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Remote sensing of Damavand volcano (Iran) using Landsat imagery: Implications for the volcano dynamics

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ABSTRACT

Remote sensing techniques are applied to retrieve land surface temperature (LST), radiative heat flux (RHF), geothermal heat flux (GHF), and to map hydrothermal alteration zones around the Damavand stratovolcano (Iran). Landsat Enhanced Thematic Mapper Plus (ETM+) day and nighttime images are used and merged to available geological data to identify thermal anomaly areas. RHF is determined using the Stefan–Boltzmann equation after preprocessing (geometric, radiometric and atmospheric correction) and processing (emissivity calculation and LST retrieval) of thermal infrared bands. In order to estimate GHF from daytime image, solar radiation and albedo maps are generated to minimize these effects. The GHF values are derived from nighttime image using the background subtraction technique. Using Boolean operation, only those pixels with the GHF values greater than 30 W/m^2 obtained from daytime image and the GHF values greater than 10 W/m^2 estimated from nighttime image are identified as thermal anomalies. The geothermal areas are identified by combining the thermal anomaly map and other geological information. Thermal anomalies have close spatial correlation to faults, thermal springs, and high heat flow measurements from subsurface data and lithology. Some of the thermal anomalies and hydrothermal alteration areas also overlap active deformation areas. This suggests role of heat and hydrothermal alteration on flank instability processes. The thermal anomaly areas show an arc-shaped pattern. This pattern and the concentration of higher GHF areas in the eastern sector of the volcano are consistent with a release of fluids in a transition zone between a transpressional and a transtensional tectonic regime. The combination of thermal infrared data with other geological information layers can be used to detect geothermal areas as well as to analyze the complex relationships among geothermal activity, active tectonics, and gravity instability processes on volcanoes.

1. Introduction

Thermal infrared (TIR) remote sensing with satellite imagery has been applied to derive land surface temperature (LST) in various disciplines such as geology and volcanology, environmental studies, meteorology, urban climate, vegetation monitoring and soil moisture studies (Prakash, 2000; Weng, 2009; Li et al., 2013 and refrences therein). Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper plus (ETM+) have been extensively used for the remote sensing of volcanoes and geothermal fields (Flynn et al., 2001; Ramsey and Flynn, 2004; Ramsey and Harris, 2013). Geothermal exploration (Qin et al., 2011; van der Meer et al., 2014), monitoring of active (Harris et al., 2004) and dormant volcanoes (Ji et al., 2010), measure of radiative and geothermal heat flux (Watson et al., 2008; Savage et al., 2010; Mia et al., 2012), and hydrothermal alteration mapping (Mia and Fujimitsu, 2012) are examples in which Landsat TM and ETM+ imagery have been adopted in the field of volcanology. Most of the research on TIR remote sensing of volcanoes focused on the monitoring of eruptive activity and measure of heat loss from active volcanoes (Urai, 2002; Ramsey and Harris, 2013). TIR remote sensing data can also be used to map and quantify the temperature anomalies in and around dormant volcanoes (Lagios et al., 2007; Savage et al., 2012). Little attention has been devoted to combine surface information from remote sensing of active geothermal areas around the volcanoes with other geological datasets and subsurface data in poorly known volcanoes (Qin et al., 2011; van der Meer et al., 2014). We show that thermal anomalies detected from remotely acquired data could be related to tectonic activity and areas of deformation of the volcano. This study aims to investigate the retrieval of LST and radiated portion of geothermal heat flux (GHF) on Damavand volcano (Iran) based on TIR remote sensing. The main objectives include the detection of thermal anomalies and hydrothermal alteration around the Damavand volcano based on remote sensing and field evidence, validation of thermal anomaly areas with

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available geological data and manifestations of geothermal activity and finally the study of the relationships between thermal anomalies and the tectonic setting and deformation of the volcano.

Damavand volcano is located about 50 km NE of Tehran capital city, Iran. Damavand is a Quaternary, 5610 m high, quiescent strato-volcano (Fig. 1). The volcanic edifice (~400 km^3) is one of the largest known on land (Davidson et al., 2004), and it is made of trachyandesite–trachyte lava flows and subordinate pyroclastic deposits overlying the active fold and thrust belt of the Central Alborz Mountains (Fig. 2). Although the last magmatic activity of Damavand dates back to 7300 years (Davidson et al., 2004), seismic activity (Tatar et al., 2012), hot springs on flanks and fumaroles near the summit provide evidence of its activity. Therefore, Damavand is still active and potentially hazardous. Recent investigations suggest that Damavand volcano is actively deforming (Shirzaei et al., 2011) and it is subject to potential sector collapses, debris avalanches, and mud flows (Davidson et al., 2004). In 2007, an increase in the activity of the summit fumaroles has been observed as well as an earthquake with M = 2.9 occurred in January 2007 close to the volcano flanks. As a consequence, there is an increasing interest about a possible destabilization and, possibly, a future eruption at Damavand (Mortazavi and Sparks, 2011).

