gypsum
	Ustaömer & Rogers (1999)	Bolu Massif	Geochemistry – Evolution model
Engineering	Orkan *et al.* (1977)	Highway Route	Elementary landslide susceptibility map
	Canik (1980)	Bolu	Hydrogeology
	Aktimur *et al.* (1983)	Bolu	Landuse pattern and NAFZ related problems
	Dalgıç (1994 a,b)	Bolu Mountain Highway Pass	Engineering geology of Highway pass and Bolu Tunnel
	Dalgıç et al(1995)	Asarsuyu	Stability and nature of the Yumrukaya landslide
	Dalgıç & Gözübol (1995)	Bolu Tunnel	Stability problems in Bolu Tunnel
	Astaldi (1995)	Asarsuyu	Enginering geology of the Asarsuyu region for Bolu Tunnel construction
	Dalgıç (1997)	Bolu Tunnel	lithology and the fracture pattern in the Bolu Tunnels
	Simşek & Dalgıç (1997)	Düzce	consolidation properties of the clays at Düzce
	Aydan & Dalgıç (1998)	Bolu Tunnel	Prediction of Deformation inside the Bolu tunnel
	Dalgıç (1998,a)	Asarsuyu	slope stability problems in the Asarsuyu valley
	Dalgıç (1998,b)	Asarsuyu	Selection of crushed Rock Quarries

Table 3.1. (continued)

Engineering	Işın (1999)	Bolu Mountain Highway Pass	Investigated two landslides in the highway by insitu instumentation
	Unterberger and Brandl (2000)	Bolu Tunnel	Deformations in the Bolu Tunnels after the 12. Nov 1999 Düzce earthquake
	Aydan *et al.* (2000)	Düzce	Interdisciplinary study concerning the geological, engineering geological, seismological and geotechnical aspects of Düzce earthquake
	Sucuoğlu *et al.* (2000)	Regional	Engineering report regarding both the Marmara and Düzce earthquakes
NAFZ (Tectonics)	Ketin (1969)	Regional	First definition
	Ambraseys (1970)	Regional	Characteristic features
	Tokay (1973)	Gerede-Ilgaz	Characteristics
	Gözübol (1978)	Mudurnu-Dokurcun-Abant	Structural properties of the NAFZ
	Şengör & Canıtez (1982)	Regional	Characteristics + evolutionary model
	Öztürk *et al.* (1984)	Abant-Yeniçağa	Paleo and Neo-tectonic structures
	Nurlu(1993)	Bolu-Sapanca	RS
	Neugebauer (1994)	Abant	Closing-up Structures-effect of bends in NAFZ
	Astaldi (1995)	Bolu Tunnel – Asarsuyu valley	Pattern of faulting in the area, also deformation in the area gathered by GPS measurements and evaluated together with microseismic data.
	Neugebauer (1995)	Adapazarı – Bolu	Kinematics of NAFZ
	Şaroğlu *et al.* (1995)	Gerede-Eskipazar	
	Neugebauer *et al.* (1997)	Abant-Sapanca	Overstep in NAFZ
	Akyüz *et al.* (2000)	Düzce	Slip distributions of Düzce Earthquake
	Taymaz (2000)	Gölcük-Sapanca-Düzce	Seismotectonics

3.1.2. Stratigraphy

The basement of the Asarsuyu catchment is composed of pre-Devonien Yedigöller Formation, an assemblage of metadiorite-metagranite and amphibolite–amphibolite gneiss (Figure 3.2). Following in the sequence İkizoluk Formation and its Çatak member forms the Devonien which tectonically overlies the underlying Paleozoic

basement. Upper Cretaceous is characterized by Abant Complex and Elmalık Granite, which again have a tectonic contact with underlying sequence. Starting from Upper Cretaceous to Pliocene a carbona-clastic sequence (flysch) is seen in the area, which is represented by Atyayla, Bayramışlar, Fındıcak and Apalar Formations. Plio-Quaternary period is represented by Asarsuyu formation, which is a combination of terrace conglomerates and alluvial fill deposits in the Asarsuyu valley itself. Finally, Quaternary alluvial fill and slope debris cover unconformably the whole sequence in the Asarsuyu catchment.

3.1.2.1. Yedigöller Formation

Yedigöller Formation is the core of the Bolu massif and composed of Paleozoic magmatic rocks. The formation has widespread outcrops in the eastern and northern slopes of the Asarsuyu catchment (Figure 3.3) The formation is first named by Aydın et al. (1987).

The main lithologies of the formation are amphibolite, gneiss (metagranite), metadiorite and meta-quartzdiorite. Also very small unmappable aplite, andesite, basalt and diabase dikes are common. Some of these are mylonitized by regional paleo and neotectonic events. The unit is in general affected from the regional metamorphism, and show cataclastic deformation in the vicinity of the fault zones. This formation can be divided into two as one having greenschist metamophism and having no metamorphism. The greenschist facies of this formation generally have a medium degree of weathering resulting in a thin residual soil cover (1 - 3 meters).

The lower boundary of the formation cannot be seen in the catchment; however its upper boundary is tectonic with the overlying Devonian İkizoluk Formation, which is not observed in the study area.

