Geochemistry of siliciclastic sediments of the Semnan Province and NE of Isfahan Province (Iran), implication for provenance

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Abstract

Some 43 surficial sediment samples of the Semnan Province and NE of the Isfahan Province were collected. Powdered sand sized fraction of these samples were analyzed by XRF method for major elements. Some 8 selected samples along with 8 extra samples collected from more conspicuous rock units exposed around the periphery of these study areas were also analyzed by ICP-MS for REE in the laboratory of the Geological Survey of Iran (Karaj Division). A variety of rock types including silicic, to basic intrusive, subvolcanics and extrusive rocks exposed in these areas. Geochemical interpretations revealed that surficial sediments of both study areas stemmed from intermediate igneous rocks and mafic rocks for the NE Isfahan province as well. Samples of the Semnan Province show PCM (Passive Continental Margin), while those of the NE Isfahan are more complex and fall in the realm of OIS (Oceanic Island Arc), CIA (Continental Island Arc), and ACM Active Continental Margin) as well. The REE and trace element composition of 8 sediment samples and 8 rock samples (proportionally equal quantities for both study areas), show enriched LREE, high LREE/HREE ratio and depleted Eu anomaly for both areas. These evidences support an acidic igneous rocks origin (possibly tuffs of the Karaj Formation) for the Semnan area. Although for the NE of Isfahan Province, it is slightly divers. Here, igneous acidic to intermediate igneous rocks, ultramafic and ophiolites of the Anarak-Khour area, ophiolite complexes exposed along major faults (e.g. Nain-Dehshir-Baft) are invoked for the plausible provenance of the sediments.

Keywords: *geochemistry, Provenance, Semnan Province, Isfahan Province, REE*

Introduction

Geochemistry of sediments has been utilized as a useful tool to discriminate tectonic setting and provenance (North *et al.*, 2005). Siliciclastic sediments ha e been widely used for these purposes (Bahatia and Crook, 1986; Armstrong-Altrin et al., 2004). Many authors show relationships between tectonic setting, provenance and composition of siliciclastic sediments (Armstrong-Altrin *et al.*, 2004; Cullers, 1994; Bahatia & Crook, 1986; Dickinson & Suczek, 1979). XRF analysis on powdered samples has been commonly used to achieve these proposes (Zimmerman & Bahlburg, 2003). Composition of wind-blown sediments might be controlled by different factors including composition of their provenance, transportation distance and later diagenesis. Although, tectonic setting of the depositional environment are vital (Akarish & El-Gohary, 2008). Accordingly, attempts were made to constrain on the provenance and tectonic setting of the surficial sediments of Semnan Province and NE of the Isfahan Province based on interpretations of data achieved by analyses of major elements, trace elements and REE. As these areas are located in arid region, they are very susceptible for wind erosion, hence are dust prone. A major problem which countries such as Iran are recently suffers from. Normally dust could originate from arid regions, thus such studies in arid region, particularly around the Great Desert of Iran are crucial.

Geologic setting

The Semnan Province is located in the Alborz zone while the NE of Isfahan Province is located in Central Iran zone. A variety of different rocks are exposed in the both of these areas (Aghanabati, 2010). In the Semnan Province as a part of the Alborz Mountain Rang, during the late Precambrian to Ordovician an epicontinental sea existed, in early Paleozoic carbonates and subordinate siliciclastics were deposited, which were continued during late Paleozoic. Triassic sediments are limestone – dolomite. During early Jurassic sandstone and shale with subordinate basaltic –andesitic volcanic were deposited. Upper Jurassic to Cretaceous sediments are limestone and marls. Paleocene is dominated by clastic, volcanic and tuffs. During Neogene the Lower Red Fm., Qom Fm. and Upper Red Fm. were deposited. Quaternary of the Semnan Province are composed of fluvial sediments, evaporates of the playa.

The Central Iran micro-continent is a part of the Central Iran Zone which is characterized by several geosutures with ophiolites emplaced along them (e. g. Nain – Baft, Daruneh, Kashmar –Sebsavar faults). In Anarak – Jandagh, up to 7000 m thick peridotite, gabbro, diabase, basalt, shale and limestone is being reported. Paleozoic rocks are clastic, carbonates with subordinate volcanic rocks and evaporates (Aghanabati, 2010). During Triassic and Jurassic carbonaceous clastics are widespread. Lower Cretaceous sediments are shale with limestone intercalations known as Biabanak Shale (Haghipour, 1974). Upper Cretaceous sediments are carbonates, the Lower Red Fm. the Qum Fm. and Upper Red Fm. characterizing Cenozoic of the region. Aeolian deposits are the main feature forming of the regions which are visible in deserts of the Kavir mainly as sand dunes. Detailed sedimentology of these sediments were discussed by Mohseni *et al.,* 2014a; 2014b.

