Magnetic Anomalies and Low Ground Resistivity as Possible Indicators of Active Fault Location: Preliminary Results of Electric and Magnetic Observations from the Western Part of the North Anatolian Fault Zone

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In view of a possible seismic gap in the western part of the North Anatolian Fault Zone, we carried out electric and magnetic observations in the Iznik-Mekece area, aiming primarily at searching for location of an active fault and disclosing an anomalous structure associated with it. For reference, we also made similar observations at the İsmetpaşa area where an earthquake of magnitude 7.6 took place in 1944 and fault lines are well known. The preliminary results of observations are summarized as follows: in most cases, magnetic anomalies are found along fault lines, and the ground resistivity tends to be lower near fault lines. Comparison of these anomalous features in both the observation areas indicates that the active fault found in the Iznik-Mekece area is similar to the fault in the İsmetpaşa area. It is suggested, therefore, that the fault in the Iznik-Mekece area may be one of the candidates for future earthquake generation in the seismic gap region.

1. Introduction

In the northern part of Turkey lies a transform fault called the North Anatolian Fault Zone, and a number of earthquakes have taken place as a result of its intermittent activity characterized by primarily right-lateral movement (SOYSAL *et al.*, 1982). Recent activity of this fault zone has been extremely high in the sense that large earthquakes have successively taken place along almost all the segments of the zone since the occurrence of the 1939 Ercincan earthquake of magnitude 8.0 (AMBRASEYS, 1970). Earthquake occurrence seems to have migrated to the west and also to the east, starting at the Ercincan area in 1939 (TOKSÖZ *et al.*, 1979).

Although most segments of the fault zone have already suffered break, two areas seem to be unbroken yet; one between 29° and 30°E in longitude and

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the other between 42° and 43°E. TOKSÖZ *et al.* (1979) suspect that these areas may be seismic gaps of the first kind. If the areas are really seismic gaps, earthquakes larger than magnitude 7.0 are likely to occur in the near future in view of large magnitudes of neighboring earthquakes.

In an attempt to carry out earthquake prediction research in one of the above-mentioned possible seismic gap regions, we initiated electric and magnetic observations in the western part of the North Anatolian Fault Zone in 1981 and 1982. Although anomalous electric and magnetic phenomena have often been reported in association with earthquakes (e.g., HONKURA, 1981), as an initial stage we have put much emphasis on investigation of electric and magnetic structure associated with active faults. In this respect, some of the active faults in Japan have intensively been investigated in recent years by using electric and magnetic methods (NORITOMI, 1981), and a low resistivity zone has been found to exist extensively along active faults (ELECTROMAGNETIC RESEARCH GROUP FOR THE ACTIVE FAULT, 1982) and also the existence of a magnetic anomaly was suggested (MORI *et al.*, 1983). We believe that such a fundamental study should be important for the electric and magnetic approach to earthquake prediction.

The purpose of this paper is to present preliminary results obtained from observations at two sites and discuss, in a qualitative manner, their implications for active fault location. We believe that it is of some importance for similar studies of active faults to describe different kinds of data altogether for respective measurement lines. More detailed interpretation of data showing an anomalous structure will be attempted in subsequent papers.

2. Observation Sites

As an observation site in the western seismic gap region, we selected an area adjacent to the source region for the 1967 earthquake of magnitude 7.1, as shown in Fig. 1. A geological study of this area provided evidence showing the existence of an active fault running through the city of Iznik and the town of Mekece (Sipahioğlu and Matsuda, in preparation). We tentatively call this active fault the Iznik-Mekece fault and hereafter the observation site will be referred to as the Iznik-Mekece area.

Some anomalies in the surface resistivity and the magnetic field were found along the above-mentioned Iznik-Mekece fault, as will be shown later. In order to confirm that the observed anomalies are associated with the active fault, we searched for another location, where fault traces were well established and an earthquake had occurred recently, east of the Iznik-Mekece area. We then selected the Ismetpaşa area, as shown in Fig. 1, which has been known as a possible creeping segment of the North Anatolian Fault Zone (e.g., ALLEN, 1982). However, a large earthquake of magnitude 7.6 is supposed to have also occurred there in 1944.

