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Application of GPR to normal faults in the Büyük Menderes Graben, western Turkey

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ABSTRACT

Paleoseismology documents past surface-rupturing earthquakes that occurred on faults. This study is limited by the scarcity data on geomorphic and sedimentary environments that may preserve adequate records of deposition, erosion, and fault slip markers. Identifying relevant trenching sites can be difficult when a fault is buried or its surface expression has been eroded since the last tectonic motion. Ground penetrating radar (GPR) is an effective tool for locating suitable sites for trenching. Characteristic reflections are produced by boundaries between elements with contrasting electrical properties, such as grain size distribution (sorting, clay content, etc.), porosity, and water content. GPR is capable of resolving faults by imaging offset stratigraphic reflectors or reflections from the fault plane. GPR surveys were performed at two sites along the Büyük Menderes Graben (western Turkey) to precisely locate the normal fault zone; there is no clear evidence of surface rupture at these sites. We used 250 and 500 MHz antennas for receiving the GPR data. From the GPR measurements, we determined locations suitable for paleoseismic investigations and performed a trenching study across the fault plane. The comparison of the GPR results and the trenching study indicates a good correlation between these methods.

1. Introduction

Ground penetrating radar (GPR) is a shallow geophysical survey technique used to identify underground bodies and structures by digitally identifying changes in electromagnetic signals. The technique is based on the propagation, reflection, and scattering of high-frequency (10 MHz to 2 GHz) electromagnetic (EM) waves in the subsurface (Davis and Annan, 1989; Daniels, 2004). This method has been successfully applied in different disciplines such as archeology (e.g., Leckebusch, 2003; Conyers, 2004; Leucci and Negri, 2006; Yalçıner et al., 2009), geophysics (e.g., Annan et al., 1975; Jol, 1995; Bano et al., 2000), and geology (e.g., Meghraoui et al., 2001; Audru et al., 2001; Gross et al., 2002; Green et al., 2003; Ferry et al., 2004; Malik et al., 2007, and Christie et al., 2009) to investigate buried features. In addition, it has been used in contaminated land, forensic, and snow and ice investigations (e.g., Lalumiere, 2000, 2006; Scambos and Bauer, 2006; Bano et al., 2009). New types of shielded GPR antennas provide more rapid and reliable results with high resolution; however, from the viewpoint of the usefulness of the GPR data, the following parameters must be taken into consideration – the thickness of young sediments which, in general, are conductive; topographic differences between the beginning and end points of profiles; the characteristics of reflection from surface objects (e.g., electrical poles, vegetation, and trees); and the orientation of GPR profiles with respect to the fault zone (profiles should be oriented perpendicular to the fault zone).

Active fault studies require detailed investigations and the main intention in such studies is to assess the field characteristics of active faults, such as their precise location, the amount of offset on the faults, and the width of deformation zones. Such parameters can easily be obtained where evidence of faulting is preserved in the geological and geomorphological records. However, regional and local conditions (e.g., sedimentation and erosion) play an important role in the preservation of surface evidence for faulting. In addition, human activities such as agriculture and construction erase the geological and geomorphological records; thus, it becomes impossible to obtain the necessary data on the field characteristics of faults from surface evidence. In these cases, alternative techniques are required to obtain essential data. The GPR method has proved to be the most flexible and useful of all the shallow geophysical methods, and it has been applied in a wide variety of disciplines,