Methods and materials

Surficial sediments of the Semnan Province and NE of the Isfahan Province were analyzed to constrain on the origin and provenance of these sediments (Figs. 1, 2). Sampling was followed after procedure recommended by UNESCO, under supervision of their staffs in collaboration with staffs of the Geological Survey of Iran. Quantities of the collected samples were controlled by several factors including surficial proportional distribution of windblown sands, and limitation imposed by wild nature of theses deserted areas. Accessibility to all across the area is impossible, as only few truck roads exists. Sand size fractions of some 43 samples collected from surficial sediments were analyzed by XRF Philips Model PW2450 in the GSI. Precision was 0.01%. Results are presented in Table 1 and 2. A suite of 8 samples among them (samples M6, M9, M12, M13, M27, M33, M36, M40) along with 8 extra samples collected from the main rock unites exposed around these area, (labeled as samples A1 through A8) were also analyzed for REE content by ICP-MS in the GSI Lab (Karaj Brunch). Results are presented in the Table 3 and 4. Thin sections of some sand sized fraction of the sediments were analyzed under routine petrographic microscope for heavy mineral identification. Appropriate proportion of heavy minerals was also examined under binocular microscope equipped with photographic camera to identify mineralogy of heavy minerals.

Result and discussion

Interpretation of major elements content of sediments and sedimentary result could be useful for discrimination their composition (Das *et al.*, 2006). Result of XRF analysis of major elements for the Semnan Province and NE Isfahan are plotted on Fig. 3 respectively. Evidently, sediments of the Semnan Province show arkose, litharenite, greywacke and shale composition (Fig. 3 A). As it is evident in Fig. 3 A, samples of the NE Isfahan Province show litharenite and greywacke composition. Most of greywacke could deposit during active plate movement along with Island Arc (Tucker, 1994).

