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Volcanotectonic evolution of central Jordan: Evidence from the Shihan Volcano

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ABSTRACT

The E–W Siwaqa transcurrent fault is the result of tectonic activity related to the opening of the Red Sea and sinistral movement along the Dead Sea Transform (DST). During the translation and anticlockwise rotation of the Arabian Plate, dextral motion occurred along the Siwaqa Fault that resulted in opening of the crust and allowed lava to erupt intermittently from the Shihan Volcano, producing the Shihan Basalt Group. The stress field that formed the Siwaqa Fault and its related volcanic group is characterized by N–S to NNW–SSE compression and E–W to ENE–WSW extension, which is compatible with that known in Middle Miocene – Recent and related to the DST tectonic activity. The temporal and spatial distribution of the different volcanic formations was possibly affected by stress fluctuations. The first volcanic stage occurred prior to the formation of Wadi Mujib during the Messinian age. The latest erupted during the middle Pleistocene after the formation of Wadi Mujib. The Shihan Basalt Group consists of alkali olivine basalt, basanite and hawaiite. The basalt is subdivided into a silica saturated unit and an undersaturated silica unit. Crustal contamination is evident; variations in the basalt composition are due to different degrees of partial melting and fractional crystallization.

1. Introduction

The Dead Sea Transform (DST) is 1100 km long sinistral fault system that connects the Gulf of Aqaba-Red Sea spreading system to convergence zone in the Taurus – Zagrous mountains. In terms of plate tectonics it is considered to be a plate boundary between the Arabian plate in the east and Palestine-Sinai sub plate (part of the African plate) in the west. The DST is the major tectonic feature controlling the stratigraphic and structural evolution of the region since the Miocene (Al-Taj, 2000). In central Jordan, the area to the east of the DST is dissected by an east–west regional fault called the Siwaqa Fault (Figs. 1B and 2). Consequently, the area has been involved in the regional tectonics and volcanic history of the Arabian Plate. During the Neogene-Quaternary, basaltic volcanism has occurred, mainly along the western boundary of the Arabian Plate (Fig. 1). It covers huge areas, from Yemen in the south to Syria in the north (Fig. 1A). Recent eruption was reported in October 2007 from Jabal Tair in the Red Sea. In Jordan, basalts have been subdivided into DST eastern margins basalts and Harrat Ash Shaam basalts (Fig. 1B) (Barberi et al., 1979). The Shihan Volcano (SV) belongs to the DST eastern margins basalts.

Although several studies have been carried out on the basaltic outcrops of the area (e.g., Barberi et al., 1979; Saffarini et al., 1985; Steinitz and Bartov, 1992; Ibrahim, 1993; Ibrahim et al., 2003, 2006; Tarawneh et al., 2000; Illani et al., 2001; Shaw, 2003; Shaw et al., 2003, 2007; El-Hasan and Al-Malabeh, 2008; Weinstein, 2012), very little attention has been paid to the Shihan Volcano. Therefore, available published data are not sufficient for conclusions regarding the volcano-magmatic and volcano-tectonic evolution of the volcano and its morphotectonic effects. This study describes also for the first time the geochemistry of field-identified volcanistratigraphic formations recognized during a detailed geological mapping program at a scale of 1:50,000 by the Natural Resources Authority of Jordan.

2. Location and geomorphology

The SV is situated about 80 km south of Amman (Fig. 1), along the Kings Highway, and about 30 km north of Al Karak at Wadi

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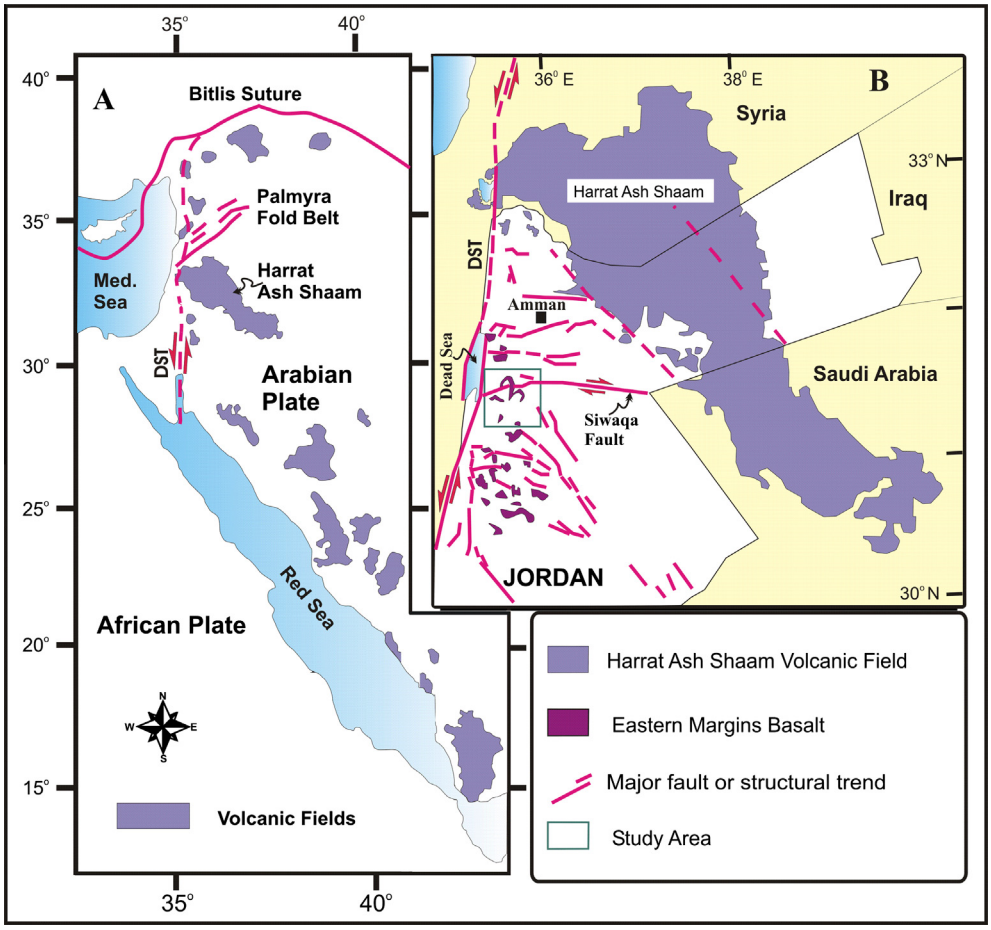