Fig. 1. Locations of Iznik-Mekece and Ismetpaşa observation areas. Solid lines denote recent fault displacements associated with major earthquake occurrences in Turkey (after ALLEN, 1982).

3. Results of Observations in the Iznik-Mekece Area

We may assume a two-dimensional structure with its strike along the fault line. Hence we made measurements along some lines nearly perpendicular to the fault line. In Fig. 2 shown are measurement lines in the Iznik-Mekece area together with sites for repeated magnetic surveys which will not be described in this paper. Except for line A-B, all the measurement lines were set so as to make measurements across the Iznik-Mekece fault line. Measurements at line A-B aim at investigating the possibility that another active fault lies in this part.

3.1 Line A-B (Mekece No. 1)

Along this line we made measurements of geomagnetic total intensity, surface resistivity and self-potential. Figure 3 shows their results together with topography along the line. The total intensity was measured at spacing of 50 meters using a portable proton precession magnetometer. During measurements, a diurnal geomagnetic variation turned out to be small, and no correction to the observed data was necessary. This is also the case for magnetic measurements at the other measurement lines. The resistivity was measured at distances of 100

Fig. 2. Locations of measurement lines in the Iznik-Mekece area. Solid circles indicate sites for repeated magnetic surveys. Topographic contours are drawn for 200 meter intervals.

Fig. 3. Distributions of total intensity, self-potential and resistivity along the measurement line A-B together with the topographic profile.

meter increment (50 meter increment at the other measurement lines except I'–J') using the so-called Wenner method. Electrode separation was fixed as 30 meters and electrodes were arranged in parallel to the measurement line.

We used the "leap frog" measurement scheme for self-potential measurements with an electrode separation of 50 meters. The result shown in Fig. 3 was derived by adding successively the measured voltage differences with the potential at the starting point assumed as zero for reference and by removing a linear trend. Before each measurement, electrodes were watered and this would be the cause of the linear potential increase toward the direction of survey; in the present case towards point B (CORWIN and HOOVER, 1979).

The total intensity tends to decrease gradually towards point A, but such a trend may be a topographic effect because a steep hill exists to the north of A. In any case, the observed total intensity data are unlikely to indicate a remarkable magnetic anomaly, compared with the results at some other measurement lines. On the other hand, a clear boundary in the resistivity can be recognized; the resistivity is evidently low on the northern side, amounting to 20 ohm·m or so. It seems significant that a pair of positive and negative anomalies of self-potential is seen at the resistivity boundary.

The resistivity anomaly may imply that the low resistivity zone on the northern side corresponds to a fractured zone of an active fault and the self-potential anomaly may reflect a streaming potential arising from underground water flow near the fault boundary (e.g., MURAKAMI *et al.*, 1984). However, we cannot draw any definitive conclusion at the present stage.

3.2 Line C–D (Mekece No. 2)

Similar measurements were made along this line. The southern half of this area constitutes a small hill as shown in Fig. 4, and there is some geological evidence showing the existence of an active fault at the foot of the hill. This hill may have resulted from cumulative upheaval of the southern side of the fault.

Remarkable anomalies were found in the total intensity and the resistivity. The magnetic anomaly having a peak-to-peak amplitude of about 500 nT suggests the existence of a highly magnetic body at the northern side of the fault. On the other hand, resistivity as low as about 10 ohm·m is found near the fault. This low resistivity zone is narrow, and even if this zone suggests the existence of a fractured zone, such a zone is unlikely to have developed considerably along the present active fault. However, the observed resistivity distribution may be affected by topography, particularly at the southern side, and no definitive conclusion can be drawn on the width of a fractured zone.