This formation comprises the southwest part of the Bolu Massif. Blumenthal (1948) assigned Paleozoic age to the metamorphics in the area. Ketin (1967) indicated that the age of the assemblage of amphibolite, gneiss and basic rock in Bolu-Gerede-Mengen-Yığılca area is Cambrian. Erendil et al. (1991) assigns the name Bolu Granitoid to the formation and cites that the age should be Pre-Late Ordovician. While Canik (1980), Aydın et al. (1987) and Cerit (1990) suggest Pre-Cambrian age. Based on these literature arguments, the age of the Yedigöller Formation is assigned as Pre-Devonian.

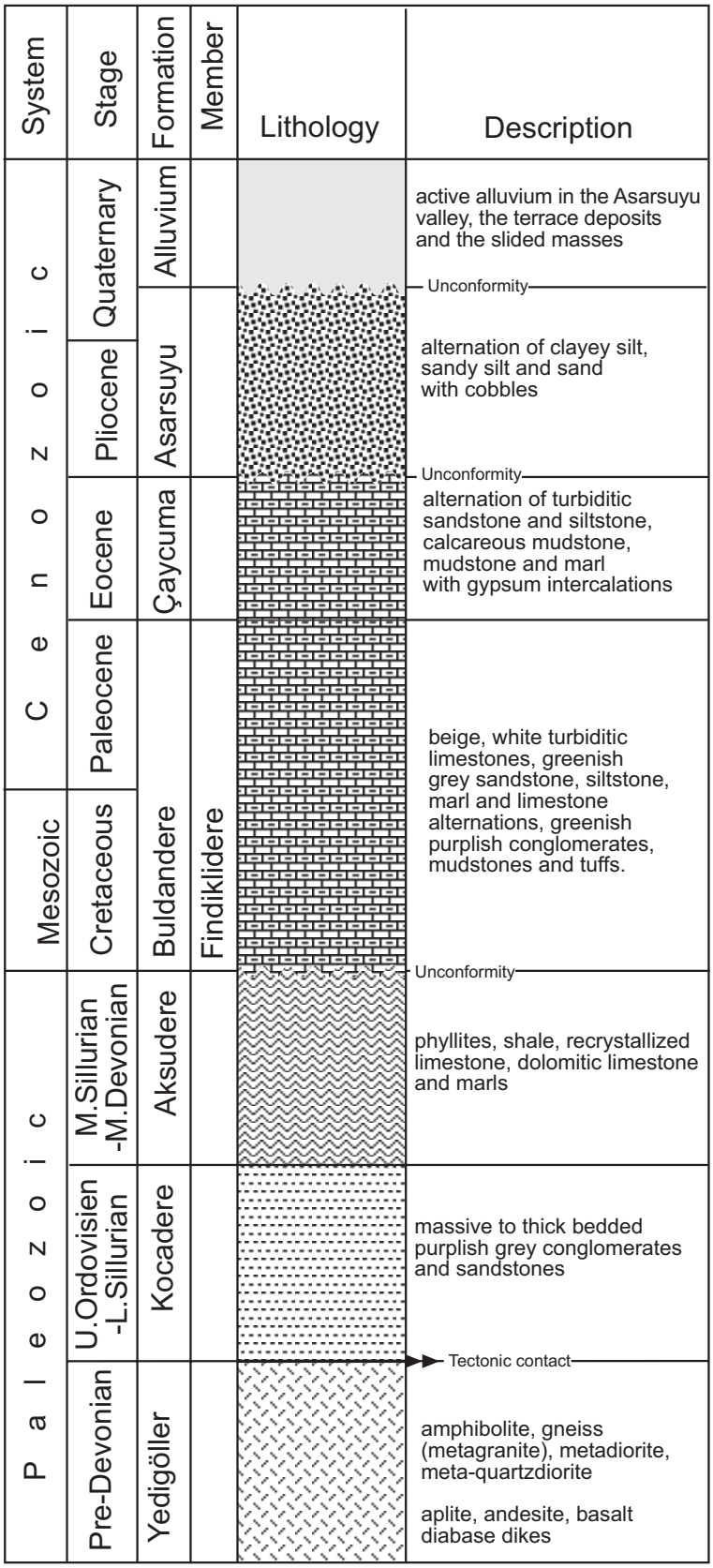

Figure 3.2. The generalized columnar section of the study area, (not-to-scale) (modified from Erendil *et al.* ,1991).