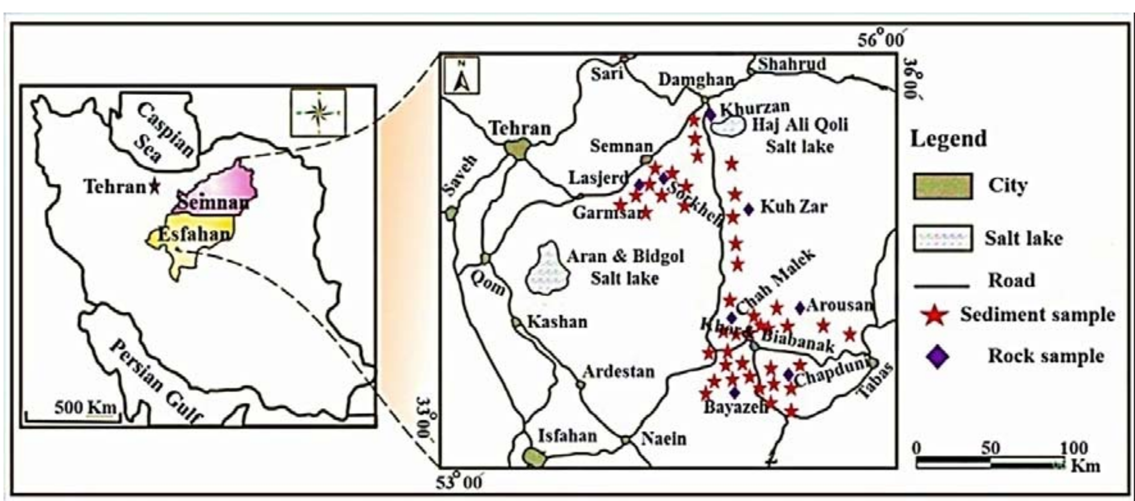


Figure 1. Lotion map of the study area

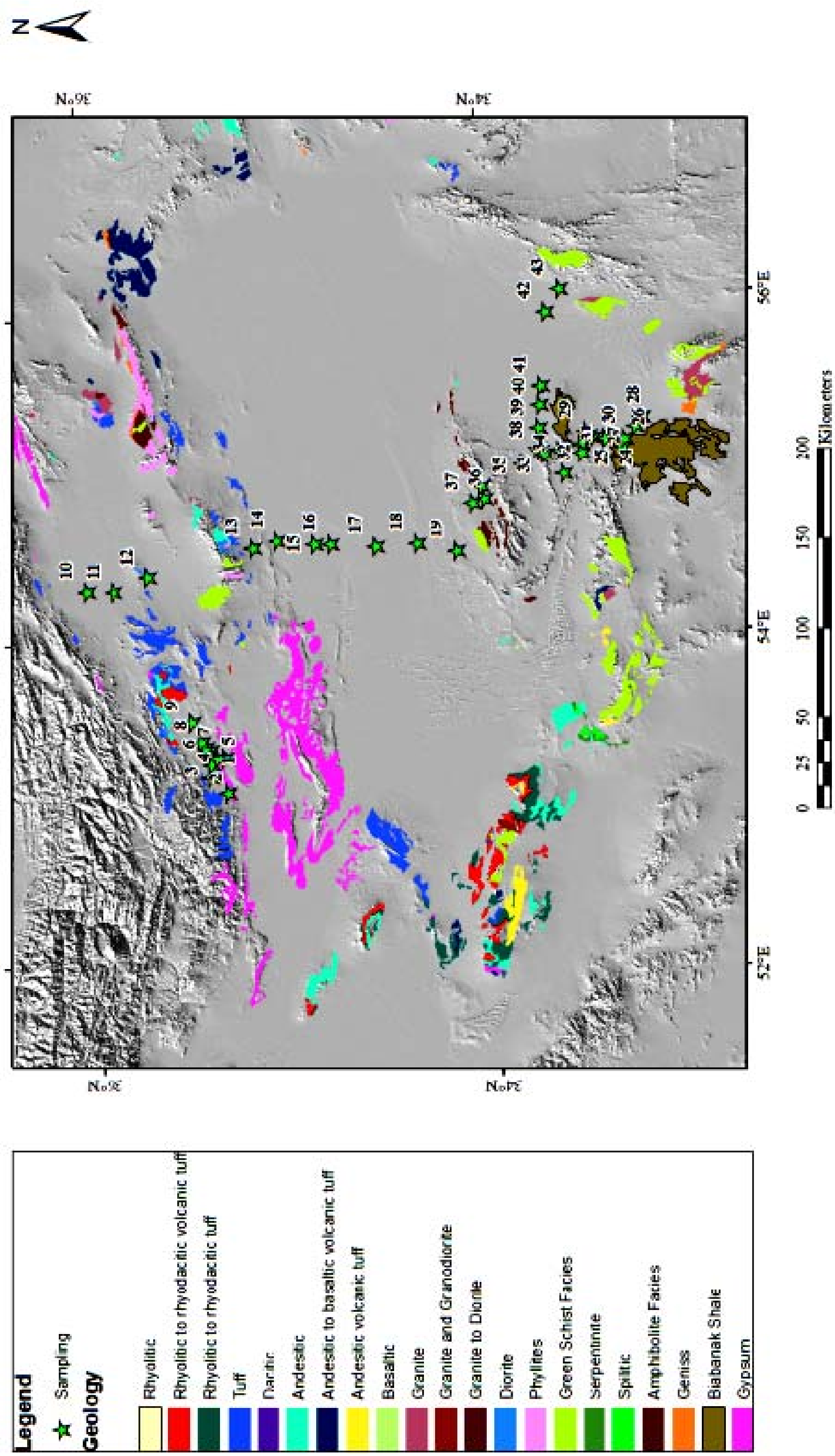


Figure 2. Generalized geology map of Semnan Province and NE Isfahan and the surrounding area (for data base see www.ngdir.org).

Table 1. Result of XRF analysis of major elements of samples the Semnan province (w%).

S.N.	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**P_2O_5**	**SO_3**	**K_2O**	**CaO**	**TiO_2**	**MnO**	**Fe_2O_3**	**L.O.I.**
M1	0.70	2.58	7.08	33.91	0.14	15.60	1.51	17.33	0.33	0.07	2.73	17.60
M2	0.54	2.30	8.48	41.99	0.15	5.20	1.96	17.23	0.37	0.11	2.73	18.64
M3	0.45	2.24	7.90	34.83	0.16	12.43	1.57	18.97	0.36	0.12	2.73	18.10
M4	3.61	6.85	5.64	25.54	0.10	19.28	1.19	12.26	0.25	0.09	2.73	20.18
M5	0.97	3.18	6.01	26.33	0.14	20.13	1.25	19.91	0.25	0.00	2.73	18.70
M6	0.89	1.82	3.67	16.89	0.08	30.82	0.77	23.33	0.19	0.00	2.73	18.98
M7	1.50	3.96	5.72	23.20	0.08	21.55	1.24	18.14	0.33	0.00	2.73	18.81
M8	2.04	4.32	9.39	31.01	0.13	7.16	1.90	16.01	0.48	0.00	2.73	20.50
M9	2.20	3.41	11.23	43.20	0.17	1.43	2.28	12.97	0.57	0.14	2.73	15.90
M10	1.78	3.62	11.39	36.07	0.15	0.84	2.00	16.01	0.58	0.11	2.73	20.70
M11	4.11	4.86	10.26	35.06	0.14	2.24	1.84	13.69	0.48	0.10	2.73	20.75
M12	1.12	2.97	11.59	46.80	0.22	2.24	2.21	12.47	0.55	0.11	2.73	14.60
M13	2.74	6.34	7.32	30.02	0.12	13.34	1.53	15.16	0.40	0.09	2.73	16.81
M14	1.23	4.24	10.34	33.53	0.15	5.90	2.21	14.13	0.55	0.11	2.73	18.30
M15	1.48	3.94	11.47	37.80	0.16	3.34	2.29	11.72	0.60	0.10	2.73	18.68
M16	2.09	4.14	10.84	35.60	0.15	1.41	2.36	12.99	0.51	0.10	2.73	19.02
Mean	1.72	3.80	8.65	33.24	0.14	10.18	1.76	15.77	0.42	0.08	2.73	18.52