The self-potential was measured using the leap frog scheme and a linear trend presumably resulting from it was removed from the measured potential distribution. Except for a positive anomaly exceeding 10 mV near the northern end, no clear anomaly can be recognized. The above positive anomaly was observed near a small river and hence it may not be considered as significant.

Fig. 4. Distributions of total intensity, self-potential and resistivity along the line C-D together with the topographic profile.

3.3 Line E-F (Çerkesli)

This area is located several kilometers west of the line C-D. The fault, as described in Section 3.2, runs near the southern end of the line E-F. As shown in Fig. 5, there exists a pond which may be considered as a sag pond along an active fault. The results of measurements of the total intensity, resistivity and self-potential are shown in Fig. 6 together with topography along the measurement line.

There also exists a remarkable anomaly of the total intensity with its peak-to-peak amplitude amounting to 400 nT or thereabouts. As was the case for the line C-D, a highly magnetic body causing the observed magnetic anomaly lies at the northern side of the fault. A zone with a resistivity of about 10 ohm·m is found near the southern end, presumably at the active fault. This low resistivity zone may be associated with a fractured zone, but it is also possible that the low resistivity is due to the effect of underground water related to the nearby pond.

The self-potential measurement was made using the leap frog scheme and a linear trend arising from it was removed. A positive anomaly seems to exist on the low resistivity zone, but its amplitude is less than 10 mV and hence this

Fig. 5. Locations of measurement lines A-B, C-D, E-F, and E'-F'. Solid circles represent sites for magnetotelluric measurements. Topographic contours are given in intervals of 50 meters. A hatched area indicates a pond.

Fig. 6. Distributions of total intensity, self-potential and resistivity along the line E-F together with the topographic profile.

anomaly may not be considered as significant, if overall fluctuation is taken into account.

Supplementary measurements were made to extend the measurement line further to the south. However, to avoid topographic undulation, the additional measurement line E'-F' was shifted somewhat to the east as shown in Fig. 5. Measurements of the total intensity, resistivity and self-potential were made along this short line and their results are shown in Fig. 7.

Since a very local anomaly in the total intensity seems to exist, more detailed measurements were made for the section E''-F''. According to our expectation, a local anomaly amounting to about 100 nT is superposed on an overall decreasing trend which is the effect of the larger-scale magnetic anomaly as described previously. On the other hand, no notable anomalies are recognized in the resistivity and self-potential, although the resistivity is generally low, 20-30 ohm·m, and the self-potential tends to be positive toward the south. In this case, both electrodes for measuring potential difference were simultaneously watered in each measurement and no correction to the observed data was made.

3.4 Line G-H (Beşevler)

In view of a similar pattern in magnetic anomalies observed at lines C-D

Fig. 7. Distributions of total intensity, self-potential and resistivity along the line E'-F'. E''-F'' indicates the section where more detailed measurements of total intensity were made.

and E-F, it is likely that a two-dimensional magnetic body lies in the east-west direction along the fault. In order to investigate the westward extension of the magnetic body, the total intensity was measured along line G-H. Contrary to our expectation, no anomaly was observed, as clearly indicated in Fig. 8. This result indicates that the western boundary of the magnetic body lies somewhere between Çerkesli and Beşevler.

3.5 Line I-J (Kaynarca)

Primarily for the purpose of confirming the result observed at Beşevler (line G-H), we measured the total intensity further west, along line I-J. Then interestingly, another anomaly in the total intensity was observed, as shown in Fig. 9, probably on the southern side of the active fault. More detailed

Fig. 8. Distribution of total intensity along the line G-H.

Fig. 9. Distribution of total intensity along the line I-J. I'-J' indicates the section where more detailed measurements were made as shown in Fig. 10.

measurements were made along line I'-J' which was chosen about 10 meters to the east to avoid unsuitable topographic conditions. More interestingly, a very local and strong anomaly amounting to about 400 nT was found as shown in Fig. 10.

