Deep Resistivity Structure around the Fault Associated with the 1999 Kocaeli Earthquake, Turkey

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Abstract. On August 17, 1999, a destructive earthquake occurred in the western part of the North Anatolian Fault Zone (NAFZ), Turkey, resulting in the catastrophic earthquake hazard in the history of Turkey. The earthquake source region has been designated as a seismic gap and M7-class earthquake has been supposed to occur someday in the near future so as to fill this seismic gap. In this paper, we report some of preliminary results of magneto-telluric (MT) survey, which we started on July 27, 1999 and had continued during and after the earthquake occurrence, just in the earthquake source region and its vicinity.

Immediately after the occurrence of the earthquake, in Izmit area, noises in the electric field completely disappeared because electric power supply system to Izmit area was completely damaged. So during the successive four days after the earthquake, in the vicinity of the surface fault rupture associated with the Kocaeli earthquake, we could obtain very high quality MT data set, which played important roll to construct a higher resolution resistivity structure model beneath the fault.

The resistivity structure beneath the northern branch (the ruptured fault) is much more heterogeneous than that below the southern branch of the NAFZ. The resistivity below the surface rupture is very low, less than 10 ohm-m or so, to a depth of about five kilometers. Below this low resistive region exists a high resistive zone. Hypocenters of the mainshock are located at northern edge of the high resistive zone and most of all aftershocks are located within this high resistive zone.

1. INTRODUCTION

Since the occurrence of the 1939 Erzincan earthquake (M7.9), M7-class earthquakes have been successively migrated toward the west along the North Anatolian Fault Zone (NAFZ), Turkey. Toksoz et al. (1979) pointed out existence of an seismic gap area in the western part of the NAFZ. Since then, the area from about 29 to 30°E, where is the west of the rupture zone of the 1967 Mudurunu earthquake (M7.1), have been paid much attention. In this area, the NAFZ branches from around 30°30′E westward into two active fault zones: the northern
branch called Izmit-Sapanca fault zone (Ikeda, 1988), and the southern branch called the Iznik-Melece fault (Sipahioglu and Matsuda, 1986). Some linear fault traces are clear in the southern branch, whereas the northern branch is complicated as characterized by some geomorphological evidence showing compressional features (Ikeda, 1988; Tuncer et al., 1991), in contrast to transtensional features implied by focal mechanism of earthquake (McKenzie, 1972; Evans et al., 1985).

A seismic observation network, called IZINET, have been in operation to monitor seismicity along the two faults since 1993 (Ito et al., 1994). A clustered seismic activity in an area very close to Izmit was observed from 1993 to 1998 along the Izmit-Sapanca fault zones, while almost no seismic activity was found along the Iznik-Mektece fault (Honkura et al., 2000). Figure 1 shows seismicity in the western part of the NAFZ in 1998.

In order to investigate the difference in the deep structure beneath the two faults, we started magneto-telluric (MT) measurements for determining the resistivity structure on July 27, 1999 at some sites along a north-south profile (Line 1) crossing both the northern and the southern branches. The Line 1 is located at a distance of several kilometers from Izmit.

On August 17, the MT observations had been made at five sites, four of which were found later to be located very close to the surface rupture zone associated with the 1999 Kocaeli (Izmit) earthquake. In this paper, we will describe preliminary result on the resistivity structure determined by the MT survey before, during and after the earthquake occurrence.
2. OUTLINE OF MT SURVEY

Figure 2 shows distribution of the MT observation sites along Line 1 across the northern and the southern branches of the NAFZ. The total length of the profile is about 60 km. The solid line in the figure denotes surface rupture associated with the Kocaeli earthquake. Locality data of latitude and longitude at each site are listed in Table 1 in a sequence from south to north. For this survey we used five 5-component, wide-band MT system (Phoenix MTU5).

We started the MT survey from the southern sites (101, 102, 103, 104 and 105) along the profile on July 27, 1999. Every observation started at 17:00 local time, and ended at 9:00 in the morning of the next day. Site 001 is set up on Aug. 8 as a reference site for remote reference data processing (Gamble et al., 1979) to reduce down-weight effects due to noise on the magnetic records, and/or to reduce locally coherent noise between electric and magnetic records, because we began to suffer severe noises came from Izmit area when we moved to sites on the northern half of the profile.

We set up sites 121 and 122 just on August 16, about nine hours before the mainshock. So sites 118, 120, 121 and 122 happened to be in operation on August 16 and 17 within the source region of the Kocaeli earthquake, as already described in Honkura et al. (2000). Site 122 is located on the northern side of the surface rupture and the others on the southern side. These sites are located at distances of only several kilometers from the epicenter of the mainshock of the Kocaeli earthquake.

Immediately after the occurrence of the earthquake, noises in the electric and magnetic fields completely disappeared because of destructive damage of electric power supply in Izmit area. So during the successive four days after the earthquake,
we could obtain very clear signals for MT analyses, which could be key data set to construct a higher resolution resistivity structure model, in the vicinity of the surface rupture associated with the Kocaeli earthquake.

