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THE BIGNOL, EASTERN TURKEY, EARTHQUAKE. CO-SEISMIC PHENOMENA AND DAMAGE DISTRIBUTION

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SUMMARY

On May 1, 2003 a large catastrophic and deadly earthquake (Mw=6.4), occurred at the Eastern Turkey, some Km to the North of Bingol city. The large scale tectonics of the region is controlled by the collision between the Eurasian and Arabian plates. This is the result of the northward motion of the Arabian plate, relative to Eurasia, which also causes the lateral escape of the Anatolian block to the West. The Anatolian block is bounded to the North by the North Anatolian Fault (NAF) and to the South by the East Anatolian Fault (EAF). These two branches of the Anatolian Fault System cross cut to the east at Karliova triple junction point. The recent Bingol earthquake occurred near the eastern part of the EAF.

The field work data show that the tectonic pattern of this area is very complicated and is representing both by NE-SW or NW-SE strike-slip faults and N-W normal faults. According to the fault plane solution this earthquake may have been the result either of the reactivation of a part of the NE-SW trending EAF or of the reactivation of someone of the NW-SE faults crossing the area. Although the aftershock distribution pattern, with M>2, is scattered, the distribution of the main aftershocks, with M>4.5 follows a clear NW-SE direction.

A zone of co-seismic strike-slip, right-lateral surface ruptures, trending to the NW-SE direction, observed 15-20 Km to the North of Bingol city. The distribution of landslides, rock falls and settlements, which took place during the seismic event, also follow the same direction. All these data suggest the reactivation of a NW-SE trending right-lateral, strike-slip fault to the North of Bingol.

INTRODUCTION

On 01 May 2003 (00:24:04 UTC), a major earthquake hit eastern Turkey. The epicenter was located at 38.991N, 40.462E (USGS), the magnitude was Mw=6.4 (USGS) and the focal depth was h=25 Km (USGS). The earthquake caused considerable damage to Bingol city and villages in vicinity. The main

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bulk of the damage was within a 50 by 30 Km zone (with a NW-SE main axis), which also included the few surface raptures and geotechnical effects (mainly landslides), caused by the earthquake.

The post earthquake damage evaluation reported approximately 174 deaths and 520 injuries, the most of which occurred in Bingol city (60 deaths and 360 injuries). The most tragic case of deaths was this of Celtiksuyu School, which totally collapsed and the result was 84 dead children and one teacher. During the earthquake in Bingol city, 308 buildings collapsed partially or totally and 2566 were heavily damaged. In the vicinity more than 2000 buildings collapse or heavily damaged (Gulkan et al. [1]).

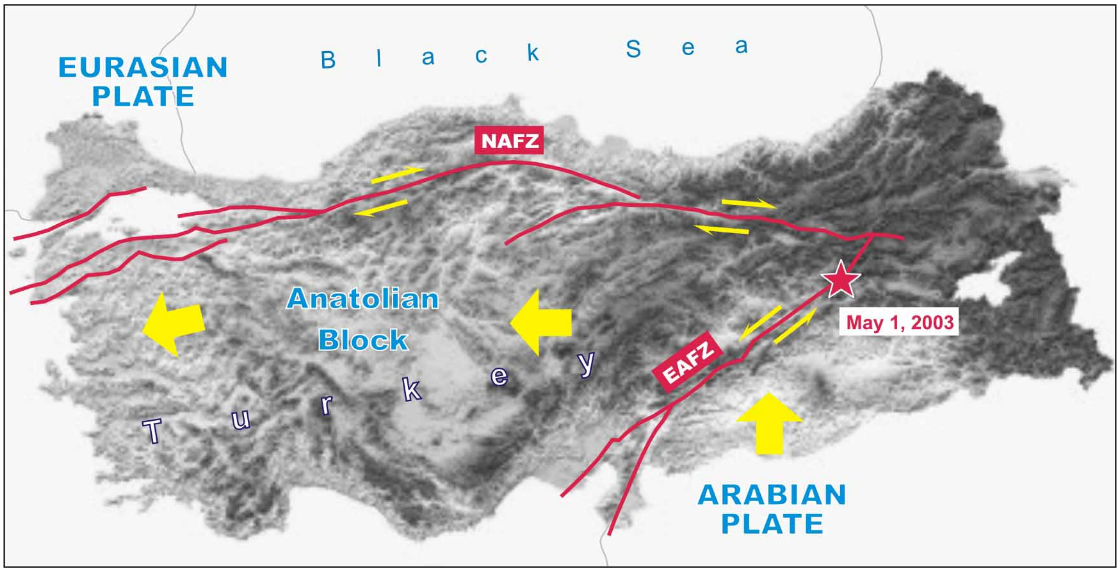

Figure 1. Location of the May 1, 2003 earthquake.