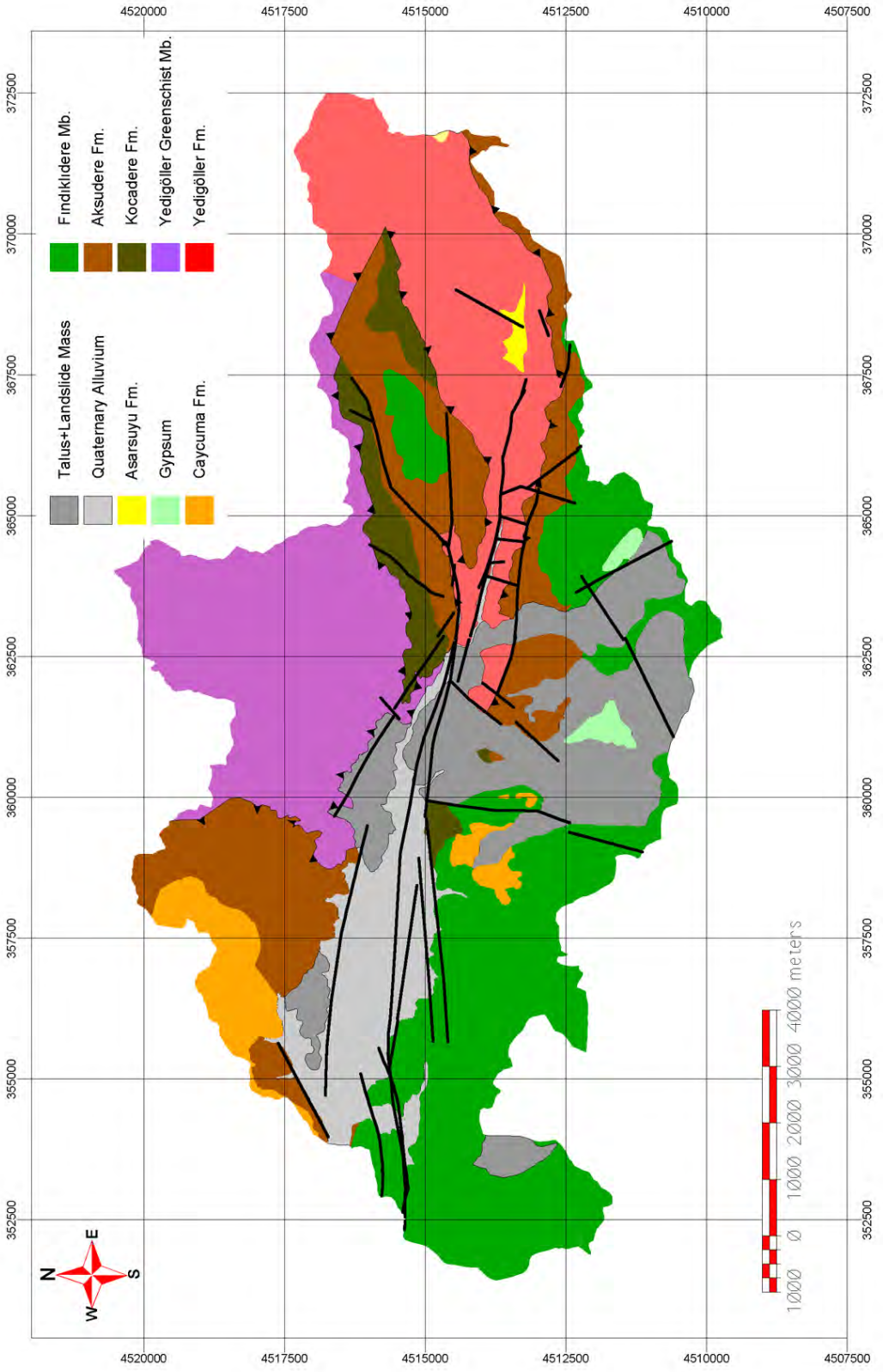

Figure 3.3. The geological map the study area (modified from Erendil *et al.* ,1991).

3.1.2.2. Kocadere Formation

This formation generally crops out as a rim to the Yedigöller Formation. The outcrops of this formation is seen only in the eastern part of the catchment at northern slopes of Asarsuyu river. The formation is defined by Erendil et al. (1991).

Kocadere Formation is composed of massive to thick bedded purplish grey polygenetic conglomerates and sandstones (greywacke). Limited mudstone and siltstone bands are also observed. Conglomerates are poorly sorted, and their components are derived from underlying metamorphics, and magmatic rocks, the matrix is composed of chlorite, quartz and serrisite (Erendil et al., 1991).

The lower boundary of the formation is tectonized and obscured. Its upper boundary is conformable with the Aksudere Formation.

The equivalent of this formation, the Kurtköy Formation of Istanbul (Kaya, 1973) is given an age of Ordovician. The other possible equivalents of this formation, “Hamzafakılı sandstones” (Tokay, 1952), Işığandere Formation (Görmüş, 1982 a, b) and “purple arkoses and conglomerates” (Batum, 1968) are aged as Late Silurian. Based on these ages, Erendil et al. (1991) assigns Late Ordovician-Early Silurian age to Kocadere Formation.

3.1.2.3. Aksudere Formation

Aksudere Formation is seen in the northern slopes of Sarıçökek village and at the eastern parts of the catchment at southern part of Asarsuyu river near Aşağıbakacak settlement and in between the two major landslides near Bakacak village. The formation is defined by Erendil et al. (1991).

Aksudere formation is represented by phyllites, shale, recrystallized limestone, dolomitic limestone and marls. The phyllites show significant schistosity and the main constituents are quartz, serrisite muscovite, chlorite, epidote and feldspars. They also host some embedded massive recrystallized limestone blocks. Phyllites and recrystallized limestones alternate with shales, siltstones, sandstones, dolomitic limestones and marls as thin to medium beds. The uppermost levels of this formation is characterized by the dominance of recrystallized limestones. The formation forms a gentle rolling topography, as it is composed of easily erodible lithologies. The main colors observed in this formation are dark grey, beige, bluish-greenish grey and brown.

The lower boundary is conformable with Kocadere Formation and its upper boundary is also conformable with Kırdoruk Formation. However, the Kırdoruk Formation does not outcropping in the Asarsuyu catchment. According to Erendil et al. (1991), the observed thickness of Aksudere Formation is about 1500-2000 meters.