Table 2. Result of XRF analysis of major elements of samples the NE Isfahan (w%).

S.N.	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3	L.O.I.
M17	4.42	4.63	10.42	37.31	0.16	3.37	1.90	12.59	0.52	0.12	2.73	15.80
M18	4.70	5.11	11.04	38.71	0.15	0.43	2.00	11.93	0.54	0.08	2.73	16.07
M19	1.07	3.90	10.89	43.41	0.16	0.59	2.04	17.40	0.53	0.14	2.73	15.32
M20	0.47	2.59	7.04	22.80	0.10	1.17	1.06	33.30	0.32	0.00	2.73	28.20
M21	0.41	3.14	10.26	28.51	0.12	2.84	1.92	24.32	0.48	0.00	2.73	23.20
M22	1.34	1.73	6.12	27.30	0.10	0.73	1.19	31.95	0.42	0.00	2.73	25.59
M23	5.91	3.42	9.41	30.85	0.11	1.76	1.68	17.39	0.41	0.00	2.73	20.38
M24	0.33	1.17	3.08	13.64	0.08	0.30	0.45	44.21	0.14	0.00	2.73	34.81
M25	1.63	3.12	10.88	38.93	0.12	0.49	1.93	18.74	0.57	0.14	2.73	18.20
M26	1.23	2.90	10.68	39.90	0.12	0.34	1.70	19.99	0.53	0.00	2.73	18.04
M27	1.12	3.05	17.87	50.94	0.14	0.32	2.75	5.50	0.64	0.11	2.73	12.08
M28	1.76	2.37	13.66	52.70	0.13	0.20	2.17	8.68	0.59	0.10	2.73	11.98
M29	2.68	2.56	10.62	41.40	0.12	0.47	1.78	17.59	0.48	0.11	2.73	17.40
M30	1.75	2.10	6.64	30.51	0.10	0.40	1.25	30.13	0.37	0.00	2.73	23.52
M31	2.33	2.19	6.40	25.90	0.08	2.17	1.11	31.10	0.34	0.00	2.73	24.30
M32	3.32	3.56	12.69	40.50	0.15	2.68	2.20	12.12	0.52	0.08	2.73	16.54
M33	0.74	2.27	6.30	21.06	0.08	6.21	0.90	31.41	0.31	0.00	2.30	27.90
M34	0.83	2.68	7.34	25.72	0.11	0.67	1.30	32.13	0.35	0.00	3.25	25.34
M35	1.82	1.51	8.53	51.30	0.12	0.14	1.74	17.56	0.33	0.08	2.86	13.91
M36	1.46	1.74	8.98	44.80	0.14	0.16	1.83	20.97	0.40	0.08	3.23	16.20
M37	1.58	2.02	8.47	46.15	0.12	0.17	1.63	19.88	0.47	0.14	3.33	15.90
M38	0.46	2.72	6.20	21.81	0.08	0.67	1.15	35.59	0.32	0.00	2.92	27.90
M39	0.47	2.38	7.09	22.62	0.08	13.37	1.19	26.66	0.32	0.00	2.85	22.50
M40	5.58	2.61	7.97	27.07	0.10	10.75	1.75	16.40	0.39	0.00	3.22	16.70
M41	3.53	6.31	10.62	37.80	0.14	1.76	1.93	12.51	0.53	0.00	4.16	16.70
M42	3.20	2.88	8.38	44.80	0.12	1.65	1.43	16.93	0.49	0.11	4.17	13.80
M43	1.97	2.58	9.08	46.92	0.14	0.14	1.45	18.50	0.46	0.00	3.93	14.54
mean	2.08	2.86	9.14	35.31	0.12	2.00	1.61	21.68	0.43	0.05	2.96	15.80

Table 3. Results of trace and rare earth elements analysis of some selected sediment samples in the Semnan Province and NE Isfahan (in ppm).