The epicenter of the earthquake (Figures 1 & 2) lies at the eastern segment of the NE-SW trending, Eastern Anatolian, strike-slip, left-lateral, Fault Zone (EAFZ). This segment is 60 Km long, from Bingol to the NW up to Karliova to the NE, where it is crossing with the North Anatolian (NAFZ) and North-Eastern Anatolian (NEAFZ) Fault Zones (Karliova triple junction). This north-eastern part of the EAFZ is very complicated while it is composed of many NE-SW closely spaced parallel left-lateral strike-slip faults, which form an NE-SW zone, approximately 20 Km wide. Important NW-SE strike-slip, right-lateral faults also observed within this zone, which seems to be active as the NE-SW one (Gulkan et al. [1], Saroglu et al. [2]).

The last major catastrophic earthquake at the same area was the 1971, M=6.8, Bingol earthquake, which caused a zone of surface raptures, approximately 40 Km long, along the EAFZ (Figure 2). Both kinematic character of surface raptures and focal mechanism solution reveal a left-lateral, strike-slip movement (Gulkan et al. [1]). In contrast to this, for the recent 2003, M=6.4 event there is not clear surficial expression of the seismogenic fault. The field observations and the study of the few surface raptures, which caused by the earthquake, in combination with the distribution of the geological effects and damages, the distribution of the after-shock sequence, and the fault-plane solutions, lead as to the conclusion that the seismogenic fault was trending NW-SE and had a strike-slip, right-lateral geometry.

SEISMOTECTONIC SETTING AND GEOLOGICAL FRAME

The dynamic and tectonic regime of the Eastern Turkey (Figure 1) is controlled by the collision between the Arabian and Eurasian Plates. The Arabian Plate moves northwards, towards the Eurasian Plate, squeezing the Anatolian Plate out and to the West, while a portion of Eastern Turkey is driven eastwards. The westward extrusion of the Anatolian Plate is accommodated through the NAFZ to the north, witch has a mean E-W trend, running from Armenia to the Sea of Marmara, and the EAFZ to the south, which has a NE-SW trend, from Karliova to Maras (Barka et al. [3], Sengor et al. [4]).

The NAFZ represent a first order tectonic structure (approximately 1500 Km long) within the Eurasian Plate and it is characterizing by a right-lateral, strike-slip motion. The total relative displacement along the NAFZ varies from 40 Km in the east, near Erzincan, to 15 Km in the west, near Marmara Sea and has given birth to a series of major earthquakes, many of them exceeding magnitude 7. Ten such large earthquakes have occurred since 1939, causing considerable damage to the population centers lying on its traces (Barka [5]).

The EAFZ is an approximately 550 Km long, strike-slip, left-lateral fault zone, trending to the NE-SW direction, which exceeds from Karliova triple junction in the NE, where it is crossing with the NAFZ, to Maras triple junction at the SW, where it intersects the Dead Sea Fault Zone (Figures 1 & 2). Estimations on the age of EAFZ range from Late Miocene to Late Pliocene. The total relative displacement along the fault zone varies between 3.5-13 and 15-27 Km. The seismic activity of the EAFZ seems to be lower than the NAFZ, while only four major catastrophic events, with a magnitude between 6.0 and 6.8, occurred during the 20th century (Saroglu et al. [2]).