2. Regional geology and volcanological setting

Damavand volcano is located in the central part of the Alborz mountain range along the southern margin of the Caspian Sea, North of Iran (Allenbach, 1966; Davidson et al., 2004). The Alborz range is a part of the Alpine–Himalayan orogenic belt. The present-

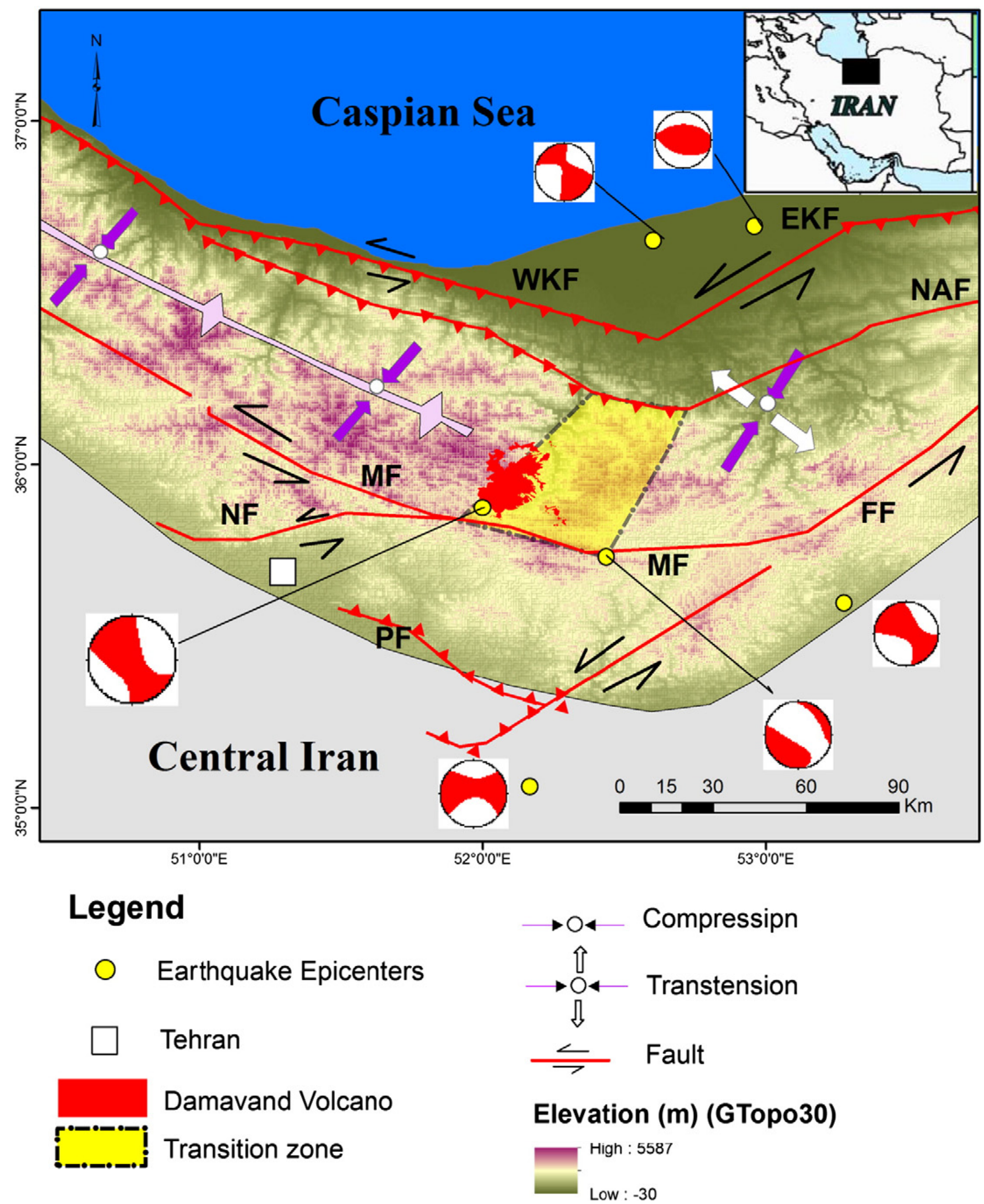

Fig. 1. Map of Central Alborz with idealized tectonic model proposed by Shabanian et al (2012) for the present-day deformation. Earthquake epicenters (large events > 5Mw) and focal mechanisms (red spheres) are from Harvard catalog (http://www.globalcmt.org/CMTsearch.html). Abbreviations refer to faults: MF, Mosha; NF, North Tehran; EKF, East Khazar; FF, Firuzkuh; PF, Parchin; WKF, West Khazar, NAF, North Alborz.