Görmüş (1982, a) stated that the equivalent of lower facies of Aksudere Formation is Kocadere formation which is Lower Devonian. The Devonian aged Kartal formation of Kaya (1973) can also be correlated with Aksudere formation. Dalgıç (1994, a,b) grouped the Kocadere and Aksudere formations under İkizoluk formation and assigned an age of Devonian. Furthermore, he subdivides the uppermost section of Aksudere formation, the recrystallized limestones as Çatak Member in İkizoluk formation. Erendil et al. (1991) assigned an age of Middle Silurian to Middle Devonian.

3.1.2.4. Buldandere Formation

Erendil et al. (1991) uses this formation name to cover all of the Upper Cretaceous-Paleocene cover units, that overlie the Paleozoic Bolu Massif.

3.1.2.4.1. Fındıklıdere Member

Fındıklıdere member comprises the middle levels of Buldandere Formation outside of the Asarsuyu catchment. The member is first defined by Erendil et al. (1991). Fındıklıdere member has widespread outcrops in the southern slopes of the catchment.

The lithology of the Fındıklıdere member consists of beige-white turbiditic limestones, greenish grey sandstone, siltstone, marl and limestone alternations, greenish purplish conglomerates, mudstones and massive to medium to thick bedded gypsums. The gypsum occurrences are generally observed near the summit of Bolu Mountain and near Dipsizgöl and Yukarıaçma villages. There are also some rock quarries opened for gypsum production in these localities. Gypsums outcrops have significant karstic dissolution features, such as siphons going up to tens of meters in depth. The association of these layers resembles an Upper Cretaceous flyschoidal sequence.

The lower boundary of the member in the study area is unconformable with the Aksudere Formation, while its upper boundary is conformable with Eocene Çaycuma Formation. The thickness of the formation is estimated by Erendil et al. (1991) as 600 meters.

For the age of this member Erendil et.al. (1991) give a long list of fossils and assign Campanian - Ilerdian age. Similar formations are named and aged as: Cretaceous Flysch (Abdülselamoğlu, 1959), Gökveren Formation – Eocene (Gözübol, 1978 and Yılmaz et al., 1981), Sarıkaya Formation – Upper Cretaceous/Paleocene (Görmüş, 1980), Akveren Formation – Campanian/Lower Paleocene (Aydın et. al.,1987), Fındıcak Formation – Upper Cretaceous/Paleocene (Dalgıç, 1994, a,b).

3.1.2.4.2. Çaycuma Formation

This formation seems like the continuation of the cover units of the Bolu Massif and Fındıklıdere member. It crops out at south of the Kaynaşlı town at Akmeşe and Türbe hills, also in the north of Yörükler village. The formation is first named by Saner et al. (1979). The main lithologies of the formation is alternation of turbiditic sandstone and siltstone, calcareous mudstone, mudstone and marl with gypsum intercalations.

The lower boundary of this formation is conformable with Fındıklıdere member, while its upper boundary is not seen in the Asarsuyu catchment. The age of this formation is assigned by Erendil et al. (1991) as Eocene and is supported by both literature and fossil records. Dalgıç (1994) defined another member in the Asarsuyu catchment as Açma member, for which the age of Late Eocene was assigned and the dominant lithologies are defined as alternations of argillaceous limestones, gypsums, calcareous mudstones and clayey gypsums, which are similar to Fındıklıdere member of Erendil *et al.* (1991).

3.1.2.5. Asarsuyu Formation

Minor differences and the spatial orientation of the outcrops led Dalgıç (1994, a,b) to differentiate this formation from Quaternary alluvium. The Asarsuyu Formation crops out near Elmalık village and near the Asarsuyu portal of the Bolu Tunnels. Main lithologies of this formation include alternation of clayey silt, sandy silt and sand with cobbles.

The Lower boundary is unconformable with the older formations and its upper boundary is again unconformable with Quaternary alluvium. The age of Plio-Quaternary is based on palynological data by Astaldi (1990).

3.1.2.6. Quaternary Deposits

The Quaternary deposits are characterized by the active alluvium in the Asarsuyu valley, the terrace deposits in the northern margins of the Kaynaşlı plain and the slided mass of the to huge landslides in the southern slopes of Asarsuyu valley.

3.2. Tectonism of the Asarsuyu Catchment

The Düzce-Bolu region is one of the most tectonically active regions of Turkey. During complex tectonic evolution of the area, the catchment had been subjected to different regimes and different deformations which are reflected in the current outcrops and topography. The active faults, belonging to the North Anatolian Fault Zone, and the older thrust faults are the major large scale structural features and form the main tectonic elements of this catchment. The thrust faults are believed to act in the compressive regime after Late Cretaceous and ceased in Late Miocene (Yılmaz et al. 1981; Dalgıç, 1994) and classified as Paleotectonic features. The deformation of the region took the form of lateral strike-slip faulting after Late Miocene period in the Neoectonic regime. The deformation is still active as the North Anatolian Fault Zone and its associated faults take the act in hand and reshape the catchment (Aydan et al., 2000). During aerial photographical interpretation studies these faults are mapped and digitized. Due to the scope of this study both the thrusts and other active faults are treated together, as large discontinuities in the catchment.