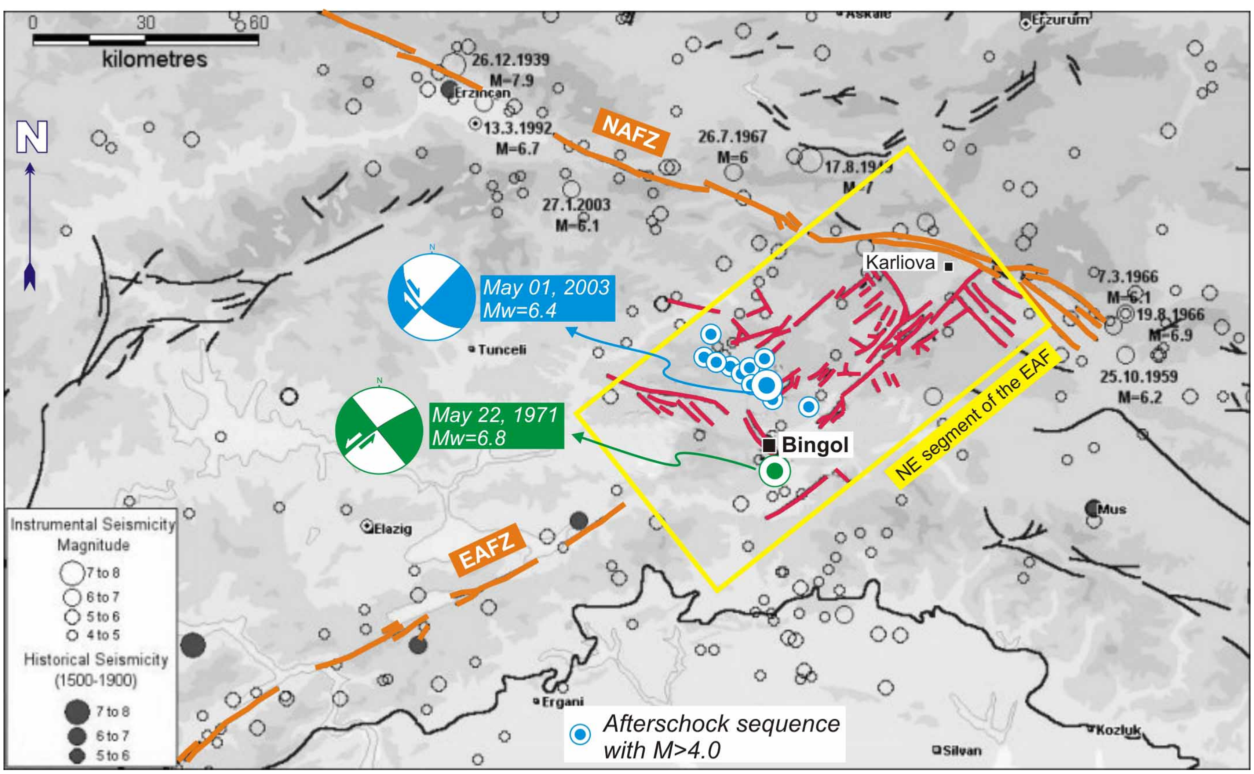

Figure 2. Simplified seismo-tectonic regime of the major area.

The NE segment of the EAFZ, which exceeds from Karliova to the NE up to Bingol to the SW, is not expressed in the surface as a single major fault line (Figure 2). The fault pattern is very complicated and it is representing of a 60 Km long and 20 Km wide, NE-SW trending, zone, which is composed of many closely spaced parallel NE-SW strike-slip, left-lateral faults. Within this zone a number of NW-SE strike-slip faults can be also observed, with a kinematic character which indicates a right-lateral geometry.

The last major catastrophic earthquake, which has been occurred in the same area, is the 1971, M=6.8, Bingol earthquake. During this event reactivated the south-western end of this segment and the earthquake seems to be connected with the NE-SW system of faults. The surficial expression of the seismic fault created a, 40 Km long, NE-SW zone of surface raptures, to the SW of Bingol city. The most of these raptures trending NE-SW and presenting a strike-slip, left-lateral geometry, which coincides with the data of the focal mechanism solution (Gulkan et al. [1]).

The epicentral area for the recent earthquake was also located at the south-western part of this segment, where both NE-SW and NW-SE trending faults can be observed (Figure 2). The satellite image interpretation and the field data show three main systems of possible faults in the study area. In the first system belong mainly long fracture zones, with NE-SW direction, parallel to the main river systems of the area. The second system of fracture zones has a NW-SE direction and is located mainly in the area north of Bingol city. Finally the third group is characterized by small scale fracture zones, of N-S direction, located mainly between the fracture zones of NW-SE direction.