Samples no. Elements	M6	M9	M12	M13	M27	M33	M36	M40	∑REE	Mean
Ce	34.90	51.20	51.40	57.40	45.50	44.90	51.70	43.90	380.92	47.61
Dy	2.53	3.70	3.34	3.72	3.53	3.03	3.23	2.99	26.06	3.26
Er	1.45	2.28	1.87	1.99	1.82	1.57	2.27	1.56	14.80	1.85
Eu	0.64	1.04	1.10	1.04	1.00	1.01	0.96	1.01	7.81	0.98
Gd	2.34	4.09	3.69	3.67	3.47	3.49	4.82	3.59	29.17	3.65
Hf	2.10	3.19	2.95	2.83	3.71	2.43	2.72	2.25	22.17	2.77
Ho	0.51	0.78	0.70	0.67	0.68	0.60	0.67	0.71	5.31	0.66
La	18.70	25.50	27.30	28.10	26.10	24.20	25.70	23.80	199.39	24.92
Lu	0.22	0.34	0.28	0.30	0.32	0.27	0.28	0.25	2.26	0.28
Nb	7.85	11.30	12.00	11.50	16.90	9.08	11.90	10.30	90.83	11.35
Nd	11.20	21.40	24.20	20.40	19.80	22.70	27.50	23.60	170.85	21.36
Pr	3.94	6.04	6.36	6.05	5.68	5.07	5.70	6.24	45.08	5.63
Sc	6.14	11.20	12.40	12.30	19.90	10.90	13.00	12.10	97.93	12.24
Sm	2.74	4.46	4.71	4.64	4.14	4.01	4.71	4.12	33.53	4.19
Ta	0.54	0.72	0.64	0.63	1.02	0.44	0.74	0.46	5.19	0.65
Tb	0.44	0.74	0.60	0.60	0.62	0.58	0.57	0.53	4.68	0.58
Th	5.09	8.60	8.05	7.62	12.10	6.28	8.85	7.76	64.29	8.04
Tl	0.57	0.93	0.91	0.83	0.88	0.51	1.13	0.72	6.47	0.81
Tm	0.20	0.32	0.29	0.32	0.35	0.24	0.34	0.27	2.33	0.29
U	1.52	2.22	2.21	2.37	2.16	1.89	2.16	1.97	16.50	2.06
W	0.68	0.92	0.97	0.99	1.67	0.98	1.10	1.06	8.38	1.05
Y	12.80	16.10	19.00	19.30	16.60	16.30	17.80	16.10	134.02	16.75
Yb	1.47	2.20	1.99	1.88	2.36	1.65	2.09	1.67	15.31	1.91
Zr	76.40	101.00	97.70	92.80	111.00	65.00	88.00	79.00	711.22	88.90

Table 4. Results of trace and rare earth elements analysis of some selected rock samples in the Semnan Province and NE Isfahan areas (in ppm).