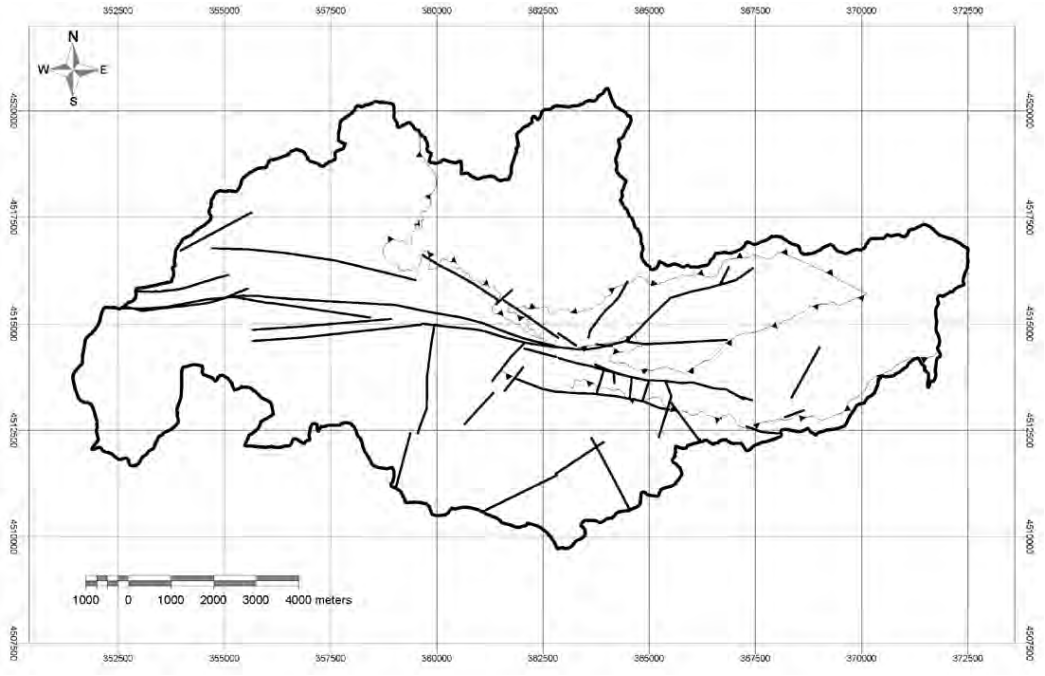

Figure 3.4. Lineament map of the Asarsuyu catchment

The earthquake activity of this region is directly controlled by the presence and activity of North Anatolian Fault zone and its associated fault segments. The North Anatolian Fault is the northern margin of Anatolian block that is escaping from the collusional zone between Arabian and Eurasian plates into the Eastern Mediterranean Sea (Şengör et al., 1985). The North Anatolian Fault is one of the most well known and most studied faults in Turkey, which has been defined some 50 years ago. The length of this fault is approximately 1200 kilometers and it is not a single fault, which in turn, worths to consider it as a fault zone (Sucuoğlu et al., 2000). The width of this zone is about 1 kilometer is widening up to 5 kilometers in the west (Demirtaş and Yılmaz, 1996). The total displacement made by this fault is reported as 20-25 kilometers by Neugebauer (1994) at Abant lake environs. Global positioning system studies (GPS) have been ongoing in the area since 1988 and the lateral slip on the Düzce fault is estimated as 7.5±1.5 mm/year (Astaldi, 1995)

The main fault strand of the North Anatolian Fault splays into two strands in the west of Bolu; the southern strand goes through the Lake Abant and then the Mudurnu valley. The northern strand steps to the north, forming the southern boundary of the Düzce basin being called the Düzce fault. In the west end of the Düzce basin, thereafter it is named the Hendek fault. Şaroglu et al. (1987, 1992) who published "Active Faults of Turkey" showed no minor connecting fault between the main trace of the North Anatolian fault and the Düzce fault. Barka and Erdik (1993) reported that there are two secondary faults, the Elmalık and Aşagı Bakacak faults that occured between the main trace and the Düzce fault as connecting faults.

3.3. Seismicity of the Asarsuyu Catchment and Environs

A total of 623 earthquakes, that are greater than 5 in instrumental magnitude have been recorded in the NAFZ in the period of January 1900 to March 2001 (Figure 3.5) having a total of 98 quakes greater than 6 in magnitude. However, the seismic evaluation of the whole fault zone is out of scope in this study, so the concentration will be turned on the study area and its vicinity. In order to compare the activity in the west and middle parts of the NAFZ and the rest of Turkey the earthquakes of the western/middle is counted and shown in Figure 3.6. 151 earthquakes out of 623 are counted, which represent nearly 25% of total earthquakes in Turkey greater than 5, in the study area. When zoomed into the study and environs, there are a total of 2596 earthquakes, of which 410 of them are greater than 3.5 in magnitude. Their spatial locations with their magnitude distributions are shown in Figure 3.7. Four earthquakes greater than 7 occurred in the area, chronologically 26-05-1957 Abant, 07-22-1967 Mudurnu, 17-08-1999 Marmara and 12-11-1999 Düzce earthquakes. The surface

rupture pattern of the 12-11-1999 Düzce earthquakes is shown in Figure 3.8. Furthermore some small landslides have occurred in the are immediately after the earthquake, some examples of these are presented in figure 3.9.