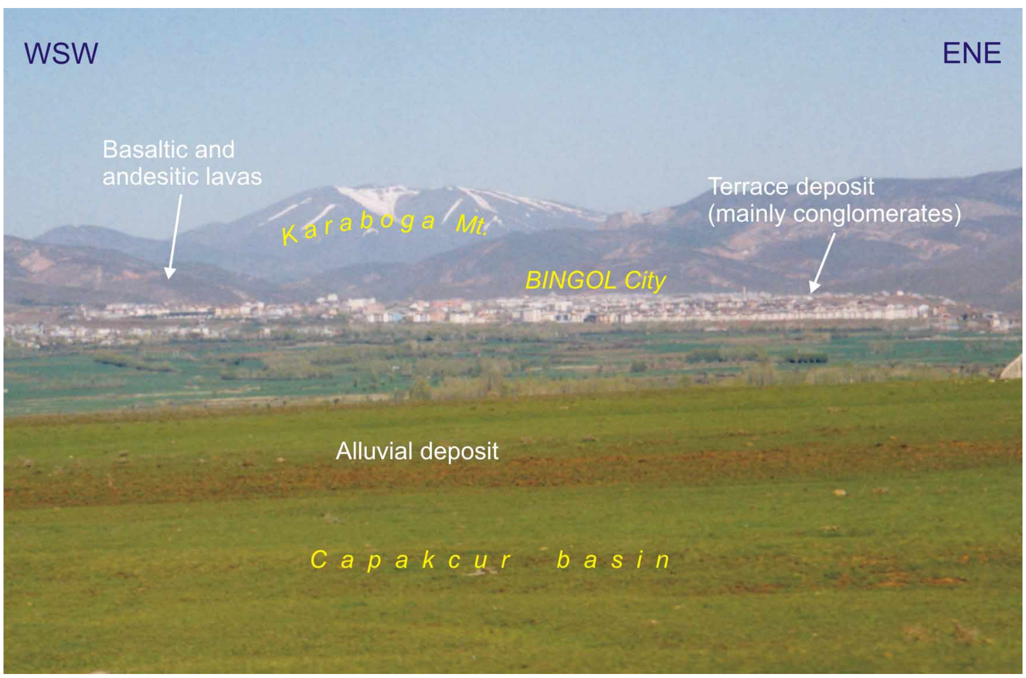

Figure 3. Soil conditions of Bingol city and the major area.

It is remarkable that Bingol city is located at the cross-cutting point between the NE-SW and NW-SE fault systems. The city is built on the alluvial fans and terraces of the northern border of Kapakcur basin, which mainly consist of conglomerates. The geologic formations of the bed-rock and the surrounding region are mainly composed of Plio-Quaternary basaltic and andesitic lavas (Figure 3).

THE EARTHQUAKE PARAMETERS

The seismic sequence generally located 15-20 Km to the north, north-west of Bingol city. The main shock (May, 1) showed a magnitude of M_W=6.4 on the Richter scale (USGS, INGV) and it is located near Kartal village, about 10 Km N-NW of Bingol. The earthquake was shallow with a focal depth of the order of 25 Km (USGS). The main shock and the aftershock sequence occurred in an area that historically host major earthquakes, although a few major earthquakes occurred during the 20th century (Figure 2).

The strongest historical and present-century earthquakes in the neighboring areas were : (i) the 1789 and 1875 events of M≈6.5, (ii) the 1905, M=6.8 Malatya earthquake, (iii) the 1908 event of M=6.7, (iv) the 1971, M=6.8 Bingol sequence and (v) the 1986, M=6.0 Surgu earthquake.

The moment-tensor solution for the main shock (data from USGS and INGV) show that they occurred as the result of movement on a strike-slip fault, with some normal component, with the two nodal planes trending NW–SE and NE–SW. Thus, according to the focal mechanism, the seismic fault would be either the NE–SW left-lateral fault or the NW–SE right-lateral one.

Elaboration of the aftershock sequence data, recorded by a local network (data from INGV), showed that the spatial distribution of the surface projection of the aftershocks with M>2 is diffused and scattered. Focusing on the aftershocks with M>4, the distribution follows a clear NW-SE zone. This zone extends from the Aricilar village to the NW to Goltepesi village to the SE and probably represents the surface projection of the seismogenic source.

SURFACE RAPTURES AND OPEN CRACKS

The extensive research which was carried out in the greater area after the earthquake enhanced to reveal a number of tectonic structures and geotechnical effects in direct correlation to the seismotectonic frame of the recent seismic event. These elements are described bellow.

Although the magnitude of the earthquake was important there was no clear surface expression of the seismic fault, contrary to the 1971 earthquake of similar magnitude. A number of surface raptures were observed in the area north of Bingol, from Kartal and Dikme villages to the SE up to Sancac and Yazgulu villages to the NW (Figures 6 & 8). They were crossing through alluvial deposits or unconsolidated sediments as well the roads of the area. Their length appears from one meter up to ten meters long and rarer up to several ten of meters, whereas they have mainly an NW-SE and rarely an NE-SW direction.