Along the line I'-J', we also measured the resistivity and self-potential. The resistivity measurement is based on the Wenner array with electrode separation of 30 meters as used at the other lines, but measurements were made at distances of 10 meter increment. For self-potential measurements we fixed an electrode at the southern-most point and set the other electrode at distances of 10 meter increment. In view of maximum spacing of 180 meters, the effect of electric fields induced by geomagnetic variations is unlikely to be large enough to affect the result considerably. In contrast with the total intensity, no anomalies were found in the resistivity and self-potential.

Fig. 10. Distributions of total intensity, self-potential and resistivity along the line I'-J'.

3.6 Line K-L (Çardak)

In order to investigate the eastward extension of the approximately two-dimensional magnetic body as found at the lines C-D and E-F, we made measurements of the total intensity along line K-L. This line crosses the Sakarya River and because of sediments no geological information on an active fault was obtained. As shown in Fig. 11, the distribution of the total intensity as derived from surface measurements is remarkably smooth owing to weak magnetization of sediments. Thus a magnetic anomaly amounting to about 100 nT could easily be detected.

Ascribing the amplitude reduction to deeper location of a source causing the magnetic anomaly, we may tentatively conclude that this anomaly is the continuation of the anomalies found at the lines C-D and E-F and the magnetic body extends to this area. This tentative conclusion, if reasonable, implies that the fault exists near the southern boundary of the magnetic body and hence the active fault also extends to this area.

3.7 Magnetotelluric observations

The resistivity measurement based on the Wenner array with electrode spacing of 30 meters yields only the resistivity structure to a depth of 30 meters or so. In addition to the resistivity sounding with longer electrode spacing which was undertaken at the lines A-B and C-D, we used the magnetotelluric method to investigate the subsurface resistivity structure. In particular, we aimed at observing electromagnetic signals having a frequency range around 10 Hz. In the Iznik-Mekece area, we made observations at 16 sites which are shown in Fig. 5. Analyses of the observed magnetotelluric fields are in progress and their results will be presented elsewhere.

Fig. 11. Distribution of total intensity along the line K-L.

4. Results of Observations in the Ismetpaşa Area

In the Ismetpaşa area, we selected two sites which are suitable for electric and magnetic measurements. One of them is located very close to the place where evidence showing fault creep has been found. At the other site, topographic features related to active faults, such as fault scarps and sag ponds, have typically been seen. This site is located some kilometers west of the first site.

4.1 Lines M-N and M'-N' (Ismetpaşa No. 1)

As shown in Fig. 12, lines M-N and M'-N' are located several hundred meters west of the site where the evidence of creeping was obtained. In this area two fault traces can be recognized from topographic inspection as shown by dashed lines in Fig. 12. The eastern end of the northern fault line is supposed to be creeping at present. In the southeast, a block of serpentinite crops out on the southern fault line. In the west, outcrop of a fractured zone can be seen along the river bank.

The results of measurements are shown in Fig. 13. A very local anomaly in the total intensity was found at the line M-N, while such an anomaly was not confirmed at the line M'-N'. However, wide spacing for measurements at M'-N' may have caused failure in detecting such a local anomaly.

There seems to exist a sharp boundary in the resistivity; the northern side of the fault lines is remarkably conductive. The northern-most measuring point is located in the alluvial plain and the low resistivity value at this point may not be related to the fault, but the other low value seems to be associated with the fault. Self-potential tends to be positive on the fault but the magnitude is too small to be considered as a significant anomaly.

4.2 Line O-P (Ismetpaşa No. 2)

Figure 14 shows the measurement line O-P with four fault lines as deriv-

Fig. 12. Locations of measurement lines M-N and M'-N' in the Ismetpaşa area. Dashed lines indicate active fault lines.

İSMEPAŞA NO.1

Fig. 13. Distributions of total intensity, self-potential and resistivity along the line M-N together with the topographic profile, and distributions of total intensity and self-potential along the line M'-N'. Arrows indicate active fault lines.