The historical records show that on the western zone of the NAFZ, 3 major earthquakes are recorded (Ambraseys and Finkel, 1995). The 25-05-1719 earthquake occurred east of Marmara sea resulted in 6000 casualties, and 4/5 of İzmit city is demolished. The second quake occurred at 2-09-1754 in the vicinity of İzmit Bay and approximately 1000 casualties was recorded. A third quake was recorded again in the east of Marmara Sea affecting the whole coast line of the Marmara region at 22-05-1766 resulting in 5000 casualties.

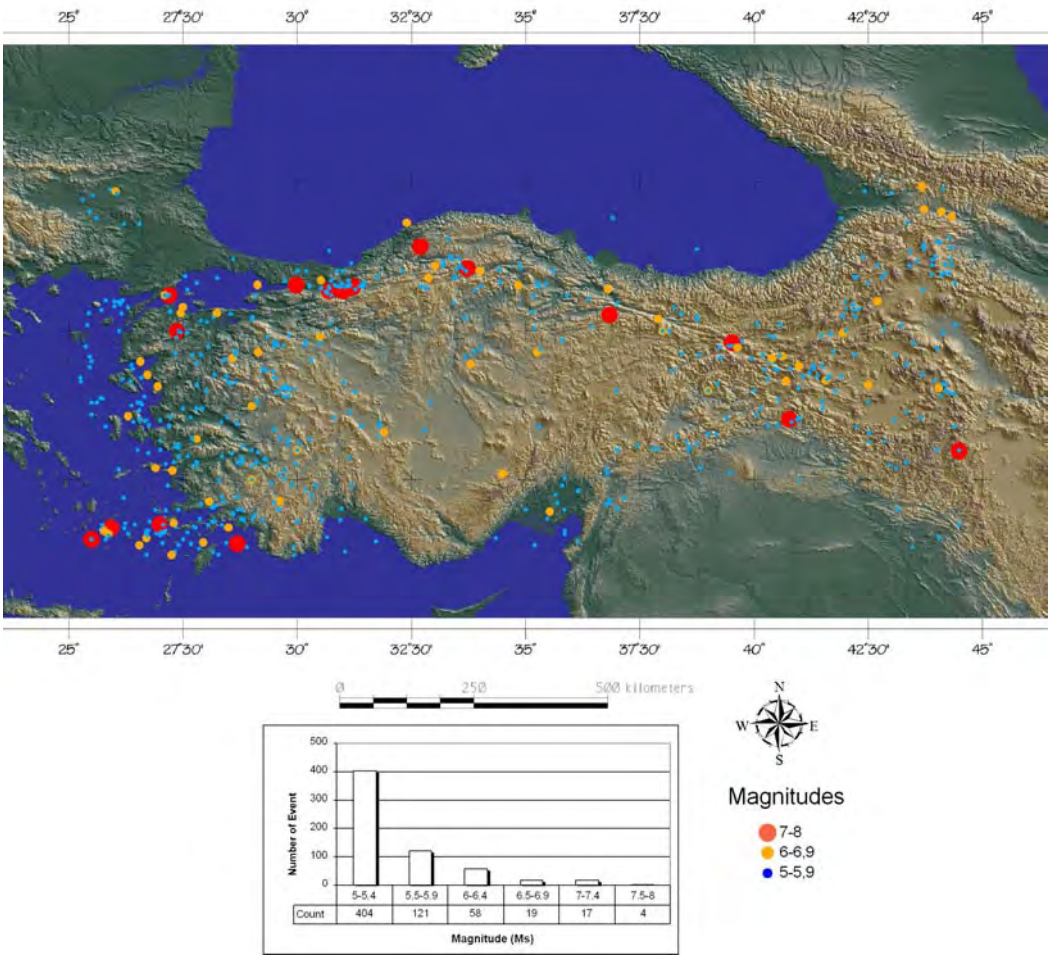

Figure 3.5. Epicenter locations of Turkey greater than 5 in magnitude (Magnitudes in Ms)