Sample No. Elements	A1	A2	A3	A4	A5	A6	A7	A8	∑REE	Mean
Ce	34.0	5.70	21.1	3.32	5.71	1.79	52.4	26.2	150.2	18.77
Dy	1.96	0.63	4.05	0.29	0.42	0.13	2.87	2.16	12.50	1.56
Er	1.08	0.36	2.38	0.18	0.24	0.09	1.58	1.37	7.29	0.91
Eu	0.72	0.15	1.03	0.07	0.13	<0.05	0.98	0.52	3.60	0.51
Gd	2.94	0.74	3.66	0.35	0.45	0.14	3.30	2.03	13.61	1.70
Hf	1.82	0.06	1.25	<0.05	0.09	<0.05	1.67	1.65	6.55	1.09
Ho	0.42	0.13	0.93	0.07	0.09	<0.05	0.62	0.45	2.72	0.39
La	15.9	4.48	10.2	3.69	4.09	1.30	27.3	15.4	82.31	10.29
Lu	0.22	<0.05	0.30	<0.05	<0.05	<0.05	0.28	0.21	1.00	0.25
Nb	8.55	1.42	9.54	4.19	1.98	1.21	6.31	5.12	38.31	4.79
Nd	14.0	2.91	13.7	1.57	2.45	0.83	16.6	13.8	65.89	8.24
Pr	3.80	1.03	2.92	0.65	1.15	0.60	5.62	3.36	19.14	2.39
Sc	13.1	<0.50	42.6	<0.50	<0.50	<0.50	9.76	6.26	71.72	17.93
Sm	3.24	0.72	3.44	0.31	0.53	0.14	4.12	2.53	15.02	1.88
Ta	0.54	<0.05	0.36	0.05	<0.05	<0.05	0.35	0.25	1.55	0.31
Tb	0.48	0.12	0.74	0.05	0.07	<0.05	0.57	0.39	2.43	0.35
Th	7.03	0.51	1.05	0.17	0.90	0.09	6.90	4.18	20.83	2.60
Tl	1.20	<0.10	<0.10	<0.10	<0.10	<0.10	0.43	0.17	1.81	0.60
Tm	0.22	0.06	0.36	<0.05	0.05	<0.05	0.26	0.19	1.14	0.19
U	1.15	1.07	0.30	1.52	2.12	0.36	2.68	3.63	12.82	1.60
W	1.06	0.15	0.28	0.13	0.26	0.19	0.67	0.73	3.47	0.43
Y	11.2	4.37	22.2	2.50	2.78	0.94	13.6	11.9	69.45	8.68
Yb	1.31	0.33	2.09	0.19	0.26	0.07	1.76	1.42	7.43	0.93
Zr	68.9	4.29	33.0	2.94	6.84	2.70	53.3	62.6	234.60	29.32

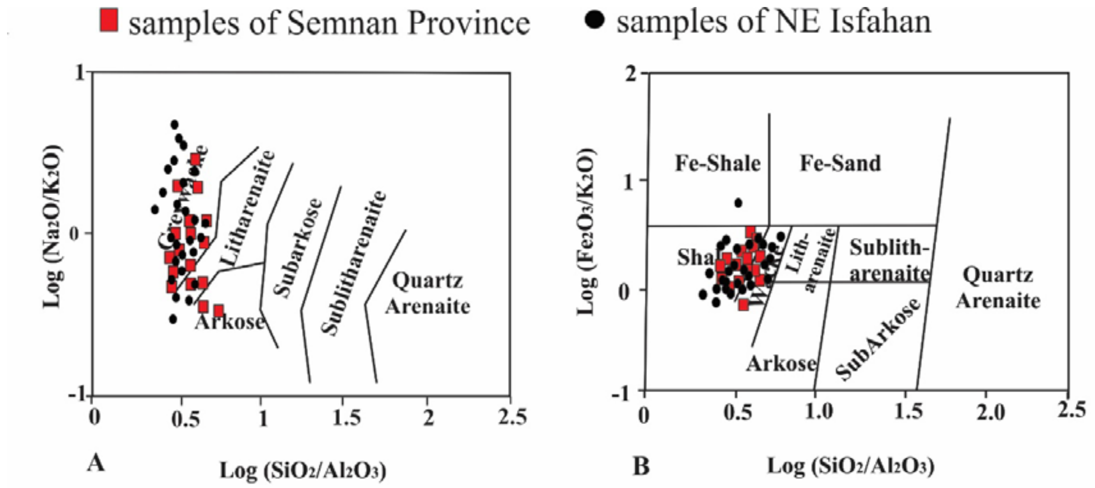


Figure 3. Composition of the samples of Semnan Province according to Pettijohn *et al.*, 1987 (A) and Herron, 1988 (B).

These samples (excluding one sample) show wacke and shale composition in Heron's diagram (Fig. 3 B).

Normally, major elements analyzed for geochemical purpose are Ca, Al, P, Na, K, Mg, Mn, Fe, Ti and Si, which are expressed as oxide (Rollinson, 1983). Ratio of Fe_2O_3/K_2O, K_2O/Na_2O, and Si_2O/Al_2O_3 are widely used for discrimination of tectonic setting and provenance of sediments (Roser & Korsch, 1986; Herron, 1988).

As the Al_2O_3 content of rocks has negligible changes during weathering diagenesis and metamorphism, it is being used as an index for comparison between various lithologies, whereas K_2O, Na_2O and CaO considerably change, in sandstones (Gateneh, 2000).

SiO_2 vs. Al_2O_3 (Figs. 4 and 5) show mutual relation, which reflect aluminosilicate mineralogy of the sediments. Litharenites have various chemical composition, although are rich in Al_2O_3 (rock fragments rich in clay and mica) and low Na_2O and MgO content (Pettijohn *et al.*, 1987, Das *et al.*, Tucker, 1994, 2006).

