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Integrated geophysical investigations in a fault zone located on southwestern part of İzmir city, Western Anatolia, Turkey

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ABSTRACT

Integrated geophysical investigations consisting of joint application of various geophysical techniques have become a major tool of active tectonic investigations. The choice of integrated techniques depends on geological features, tectonic and fault characteristics of the study area, required resolution and penetration depth of used techniques and also financial supports. Therefore, fault geometry and offsets, sediment thickness and properties, features of folded strata and tectonic characteristics of near-surface sections of the subsurface could be thoroughly determined using integrated geophysical approaches. Although Ground Penetrating Radar (GPR), Electrical Resistivity Tomography (ERT) and Seismic Refraction Tomography (SRT) methods are commonly used in active tectonic investigations, other geophysical techniques will also contribute in obtaining of different properties in the complex geological environments of tectonically active sites. In this study, six different geophysical methods used to define faulting locations and characterizations around the study area. These are GPR, ERT, SRT, Very Low Frequency electromagnetic (VLF), magnetics and self-potential (SP). Overall integrated geophysical approaches used in this study gave us commonly important results about the near surface geological properties and faulting characteristics in the investigation area. After integrated interpretations of geophysical surveys, we determined an optimal trench location for paleoseismological studies. The main geological properties associated with faulting process obtained after trenching studies. In addition, geophysical results pointed out some indications concerning the active faulting mechanism in the area investigated. Consequently, the trenching studies indicate that the integrated approach of geophysical techniques applied on the fault problem reveals very useful and interpretative results in description of various properties of faulting zone in the investigation site.

1. Introduction

Integrated approach of geophysics, especially in near surface applications, is a useful tool in solving of interested problem. The characterization and the identification of a buried or blind fault system is a crucial importance in recognition of geological structures in active tectonic zones. One of the best important ways of obtaining subsurface characterization is undoubtedly the use of integrated geophysical techniques. Therefore, the detailed interpretation of relevant fault zone might carry out by using multi-methodical approach of geophysics. There are numerous case studies about the investigation of active faults using geophysical investigation methods. However, the integrated approach is limited in determining of active fault zones as well as the existence of some important studies on this subject, and henceforward the articles associated with this subject swiftly increase in the meaning of non-invasive investigations of fault zones (Demanet et al., 2001; Liberty et al., 2003; Revil et al., 2008; Štěpančíková et al., 2011; Alexopoulos et al., 2013; Jacob et al., 2013; Galli et al., 2014; Imposa et al., 2015). This paper introduces the overall conclusions of integrated geophysical investigations carried out in potentially active fault zone located in the vicinity of İzmir city, which is third one of the largest population centre of Turkey. We have applied six different geophysical methods, which can be effective for investigating of shallow geological structures covered by fine Holocene and Quaternary formations at Güzelbahçe region of the city. Used geophysical methods are ERT, GPR, SRT, magnetics, VLF and SP. In recent years, ERT and GPR techniques have been widely used in active fault surveys due to their sensitive character of the electrical and electromagnetic methods for determining of shallow Quaternary layers and making an important contribution to the geological interpretation of active fault zones.

The ERT, which has fast and low cost to obtain 2 and 3D subsurface models, is one of the most powerful geophysical tools for the detection of buried faults in urban sites. In shallow fault investigations, ERT technique is pretty important in obtaining of the effective depth, the exact location, the structural and fluid characteristics, the damage zone and the Quaternary characteristics. Therefore, we can characterize geometry, location of shallow-depth fault, blind structures, displacement

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estimations, features of alluvial deposits, determining of altered localities and identifying of paleoseismological trenching locations using ERT technique (Suzuki et al., 2000; Demanet et al., 2001; Caputo et al., 2003; Galli et al., 2006; Nguyen et al., 2007; Improta et al., 2010; Berge, 2014). Thus, various applications performed by this technique in faulting areas are become prevalent in the world. However, the application intensity has been swiftly increased in European continent, and the experience in faulting investigations significantly improves to get the true interpretation about the faulting characterizations of near surface geological structures.

GPR is one of the high resolution geophysical methods of geophysics, and many shallow geological problems are usually investigated by GPR technique. In GPR investigations, the relative dielectric contrast is a crucial indicative parameter according to conductivity and magnetic permeability. GPR has been applied for defining the fault zones and related geological features since the mid-1980s. This technique produces high quality near surface images that show the shallow underground discontinuity and heterogeneity. Therefore, complex and deformed geological structures in different geological environments are investigated with high resolution images by using GPR technique in characterization of true geometry of sedimentary and tectonic features in faulting zones. Also the buried scarps of faulting zones can be imaged using GPR reflections (Meyers et al., 1996). In an active faulting zone, the physical features such as density, porosity, grain-size, mineralogy, liquid content and etc. play an important role on the reflections of radar waves. However, the presence of clay minerals and water content could reveal a negative effect on the radar signals resulting from the attenuation, distortion and similar problems. Against all risks, 2 and 3D investigations of GPR is a spectacular tool for the characterizing of shallow fault zones and active tectonic regions (Cai et al., 1996; Liner and Liner, 1995, 1997; Demanet et al., 2001; Chow et al., 2001; Green et al., 2003; Reiss et al., 2003; Gross et al., 2004; Tronicke et al., 2006; McClymont et al., 2008; Christie et al., 2009; Beauprêtre et al., 2012; Carpentier et al., 2012a; Ercoli et al., 2013).