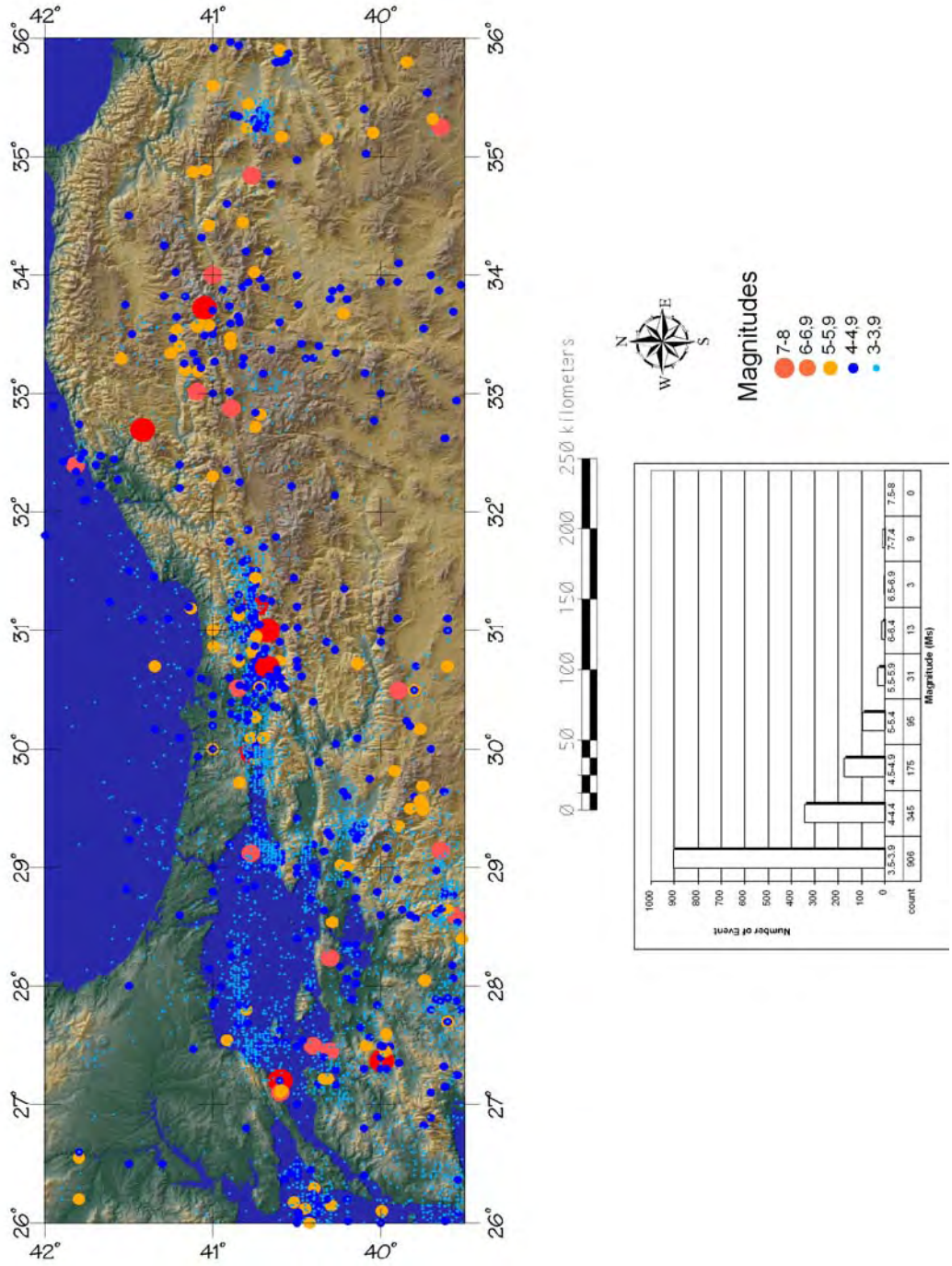

Figure 3.6. Epicenter locations of mid-west NAFZ greater than 3.5 in magnitude

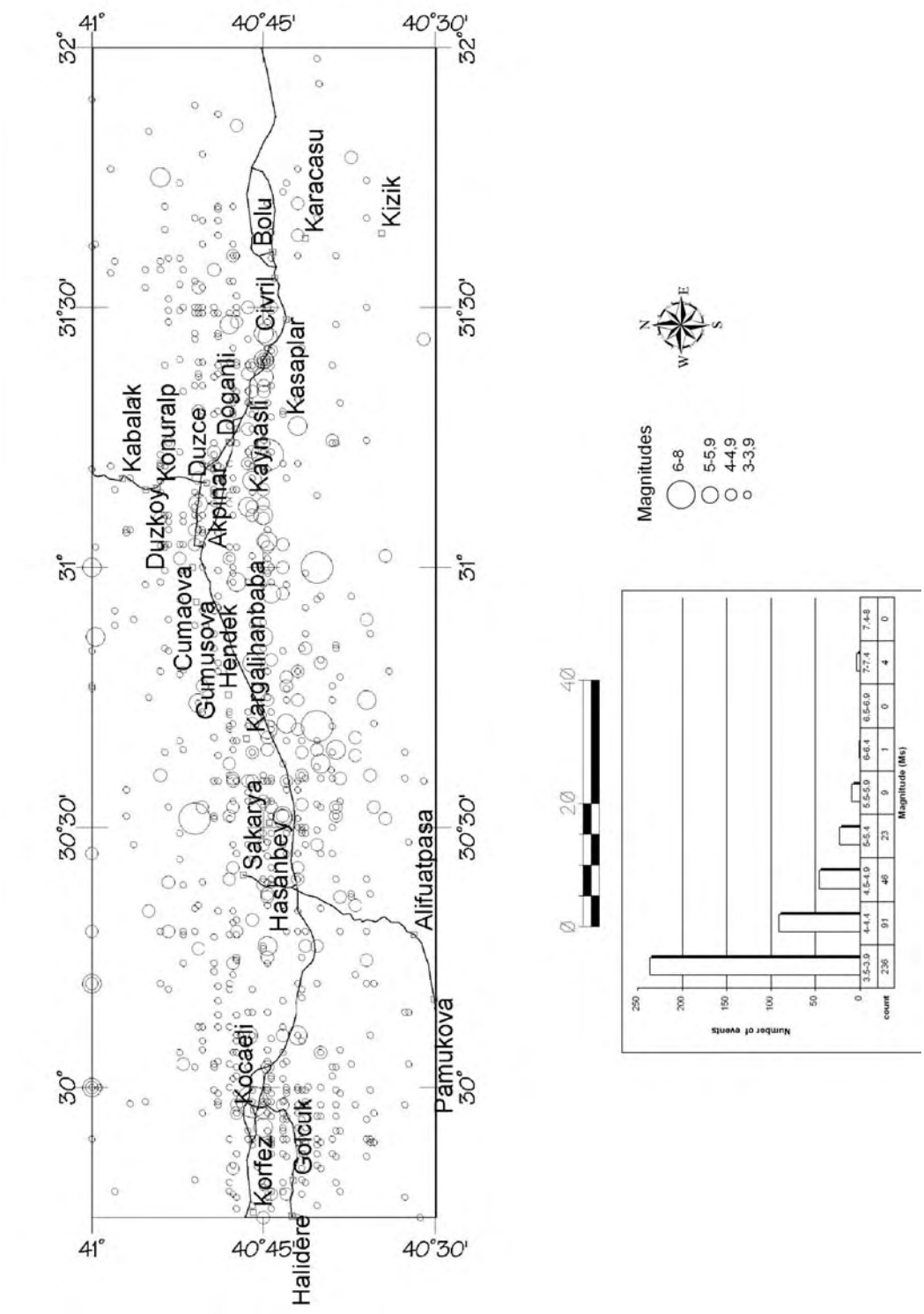

Figure 3.7. Earthquakes occurred in the nearby of the study area.