3. RESISTIVITY STRUCTURE OF THE NAFZ

As is shown in Fig. 2 and Table 1, the total number of sites is 32 except the remote reference site 001 but the data quality at the four of them (123, 113, 115 and 105) was very low, because of noises in the electric field due to the leakage
Fig. 3. A two-dimensional resistivity structure model along Line 1 deduced from the TM-mode data set (the electric field is perpendicular to the fault strike in this case, whereas the magnetic field is parallel with the strike).
Fig. 4. Fit of sounding curves derived from the model shown in Fig. 3. Solid circles: observed responses of TM mode. Solid lines: calculated TM mode sounding curves.
current from İzmit area, to where large amount of electricity is supplied. So, we
excluded these bad data sets, and applied two-dimensional inversion to the TM-
mode apparent resistivity and phase data, using a scheme based on the ABIC
optimum criterion developed by Ogawa and Uchida (1996). The strike of the
resistivity structure is chose as the EW direction in this study on the basis of
strikes of the two branches of the NAFZ and the geological structure in the survey
area. The frequency range for the data used for this inversion is between 240 Hz
and 0.0005 Hz.

Figure 3 shows the inversion result of the north-south profile. The arrow in
the right side on the panel denotes the location of the surface rupture, and the
arrow in the left side denotes the southern branch of the NAFZ. And the star
symbol in the figure denotes the hypocenter of the mainshock and solid circles
denote hypocenters of the aftershocks during August 23–29, 1999. We clearly see

![Diagram](image-url)

Fig. 4. (continued).
the difference in the resistivity structure beneath two faults. The structure below the southern branch is quite uniform, while the structure below the northern branch is heterogeneous.

There is a remarkable low resistive zone, less than 10 ohm-m or so, below the northern branch, to a depth of 5 km or so. It is also clear that high resistive zone exists below the low resistive region. The hypocenters of the main shock and aftershocks are located within this high resistive zone. Figure 4 shows the data fit of response functions of the apparent resistivity and phase derived from the resistivity structure model shown in Fig. 3, at some observation sites, as examples. As seen in Fig. 4, the model curves are fitting well to the observed apparent resistivity and phase data.

In order to obtain higher resolution resistivity structure, we applied the two-dimensional inversion to TM-mode data set of the northern half of the profile. The result is shown in Fig. 5. The star symbol in the figure again denotes the hypocenter of the main shock and solid circles also denote hypocenters of the aftershocks during August 23–29. The resistivity is very low, less than 10 ohm-m or so, below northern side of the rupture zone to a depth of about five kilometers. Below this low resistivity region exists a high resistive zone. As is clearly seen in the figure, hypocenters of the main shock and aftershocks are located within this high resistive zone.

The pseudosections of apparent resistivity and phase of TM mode along Line 1 are shown in Fig. 6. The top panels show observed pseudosections for the apparent resistivity and phase, and the bottom panels show synthetic pseudosections calculated from the best fitting resistivity model show in Fig. 5. As seen in Fig. 6, overall feature of the pseudosections observed is well represented by those calculated from the best fitting model.

4. DISCUSSIONS

Straub et al. (1997) obtained the GPS-based deformation pattern in western part of the NAFZ from the comparison between GPS positioning data sets measured in 1990 and 1996. According to their result, dextral movements are dominant along the northern branch of the NAFZ in the Gulf of Izmit resulting E-W oriented shear strain rates of 0.2 μ strain/yr. On the other hand, along the southern branch almost no significant shear deformation is observed.

As is described in the previous section, the resistivity structure beneath the northern branch is quite heterogeneous, while that beneath the southern branch is homogeneous. This difference in the resistivity distribution seems to represent difference in the strength uniformity along the fault plane of each branch. The southern branch showing homogeneity of the resistivity structure may have higher strength than the northern branch as not to accumulate shear strain along it’s fault plane, as shown by GPS-based deformation pattern. At least, vertical non-uniform distribution of the resistivity in the northern branch can be thought to play an important role for understanding the remarkable difference in the shear strain accumulation along the fault planes before the earthquake occurrence.
Fig. 5. A higher resolution two-dimensional resistivity structure model beneath the surface rupture associated with the Kocaeli earthquake along Line 1 deduced from the TM-mode data set.

Fig. 6. Pseudosection of TM mode along Line 1. The top panels show observed data and the bottom panels show synthetic data based on the best fit model of the resistivity show in Fig. 5.
As already pointed out in Honkura et al. (2000), hypocentral distribution of the aftershocks is not uniform along the fault plane, but shows patch-like distribution. And they claimed that such clustering distribution of the aftershocks along the ruptured fault plane corresponds to strongly coupled portions on the fault plane. So, lateral uniformity of the strength along the fault could be also found as a resistivity distribution image. To clarify the lateral distribution of the heterogeneity along the fault, more profile surveys of MT are required.

5. CONCLUSIONS

The correspondence between the hypocentral zone of the Kocaeli earthquake and its surrounding resistivity structure was studied by analyzing the wide-band MT data along the profile crossing the two branches of the western part of the NAFZ. By means of 2D inversion, the following two points were concluded.

1. According to the two-dimensional inversion applied to the TM-mode apparent resistivity and phase data for the frequency range between 240 Hz and 0.0005 Hz, the resistivity below northern side of the rupture zone is very low, less than 10 ohm-m or so, to a depth of about five kilometers. Below this low resistive region exists a high resistive zone. Hypocenters of the mainshock are located at northern edge of the high resistive zone and most of all aftershocks are located within this high resistive zone.

2. The resistivity structure beneath the northern branch (the rupture zone) is much more heterogeneous than that below the southern branch of the NAFZ.

Acknowledgements. We thank M. Uyeshima for critically reading the manuscript and giving valuable comments for revising the manuscript. We thank all of the participants in the field survey for their hard work. We are also grateful to THY (Turkish Airlines) and the Ataturk Airport Customs Directorate for kind help and support to our project. This study is supported by the Ministry of Education, Culture and Science, through Grant-in-Aid.

REFERENCES