The geometry and the kinematics of these raptures coincide with the focal mechanism solution and indicate a dextral strike-slip movement for the NW-SE fractures and a sinistral strike-slip for the NE-SW one. The displacement was of few centimeters up to 20 cm and rarely higher. The development of those fractures was very systematic, usually in an en-echelon arrangement, and in the most cases they was forming small scale pull-apart "basins" or releasing bands (Figure 4). They were forming two distinct zones. The first one and most important was developed from Sancac village up to Kartal whereas the second one locates more to the southwest between Kartal and Dikme villages. Both of them trending to the NW-SE direction witch coincides with the main direction of the two major fault zones which are developed parallel to the Bayram stream, NW of Bingol city (Figure 6 & 8).

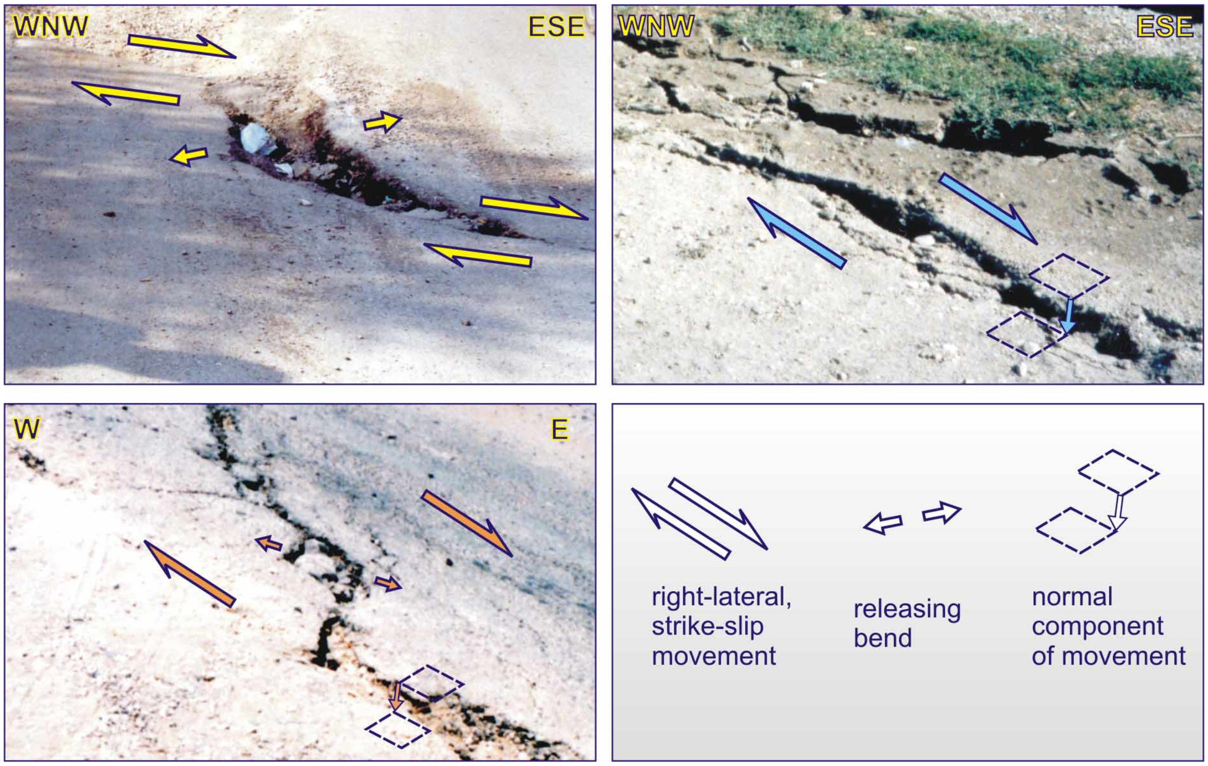

Figure 4. Kinematic interpretation of the NW-SE surface raptures.

The most of the NW-SE raptures form a scarp in the surface of a few centimeters and rarely of more than 10-15 cm. No particular opening has been observed along these raptures, which mainly dips 70-80 degrees to the SW. The overall geometry and kinematics of these raptures, except the main dextral strike-slip movement (hanging wall has been moved to the SE and footwall to the NW), also indicate a very small normal movement, with the north-eastern part uplifted in relation to the south-western one, giving as a result a normal oblique-slip kinematic character to these raptures.

A number of systematic surface raptures with a different N-W or NNE-SSW trend also observed in the same area. They also show a completely different kinematic and dynamic character and the most of them represent open or extensional cracks. They are located mainly in the surrounding region of Baliklicay and Kartal villages. Their size varies from a few centimeters up to a few meters and they are developed systematically along distinct zones with a general NW-SE trend of direction. They are characterized by an en-echelon arrangement and represent the open cracks that are developed in a dextral shear zone with an NW-SE general trend (Figure 8).

