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Geochemistry, petrogenesis and tectono-magmatic setting of the basic magmatism in Ardekan and Isfahan, Central Iran

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ABSTRACT

In this paper, the basic magmatism in northeast of Ardekan and northeast of Isfahan are described. Both areas are located in Central Iran. In Ardekan, the studied section is composed of a late Devonian- carbonate and terrigenous succession. There are some volcanic horizons in this section which represent basic submarine volcanic activities. In northeast of Isfahan (Zefreh–Bagherabad), small intrusive (hypabyssal) bodies intruded into the late Devonian succession. The geochemical characteristics suggest that magma was produced by partial melting of a garnet-lherzolite zone. Of course the role of partial melting of a plagioclase-bearing source shouldn't be ignored. Based on clinopyroxenes analysis, magma in the storage region crystallized in relatively low pressure conditions. The evidences of crustal contamination are not significant, which can be attributed to the rapid ascent of the parental magma. Based on geochemical and tectonic data, these rocks are of alkaline to tholeiitic affinity and were created in a continental rift in an extensional regime probably related to the tensional movements in Central Iran during the Paleozoic.

1. Introduction

Central Iran is one of the main structural zones in Iran. Based on Ghorbani (2013), rocks with variable ages (Precambrian to the Quaternary), numerous episodes of orogeny, metamorphism and magmatism can be recognized in this zone. Central Iran is surrounded on the north by the Alborz Mountains, by Lut Block in the east and by Sanandaj–Sirjan in the south–southwest (Stöcklin, 1968). Of course based on Nabavi (1976), the northern part of the Lut Block is a part of Central Iran. The volcanic rocks with composition of andesite to basalt accompany upper Paleozoic sedimentary strata in many areas throughout Iran.

The Paleozoic magmatic activity and especially the extensive basaltic eruption in Silurian and its relation to the formation and expansion of the Paleo-tethys is one of the main topics of Iran geology (Derakhshi et al., 2014). Darvishzadeh (1996) argues that the Paleo-tethys oceanic crust was formed during the Ordovician; however the main volcanic events have occurred within the Silurian – Devonian period. A large part of the structural zones of Iran (Alborz, Sanandaj–Sirjan, Central Iran) have been affected by this basaltic magmatic activity especially in Silurian (Derakhshi et al., 2014). In addition, in the Alborz range, the east of Iran, Anarak area (Central Iran) and some other regions in Sannandaj–Sirjan zone we have some evidences of late Devonian basic volcanic activities (e.g., Darvishzadeh, 1996). The presence of alkaline magma within the Iranian plate during the Silurian and Devonian can be an evidence of extensional tectonics in this plate. Also, the presence of basic volcanism and formation of numerous grabens results from continental rifting within the Iranian plate in that interval (e.g., Darvishzadeh, 1996). The Middle Ordovician magmatic activity in Alborz and many parts of Central Iran has interpreted as the Paleo-tethys rifting sequences (Stampfli, 1978; Berberian and King, 1981; Boulin, 1991; Alavi, 1996; Stampfli et al., 2002; Bagheri and Stamppfli, 2008).

However available data on Paleozoic magmatism of the Iranian plate (especially in Central Iran) are limited, due to their rare occurrence. To investigate the characteristics of Paleozoic magmatism in Central Iran, the volcanic rocks of some area like Zefreh–Bagherabad (northeast of Isfahan) and Dalmeh (northeast of Ardekan) which are as volcanic horizons, have been studied. These mafic volcanic horizons occurred as lava flows with massive and pillow structures and are interbedded with several sedimentary layers such as sandstones and carbonates. This interlayering suggests that these volcanic rocks were generated in an extensional setting which is related to the extensional–compressional movements in Central Iran during the Paleozoic period. These movements are comparable with Hercynian orogeny (Late Devonian to Middle Triassic). The role of Hercynian in Iran is controversial because of insufficiency of magmatism and metamorphism related to this episode. This episode is mainly represented

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by extensional rather than compressional tectonics (e.g., Sanandaj–Sirjan; Hosseini, 2011) (Ghorbani, 2013). Some Paleozoic magmatic rocks which are more or less similar to the studied volcanic rocks in chemical composition have been reported from some areas such as jam (e.g., Alavi Naini, 1972; Naji, 2004), Pole-Khavand (Hashemi, 2007), Shirgasht (e.g., Ghasemi and Derakhshi, 2008), Jahagh (Mirlohi, 2008) and Soltan-Maydan (e.g., Ghorbani, 2009; Derakhshi et al., 2014). The petrology and geochemistry of the studied igneous rocks have not been studied in detail previously. The main purpose of this study is investigation of the geochemical characterization of these Paleozoic volcanics in order to infer their source and geotectonic environment.

2. Methodology

Over fifty rock samples were collected from the least altered volcanic rocks and have been described petrographically. Eleven samples were analyzed for major element compositions using X-ray fluorescence (XRF) at the Isfahan University central laboratory (Iran). These elements determined by XRF analysis on fused glass discs. Some trace elements such as Ni, Cu, Zn and V were measured by X-ray fluorescence spectrometry on pressed powder pellets. Trace and REE element compositions determined by inductively coupled plasma mass spectrometry (ICP–MS) at the Amdel laboratory in Adelaide (Australia). About ten pyroxene phenocrysts which are selected mostly from basaltic andesite samples of Dalmeh and Zefreh–Bagherad were analyzed by electron microprobe at Oklahoma University, USA.