Fig. 14. Location of measurement line O-P. Solid circles denote sites for magnetotelluric measurements. Dashed lines indicate active fault lines.

ed from topographic inspection. At this site there exist two sag ponds as shown in the figure. The results of measurements are shown in Fig. 15. It is quite interesting to note that four maxima in the total intensity and four minima in the resistivity seem to correspond very well to four fault lines indicated in the topographic profile. The southern-most anomalies are the most remarkable and hence the southern-most fault line is likely to be the most active. Self-potential tends to be positive on the fault lines and takes a maximum value on the inferred main fault line. The potential of 30 mV or so can be considered as significant, compared with the other results of self-potential measurements.

4.3 Magnetotelluric observations

At this site we made measurements of magnetotelluric fields at seven sites as shown in Fig. 14. Because of bad topographic conditions for magnetotelluric measurements on the southern side of the southern-most fault line, we could select only one site there. The result of analyses of the observed magnetotelluric fields will be presented elsewhere with particular emphasis on a frequency range around 10 Hz.

5. Discussions

The western part of the North Anatolian Fault Zone seems to be characterized by the existence of magnetic anomalies along the fault lines, although magnetic

Fig. 15. Distributions of total intensity, self-potential and resistivity along the line O-P together with the topographic profile. Arrows indicate active fault lines.

surveys were carried out only in two areas. If this turns out to be a general feature in the North Anatolian Fault Zone, magnetic anomalies can be used as an indicator for locations of active faults, particularly in areas where no geological information can be derived. For instance, on alluvial plains and even on sea or lake surfaces, magnetic surveys can easily be carried out and magnetic anomalies can be derived as was the case for the Çardak area.

Although in this preliminary paper, no interpretation was attempted for the observed magnetic anomalies, a two-dimensional dike-like structure has been inferred from model calculations of magnetic anomalies (Işıkara *et al.*, in preparation). Geological history of Turkey indicates that the present North Anatolian Fault Zone is a suture zone where the Tethyan Sea was closed and some fragments of oceanic crust were left and suffered complex deformation (e.g., ŞENGÖR and YILMAZ, 1981). It has been presumed that the upper basaltic layer of the oceanic crust is highly magnetized and responsible for measured magnetic anomalies (e.g., JOHNSON, 1979). However, no basaltic rocks could be found in the observation areas, and instead an outcrop of serpentinite was seen on the fault line in the Ismetpaşa area. This implies that serpentinite may be responsible for the observed magnetic anomalies. It is not unlikely that serpentinite having a flow property came up near the earth's surface through fractured zones. For details we require quantitative interpretation of the observed magnetic anomalies and also magnetic studies of serpentinite and other rocks prevailing at the observation sites.

The resistivity measurements using the Wenner method revealed low resistivity zones near the fault lines, and hence low ground resistivity may also be helpful as another indicator for locations of active faults, as has been demonstrated more clearly by ELECTROMAGNETIC RESEARCH GROUP FOR THE ACTIVE FAULT (1982). However, special care must be taken to avoid misinterpretation due to other local features, particularly an underground water distribution unrelated to active faults. One of the means of avoiding such misinterpretation is to investigate the deep resistivity structure. In this respect, we used magnetotellurics for the ELF band, since recently ELF magnetotellurics has often been undertaken in Japan and low resistivity layers have been found in association with active faults (e.g., HANDA and SUMITOMO, 1979). Detailed analyses of the observed magnetotelluric fields will provide important information on the subsurface resistivity structure near the active faults in the present observation areas.

No significant anomalies in self-potential have been found in the Iznik-Mekece area, while positive anomalies seem to exist on the fault in the Ismetpaşa area. In recent years self-potential anomalies near active faults have been interpreted in terms of streaming potential (MIZUTANI *et al.*, 1976; FITTERMAN, 1979; MURAKAMI *et al.*, 1984), and if the observed positive anomalies turn out to be accounted for by such a mechanism, flow of underground water would be more active in the Ismetpaşa area than in the Iznik-Mekece area.

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