Apparently most samples of the both area have reasonable correlation (Figs.4 and 5) for various elements. TiO_2 of the most of the samples increases with increase in Al_2O_3. This may reflect inclusion of TiO_2 (titanomagnetite?) within some minerals (e.g. magnetite) (Dabard, 1990). Positive correlation between K_2O and Al_2O_3 may imply presence of K bearing minerals such as muscovite and illite.

Provenance and Tectonic setting

Geochemical investigation of sediment is well appreciated for discriminating tectonic setting and provenance (North *et al.*, 2005). Composition of aeolianites are controlled by their provenance, distance of transportation and digenetic processes, however role of tectonic setting of the sedimentary basin is vital (Akarish & El-Gohary, 2008). Hence attempts were made to interpret of the provenance of the sediments using geochemical approach.

Provenance

Some volcanic rocks exposed in SE of the Semnan province along the southern border of the Attari fault, which are Eocene in age and comprise basic, acidic and intermediate rocks, of which the latter is predominant rock type. Petrography of these rocks revealed andesite, basalt, trachyandesite, dacite, and tuffs as well (Hashemi- movahed *et al.*, 2014). Evidently, these rocks contributed a major

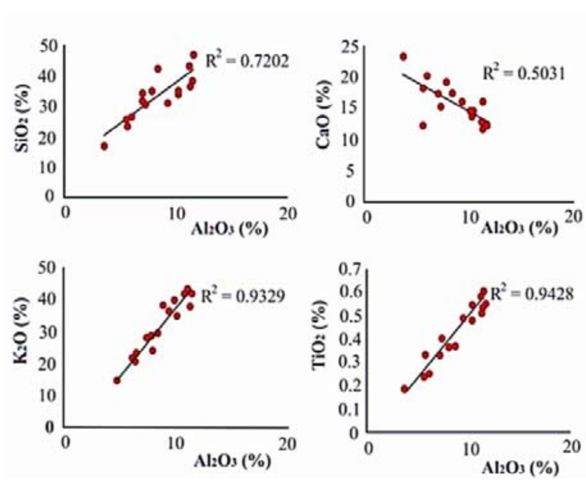


Figure 4. Cross- plots of various major elements oxides vs. Al_2O_3 for Semnan area.

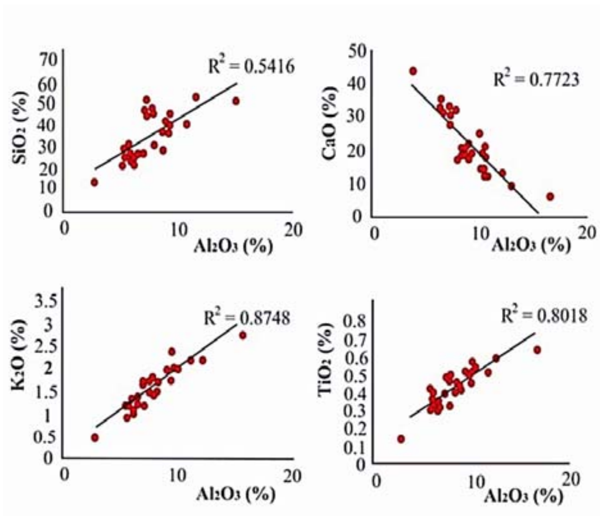


Figure 5. Cross- plots of various major elements oxides vs. Al_2O_3 for NE Isfahan.

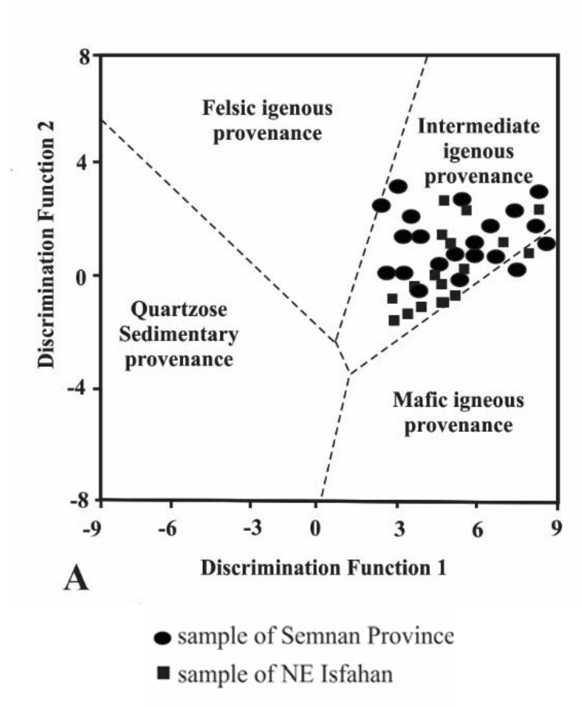


Figure 6. Discrimination Function plot using major elemenet (Roser & Korsch, 1988), suggest intermediate igneous provenance and mafic igneous provenance many sample in for NE Isfahan Province.