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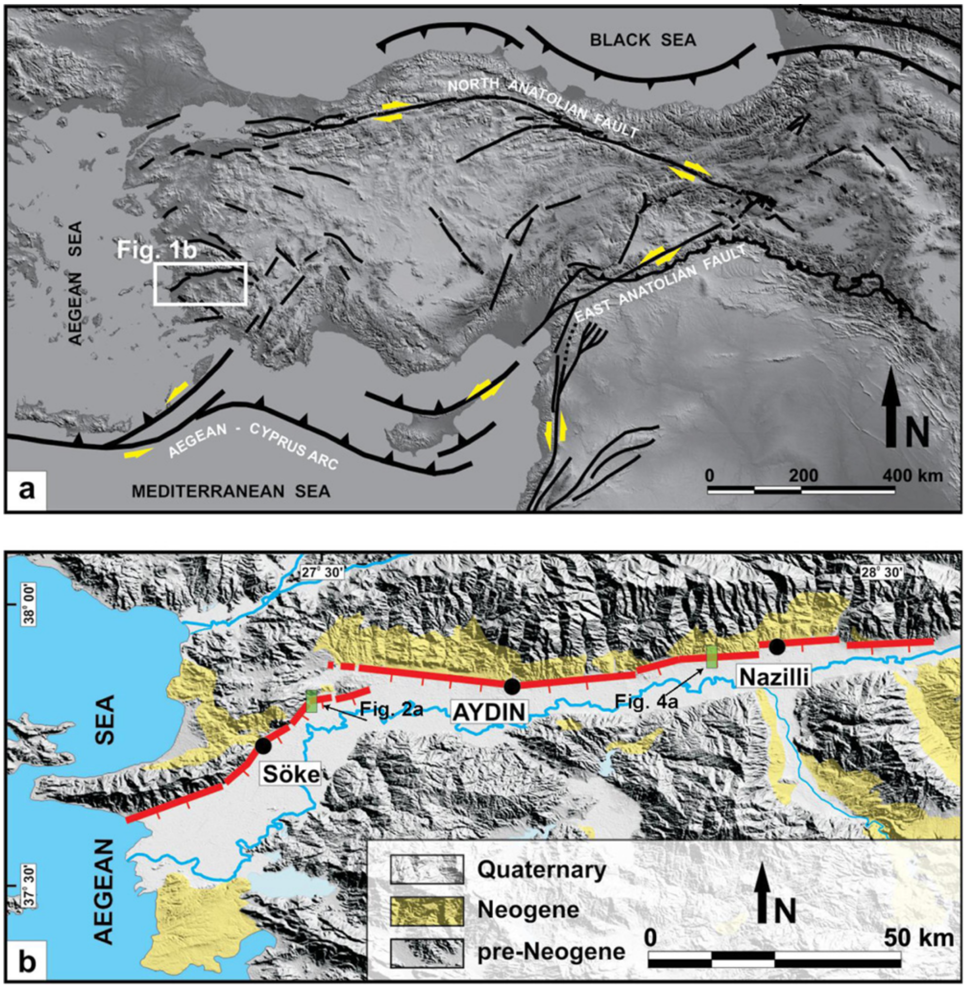

Fig. 1. (a) Map of major active tectonic structures in Turkey. (b) Simplified geological map of the Büyük Menderes Graben on shaded relief (SRTM). Red lines are the active faults along the northern side of the graben (Altunel et al., 2009). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

including active tectonic studies. For example, Bano et al. (2000) conducted GPR prospecting at a Quaternary sedimentary site to image the structures and tectonic features. Audru et al. (2001) measured three GPR profiles on an active strike-slip fault within an urban area to comprehend the geometry of the fault and minimize the impact of surface and subsurface infrastructural elements (e.g., power poles, sewers, and water mains) and traffic. Gross et al. (2002) and Green et al. (2003) applied the GPR method to investigate the location and shallow geometry of the San Andreas Fault as well as the displacement on the fault. Meghraoui et al. (2001) combined GPR investigations with electrical resistivity and seismic studies to determine precise locations for trenching. Ferry et al. (2004) identified the offset of a buried Ottoman aqueduct and stream channels on the North Anatolian Fault using GPR. Malik et al. (2007) identified shallow subsurface deformation and geometry along the Pinjore Garden Fault (NW Himalaya) using GPR. Christie et al. (2009) estimated fault displacement and off-fault deformation along the Emigrant Peak Fault (Walker Lane-Eastern California shear zone) by conducting a 3D GPR survey. Although the ability of GPR to identify buried features has been demonstrated, most investigations have been concerned with the location of buried structures. It is necessary to examine the capability of the GPR technique to estimate the amount of displacement on an active fault.

The Büyük Menderes fault zone can be easily identified in the field; it separates Holocene sediments from pre-Holocene clastic units. However, rapid erosion and modification at some locations, it is sometimes difficult to trace the fault; this is the case in locations where the fault cuts loose deposits. The Büyük Menderes Graben experienced large earthquakes in historical times (e.g., Sipahioğlu, 1979; Ambraseys and Finkel, 1995), and previous studies (e.g., Ilhan, 1971; Allen, 1975; Ambraseys, 1988; Paton, 1992; Altunel, 1999) showed that surface faulting occurred along the northern margin of the Büyük Menderes Graben. However, surface ruptures of historical events are only partly visible, either because they are covered by sediments or because of removal of the traces by erosion or man-made modifications. In this study, surface ruptures of historical earthquakes in Holocene deposits were identified and located, and the vertical displacements on the faults were estimated using GPR profiles. On the basis of GPR results, trenches were dug in the same locations, and the interpreted GPR profiles were compared with logs of the trench walls.

2. Geological and tectonic setting of the study area

The Büyük Menderes Graben is one of the principal active structures of western Turkey, which is one of the most seismically active regions of the world (Jackson and McKenzie, 1988). The width of the E–W trending Büyük Menderes Graben varies from 8 to 12 km, and mapping of geological units showed that there are three main rock associations around the Büyük Menderes Graben (e.g., Cohen et al., 1995; Emre and Sözbilir, 1995; Bozkurt, 2000). These