Along the Goynuk stream some small surface raptures, with a length no more than a half of meter, have been also observed. They do not indicate any distinct distribution and in most cases they tend to lie in different directions (E-W, WNW-ESE, NNW-SSE and, rarely, N-S). Usually they are parallel to the morphological structures, such as river beds, valley slopes etc., and they seem to be related with the rare liquefaction phenomena.

GEOTECHNICAL EFFECTS AND DAMAGE DISTRIBUTION

The geotechnical effects observed in the area due to the earthquake was mainly slope failures and some restricted liquefaction phenomena. The slope failures were represented mainly by landslides, settlements and topple failures and were observed in many places within the stricken area. Their spatial distribution, although scattered, follows a secondary NW-SE zonation (Figure 6).

These phenomena have been detected in the areas where the morphological slopes, the lithology and the geometry of joints and other discontinuities of the rocks, generated the proper conditions. The morphology of the region, which is the result of the active tectonics, is the principal factor provoking the slope failures. These phenomena took place at the scarp of morphological discontinuities, which are mainly related with the faults of the area, at the slopes of the valleys which are crossing the area because of uplifting, but also at the road-cuts.

The restricted liquefaction phenomena have been observed only in two places along the Goynuk stream and recognized in the surface as small scale sand boils or extensional failures. They are related to the local ground conditions (alluvial deposits in the flood plains of the rivers), as well as to the depth of water table (Figure 5).

Figure 5. Small scale liquefaction phenomena south of Bingol city.

The damage distribution is another factor which usually gives us much information about the seismotectonic characteristics of an earthquake. In this case the buildings of the Bingol city and the affected villages were both old structures and modern ones and as was expected the old buildings suffered most damage. It is remarkable that structural performance of the reinforced concrete buildings was also very bad, while a lot of them collapsed or suffered heavy damage (Figure 7). The poor quality of the concrete and the poor detailing at the critical region of the structural elements created favorable conditions for the collapse of these buildings in most cases, such as that of the school of Celtiksuyu with such tragic results.