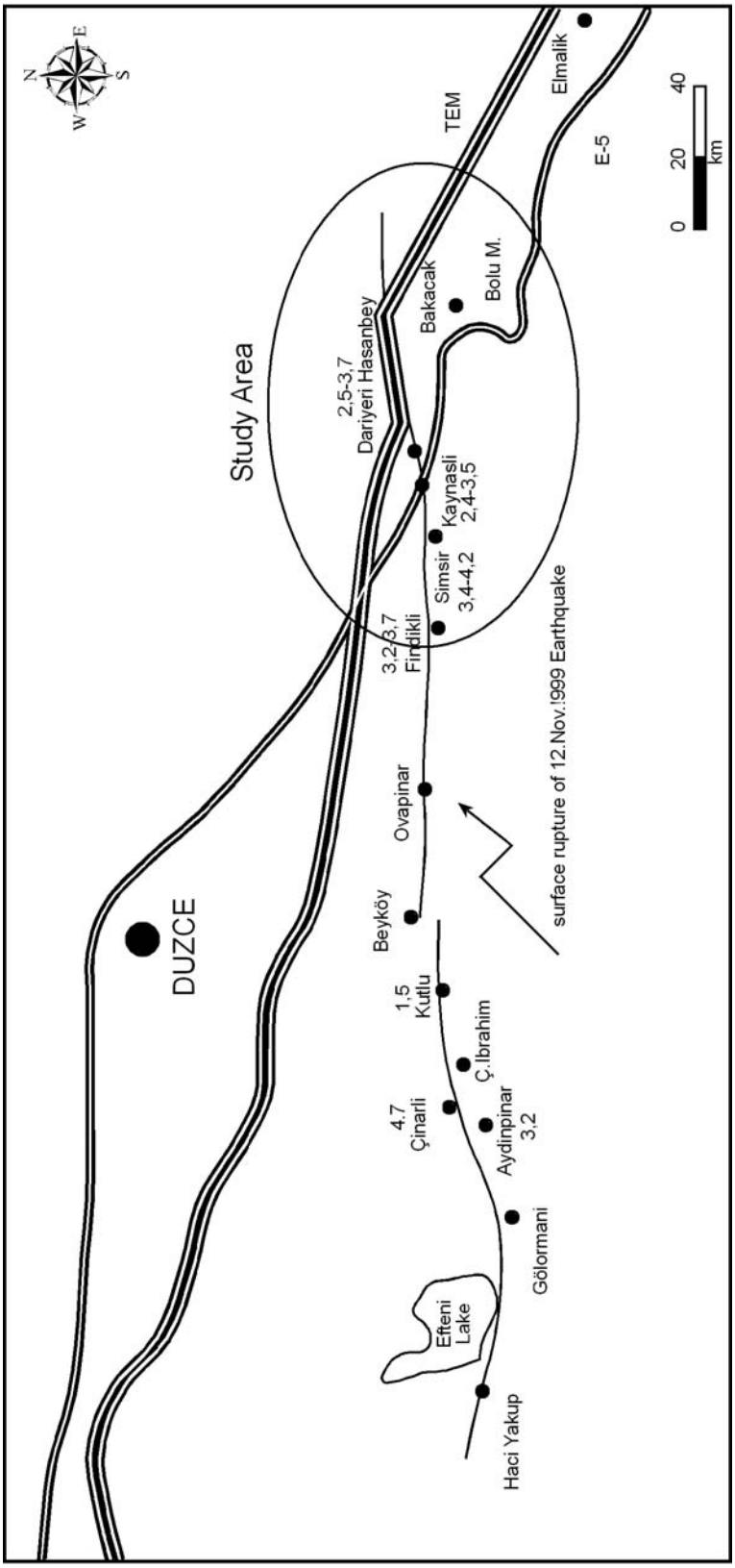

Figure 3.8. Surface ruptures of the 12 November 1999 Düzce earthquake (Aydan et al., 2000), Displacements are in meters.

Figure 3.9. Some examples of landslides occurred after 12 November 1999 Düzce earthquake.