Fig. 1. Distribution of intraplate volcanic fields of the Arabian Plate (A) and tectonic setting of Jordan and location of study area (B).

Mujib. The volcano is about 1061 m above sea level, which is the highest point in the study area. Lava flows have erupted from the volcanic center since the Messinian of the Miocene (6.0 ± 0.5, 6.0 ± 1.2 and 6.1 ± 0.2 Ma) (Barberi et al., 1979; Duffield et al., 1988) and continued until the Pleistocene. Lava from the JVS covers an area about 20 km wide in the E–W direction and about 40 km long in the N–S direction. Now it is estimated that more than 70% of the eruption area is covered by soil.

Four distinctive geomorphological elements are recognized in the study area, including: the volcanic center (SV); basaltic lava and soil plateau; topographic ridges and highs of the Siwaqa Fault; and Wadi Mujib and its two branches, Wadi Salayta and Wadi Nukhayla (Fig. 2). The SV is a conical outstanding volcanic center that overlooks a gently undulated landscape. It represents one of the continental plateau basaltic volcanic centers mantling the Upper Cretaceous – Paleogene carbonate peneplain. Lava flows from the volcanic cone radiate outwards onto the peneplain from the vent forming a basaltic lava plateau and filling courses of older wadis.

The peneplain and the basaltic plateau vary in elevation from 980 to 750 m above sea level. The Siwaqa Fault topographic ridges and highs are described below.

Wadi Mujib, a deeply incised valley (the great canyon of Jordan), dissects the region almost from east to west toward the Dead Sea and forms steep slopes. The base of the wadi in the vicinity of the volcanic center is 96 m, whereas the base at the discharge point in the Dead Sea shoreline is about −414 m (i.e., below sea level). Parts of the lava flows from the SV are now isolated by the intervening canyon of the wadi in two localities (Fig. 2), indicating that the wadi is younger than basaltic flows erupted from the SV.

3. Tectonic setting

The structural pattern of Jordan was affected by the opening of the Red Sea and the Gulf of Aden. The area was subjected to SE–NW compression stresses during the Oligocene–Miocene that were responsible for reactivating pre-existing faults and weakness zones and creating new fractures and discontinuities. This reactivation is believed to have caused the volcanic activity. Fig. 1B shows a generalized regional picture of the structures in Jordan. The DST is the main structural feature in Jordan. It consists of left-lateral fault segments that connect the active oceanic spreading centers in the Red Sea to the compressional deformation zones in southeast Anatolia and the Zagros. Along the DST, regions of overlap between left-stepping and right-stepping fault segments are determined (Garfunkel et al., 1981; see also Cunningham and Mann, 2007). Basins and ridges of varying size, shape, and depth along the DST have been forming due to fault bends or stopovers (ten Brink et al., 1999; Al-Taj et al., 2007). It accommodates sinistral motion between the Arabian plate and the Palestine-Sinai subplate. 107 km of cumulative left-lateral slip along the DST has occurred over the last 15 million years (Marco, 2007). The average rate of movement along the DST is 4.9 mm/yr (Ferry et al., 2011). This is based on observations from four independent sources: regional plate tectonics, local geology, seismology and geodesy.

Other structures of central Jordan are the E–W, NE–SW, NNW–SSE and NW–SE fault trends. The Siwaqa Fault is a transcurrent fault, trending E–W (Figs. 1B and 2). It crosses Jordan from the Saudi Arabian border in the east to the Arabian Plate boundary in the west (vicinity of the Dead Sea). The Siwaqa Fault is composed