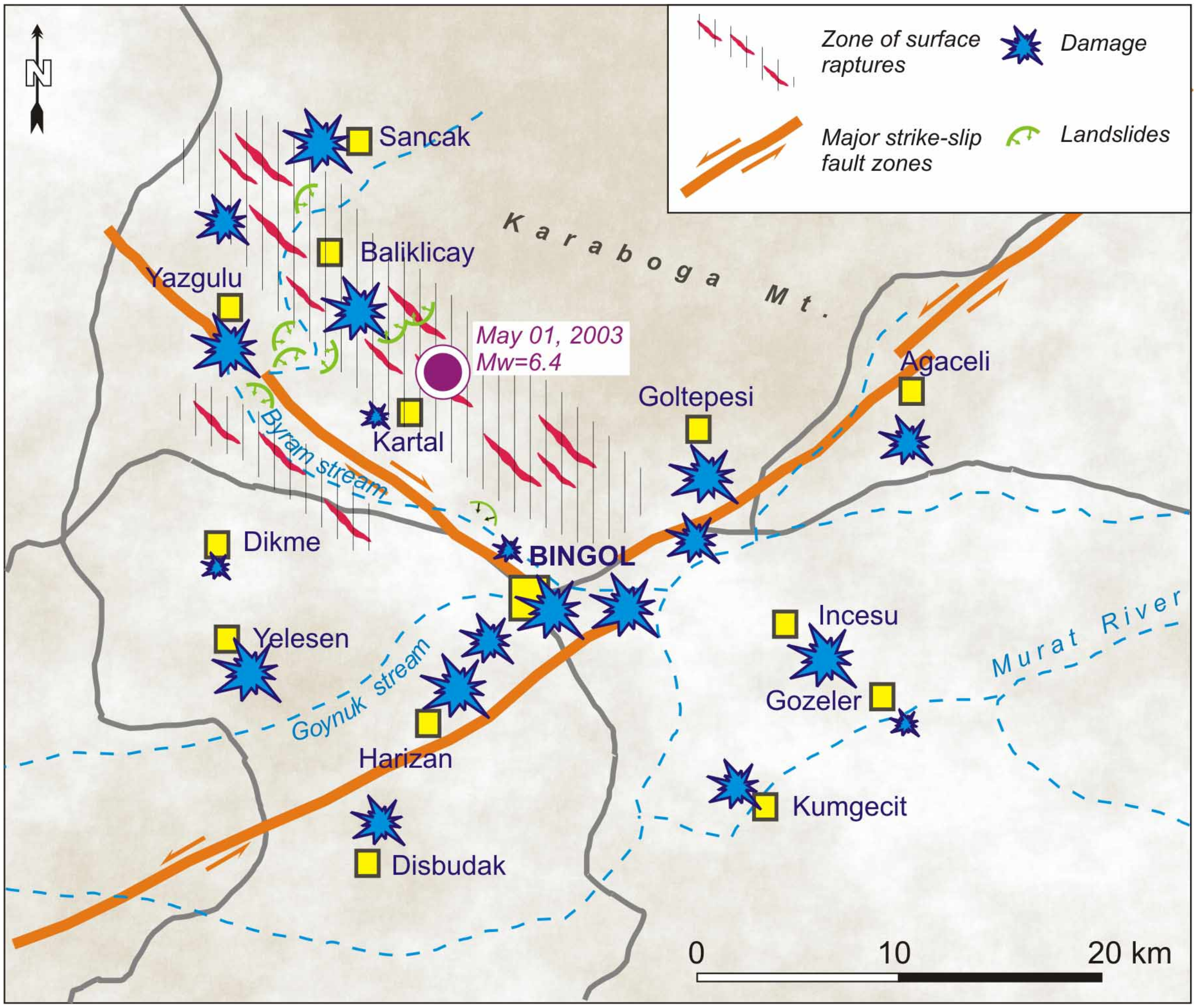

Figure 6. Spatial distribution of surface raptures, geotechnical effects and damages.

Most of the damage occurred in Bingol, Sancac, Baliklicay, Yazgulu Goltepesi, Dikme, Yelesen, Incesu and Haziran. Serious damage occurred to Ilicalar, Ekiniolu, Y. Akpinar and Akdurmus. Minor damage was also observed in other villages in the wider area, such as Aricilar, Kartal, Agaceli, Gozeler and Disbudak.

The main axis of the macroseismic intensities and the spatial distribution of the damage follow the NW-SE Baliklicay - Incesu direction and coincide with the aftershock distribution as well as with the distribution of surface raptures and geotechnical effects (Figures 6 & 8). A secondary NE-SW axis of heavy damages, from Haziran village to SW up to Incesu village to the NE, also occurs and coincides with the general trace of the NE segment of the EAF. It is also remarkable that the most of the damage localized at the junction point of these two axes and at the footwall of the main NW-SE zone of surface raptures.

DISCUSSION AND CONCLUSIONS

The greater area of Bingol is characterized by an important seismic activity with focal mechanisms indicating mainly strike-slip movement. This is also argued directly through field observations since the region is crossed by large-scale NE-SW left-lateral strike-slip faults which belong to the northeastern segment of the Eastern Anatolia Fault System (near Karliova triple junction). Secondary NW-SE, right-lateral faults also observed in the major area and belong to the same fault system.