Seismic method in investigation of fault zones has been used for a long time. Particularly it has been applied extensively in determination of lithospheric structures and in mapping of basements of sedimentary basins by using the earthquake travel time data or deep seismic investigations. Seismic reflection technique has been commonly carried out in determining of shallow subsurface targets such as faulting and sedimentological investigations due to its high-resolution character. However seismic refraction survey has been rarely used in determining of shallow geological properties. Recently, it has been applied as a tomographic tool to reconstruct the geometry together with physical and mechanical properties of the subsoil. Seismic refraction tomography (SRT) method that uses velocity differences between the layers is crucial in defining of geological structures and trench locations for paleoseismological studies. However, the resolution is usually weak due to high attenuation induced by weathering zones and shallow sedimentary layers. SRT can also image the deformations associated with faulting, while it generally produces smooth image of the subsurface due to the limited azimuthal coverage of the rays (Sheley et al., 2003; Campbell et al., 2010; Carpentier et al., 2012b; Imposa et al., 2015; Taylor et al., 2015). Also Morey and Schuster (1999) pointed out the usefulness of 3D SRT investigation to determine the shape and depth of a colluvial wedges across a normal fault. In fact, the colluvial wedges give us lower P-wave velocities according to alluvium layer. Therefore SRT contributes clearly to site selection of paleoseismological trenching investigations, and we can determine the evidence of ancient earthquakes by trenching studies.

VLF method uses the low frequency electromagnetic radio waves (15–30 kHz), and its instruments measures two major components (in-phase and quadrature) of magnetic fields that constitute from the conductive subsurface bodies. The method, which is a passive electromagnetic technique, is rarely used to investigate the faulting locations in active tectonic researches. It is generally applied to locate sources such as conductive fractures and faults that contain fluid materials or other conductive properties in tectonic investigations. Also it has been used to define the faults and fractures, in particular the detection of geothermal systems (Phillips and Richards, 1975; Jeng et al., 2004; Drahor and Berge, 2006; Zlotnicki et al., 2006; Gürer et al., 2009; Alexopoulos et al., 2013; Jacob et al., 2013). The evaluation in this technique has been carried out using qualitative interpretations until last two decades. Today, the quantitative interpretation of VLF data using inversion algorithms have been increased together with the emerging interest toward the method, and successful results have been obtained using inversion techniques on different investigation areas (Beamish, 1994; Kaikkonen and Sharma, 1998; Sharma and Kaikkonen, 1998; Monteiro-Santos et al., 2006; Baranwal et al., 2011). However, we can determine that the quality of data is very important to achieve the successful inversion results, and particularly the geological noises (nonlinear causative backgrounds) affect the VLF signals (Everett and Weiss, 2002). The conventional filtering techniques could not be sufficiently performed to remove these noises, and therefore we should be very careful during the data evaluation and interpretation stage of the inversion procedure. Despite all, some results showed that the careful investigations performed by VLF technique could give useful and interpretative results in the investigation stage of non-mineralized shallow fault zones.

Natural electrical currents cause the electrical potentials, which are generally emerged by some physical and chemical changes such as electrokinetic activity, geochemical process and thermoelectrical process, on the surface of earth. Not only the SP method is also rarely applied technique in determination of faulting locations, but also it has found large application area such as geothermal, environmental, engineering, volcanic, tectonic and archaeological applications (Fitterman, 1978, 1979; Sill, 1983; Corwin, 1990; Di Maio and Patella, 1991; Drahor et al., 1996; Di Maio et al., 1997; Drahor, 2004; Revil and Jardani, 2013). In active tectonic zones, SP anomalies are mostly occurred by electrokinetic and electrochemical mechanisms. For this reason SP studies have been frequently applied in geothermal and hydrothermal areas to define the dynamic flow systems along a fault or fracture systems. Upflow thermal fluids give positive SP anomalies along the fault or fracture systems in geothermal systems, while the recharge of the fluids to downflow in hydrothermal systems generates the negative SP anomalies (Finizola et al., 2002, 2004; Hase et al., 2005; Bedrosian et al., 2007; Siniscalchi et al., 2010). The investigations conclude that the geological interfaces such as faults can give the combination of upward and downward flows together, and at that point the W-shape SP anomalies commonly appear (Nishida et al., 1996; Zlotnicki et al., 1998; Aizawa, 2008). We know that the active tectonic zones have also similar characteristics, and the discharge areas would give the positive SP anomalies, while the downward flow, recharge and clayey zones would generate the negative SP values. Thus it can be pointed out that SP method would be useful in identification of fluid flow and clayey zones, and other locations that contain physical and chemical changes in active tectonic sites (Balderer, 1994). In addition, oxidation-reduction processes, moisture and high ion concentration in faulting zones and soils cause some negative anomalies with weak amplitudes (Ishido and Mizutani, 1981; Sill, 1983; Massenet and Pham, 1985; Ishido, 1988; Morgan et al., 1989; Antraygues and Aubert, 1993). Also SP anomalies are affected by natural and cultural noises, soil temperature, bioelectricity, the pH variation inside the soil, moisture and similar changes. Therefore, the SP observations should perform carefully considering these variations during the interpretation stage of active tectonic fault investigations (Miyakoshi, 1986; Giano et al., 2000).

In active tectonic investigations, the application rate of magnetic method is also rarely seen due to the lacking information about the mechanisms of magnetic anomaly that observe in active faulting zones. Recently, the frictional heating process on earthquake mechanism and faulting is discussed by some researchers according to laboratory experiments and field tests. This process is one of the reasons of occurrence of magnetic anomalies resulted from the friction-induced