Analytical equipment included Cameca SX50 comprising 5 asynchronous wavelength dispersive spectrometers and PGT PRISM2000 energy dispersive X-ray detector. The instrument was set for 20 kV acceleration voltage, 20 nA sample current and 3 μm spot size. L-alpha emission was used for Ba but the rest of the elements were investigated by K-alpha emissions. Measurements were completed by 30 s of counting times resulting in detection of $\leqslant$0.02 wt% of the oxide for all components apart from Ba and F that were 0.09 wt% BaO and 0.10 wt%, respectively. The standard set comprised natural minerals and synthetic compounds. Representative pyroxene analyses from the studied rocks and whole-rock geochemical data from representative samples are listed in Tables 1 and 2 respectively.

3. Geological setting

Dalmeh and Zefreh–Bagherabad regions which are about 220 km away from each other, are located in Central Iran (Fig. 1).

3.1. Dalmeh

This area is located in 60 km northeast of Ardekan and 285 km east of Isfahan. The oldest rocks in Dalmeh area consist of Precambrian phyllite, micaschist and gneiss as a member of the Tashk unit (Haghipour et al., 1977). This sequence is overlaid by rhyolite, evaporite and thick dolomite as Rizu series (Fig. 2). After a long hiatus (in Ordovician-Middle Devonian), a late Devonian succession is observed (including limestone, dolomite, shale and sandstone) as a terrigenous portion in lower part and a carbonate portion in upper part. This carbonate portion with 3 meters thickness is an equivalent of the Shishtu formation in the East of Iran. Five volcanic horizons (basalts- basaltic andesites) are associated with these sediments which can be assigned based on conodonts to the early to middle Famennian (e.g. Hairapetian, 1999; Hairapetian and Yazdi, 2003 First volcanic horizon with 1.8 m thick and the second horizon with the most thickness (about 8 m) are related to the early Famennian. Third and forth volcanic horizon is separated by a limestone layer with 2.7 m total thickness (Fig. 3). Conodonts recovered from limestone layers below and above the volcanic horizons represent Early Famennian. The fifth or last horizon is located in the Middle Famennian and is 2 m thick (e.g. Hairapetian, 1999; Hairapetian and Yazdi, 2003). All volcanic horizons are interbedded with limestone layers. Pillow structures can be seen in some of these volcanic rocks. The contact between volcanic rocks and carbonates tends to form only a thin recrystalized limestone (marble) in underneath. These features associated with pillow structure and vesicular textures are evidences for a synsedimentary submarine eruption. The presence and alternation of these volcanic horizons can be attributed to extensional phases.

Table 1
Results of microprobe analysis and number of cations per formula unit of clinopyroxene (6 oxygens).

Sample no	Z1	Z2	Z3	Z4	Z5	D6	D7	D8	D9	D10
SiO_2	48.65	50.11	48.98	50.31	50.22	49.50	50.42	51.31	49.12	51.36
TiO_2	1.18	1.1	1.30	0.87	0.12	1.19	0.88	0.85	1.54	0.84
Al_2O_3	3.55	3.31	3.75	3.01	3.07	4.03	2.6	2.08	4.59	2.77
Fe_2O_3	3.98	3.21	3.05	3.52	2.5	2.95	3.64	2.59	2.59	1.87
FeO	2.9	3.01	4.13	2.88	3.62	3.73	2.9	4.01	4.78	4.28
MnO	0.13	0.11	0.12	0.13	0.12	0.14	0.12	0.14	0.12	0.14
MgO	15.81	16.27	15.44	16.51	16.11	15.64	16.69	17.18	15.51	17.02
CaO	21.61	20.67	20.99	21.35	21.14	20.81	21.33	20.55	20.56	20.47
Na_2O	0.27	0.28	0.23	0.25	0.25	0.27	0.24	0.21	0.28	0.25
Tot	98.08	98.07	97.01	98.83	97.15	98.26	98.82	98.92	99.09	99
Si	1.83	1.88	1.80	1.87	1.89	1.84	1.87	1.90	1.83	1.90
Ti	0.03	0.03	0.035	0.02	0.00	0.04	0.03	0.02	0.04	0.02
Al^{IV}	0.16	0.12	0.15	0.13	0.11	0.15	0.11	0.09	0.17	0.10
$Al^{V}i$	0.00	0.02	0.02	0.00	0.03	0.02	0.00	0.00	0.03	0.02
Fe^{3+}	0.11	0.09	0.08	0.10	0.07	0.08	0.10	0.07	0.07	0.05
Fe^{2+}	0.09	0.09	0.13	0.09	0.11	0.12	0.09	0.12	0.15	0.13
Mn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mg	0.89	0.91	0.84	0.91	0.91	0.87	0.93	0.95	0.86	0.94
Ca	0.87	0.83	0.85	0.85	0.85	0.86	0.85	0.82	0.82	0.81
Na	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Sum cations	4.00	4.00	3.92	4.00	4.00	4.00	4.00	4.00	4.00	4.00
WO	44.31	43.07	44.15	43.45	43.83	44.23	43.12	41.51	43.03	41.85
EN	45.11	47.17	44.75	46.75	46.48	45.20	46.95	48.28	45.16	48.41
FS	10.58	9.77	11.10	9.81	9.69	10.57	9.93	10.22	11.81	9.74
JD	0.00	0.44	0.28	0.02	0.57	0.34	0.00	0.00	0.64	0.52