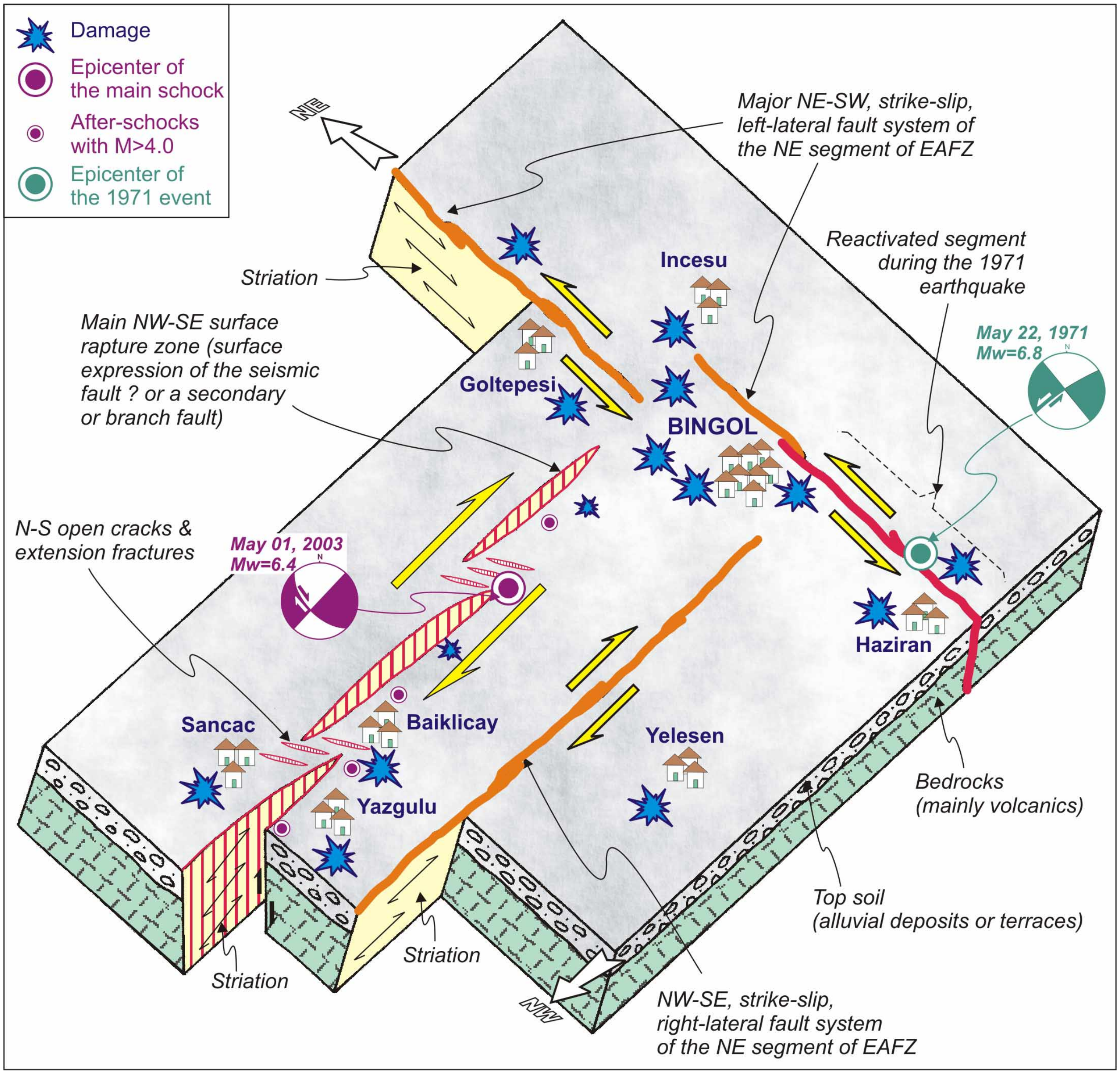

Figure 8. Schematic block-diagram representing the tectonic structures, geotechnical effects and damages occurred during the May 1, 2003 earthquake.

The first question is whether the main seismic fault, which caused the earthquake, was expressed on the surface with kinematic and dynamic characteristics which coincide with those defined by the earthquake focal mechanism (strike-slip movement) and the left-lateral character of EAF. This question becomes more important since the previous strong earthquake which struck this region (Bingol, 1971, M=6.8), created large scale left-lateral surface breaks mostly along the southwestern end of the northeastern segment of EAF.

The recent earthquake did not produce extended surface raptures or geotechnical effects. All these phenomena localized 10-15 Km north of Bingol. According to the focal mechanism of the main shock the seismogenic fault is representing by a strike-slip one and can be trending either to the NE−SW direction as left-lateral or to the NW−SE as right-lateral. The second hypothesis seems to be more probable, for the following reasons:

– The surface raptures that have been produced by the earthquake, are distributed in a narrow NW-SE zone, north of Bingol. The epicenter of the earthquake lies at the southeastern part of his zone.
– The main system of surface raptures trends to the NW-SE direction and from the kinematic point of view indicate a clear strike-slip or oblique, right-lateral movement, which coincides with this of the focal mechanism solution.
– The spatial distribution of the aftershock sequence depicts a distinctive NW−SE narrow zone, which coincides with this of the surface raptures.
– The geotechnical effects, which present scattered distribution, while they are controlled by high slope instability, show a secondary NW−SE zonation.
– The main axis of damage distribution follows the same NW-SE direction.

The geometric, kinematic and dynamic characteristics of the NW-SE raptures indicate that they could be regarded as the expression in the surface of the seismic fault or of a secondary tear fault or branch fault (Figure 8). The NE-SW left lateral fractures, which are more rare and accompanying in some places the NW-SE one, possibly represent the conjugate Riedel (R′) shear. The N-S extension fractures and open cracks represent en-echelon structures due to the right-lateral shearing of the reactivated fault.

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