Discrimination Function 1: - 1.733 TiO_2 + 0.607 Al_2O_3 + 0.76 Fe_2O_3 (t) - 1.5 MgO + 0.616 CaO + 0.509 Na_2O - 1.224 K_2O -0.909

Discrimination Function 2: 0.445 TiO_2 + 0.07 Al_2O_3 - 0.25 Fe_2O_3 (t) - 1.142 MgO + 0.438 CaO + 1.475 Na_2O + 1.426 K_2O - 6.861

proportion of the sediments of the Semnan Province (see Figs. 6, 7, and 8). Volcaniclastics of the Karaj Formation are well exposed in the Sartakht anticline (Bazargani Gilani & Rezai, 2007). Hence these volcanic to volcaniclastics could produce considerable amounts of weathered materials, which may be transported to the low lands. Roser and Korsch (1986) suggest four distinct provenances to discriminate between sediments as mafic, intermediate, felsic igneous rocks and quartzose sediments. According to their purposed diagram, oxides of major elements including Al, Ti, Na, Ca, Mg, Fe, K is being used to discriminate between these four provenances. Whereby, sediments of the both study area suggest intermediate igneous provenance Semnan Province and intermediate igneous provenance and mafic sample many for NE Isfahan (Fig. 6). Igneous rocks exposed along major regional faults in the NE of the Isfahan Province and Eocene volcanics and tuff of the Semnan Province could be invoked for these results (see also Fig. 8).

Furthermore negative anomaly of Ce in sediments of both areas clould reflect intermediate igneous rocks originated from mantle, but contaminated by crustal materials (*senso* Nichelson et al., 2004; Azer *et al.*, 2021). Ultramafic-mafic rocks and associated tuffs of the Anarak—Poshte Badam are likely late Proterozoic in age (Aghanabati, 2010), were were also interpreted as evidences of a continental drift which separated Anarak-Biabanak and Bafgh (Hushmandzadeh *et al.*, 1989).

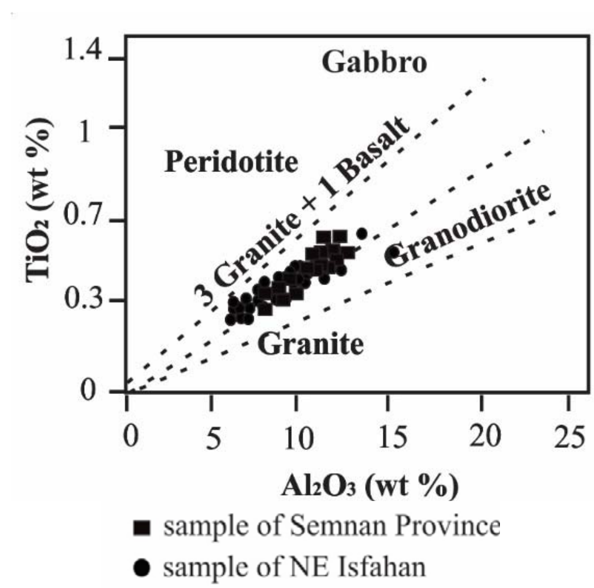


Figure 7. Al_2O_3 vs. TiO_2 (Schieber, 1992), sediments of NE Isfahan and Semnan Province show basalt and granodiorites tendency.

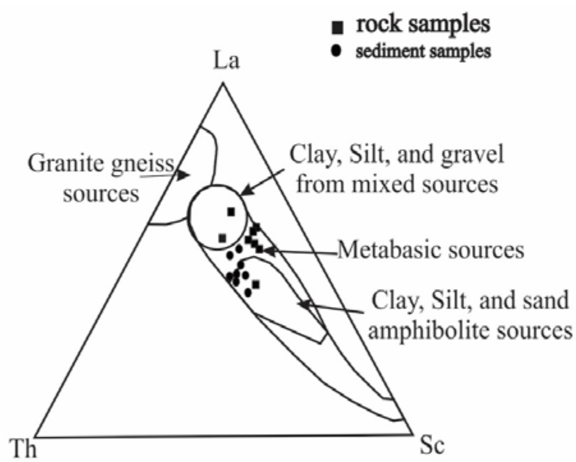


Figure 8. Triangle plot of trace elements from Semnan Province and NE Isfahan which purpose Granite gneiss source (after Cullers, 1994).

Thereby, it is reasonable to conclude that the majority of the sediments of the NE of Isfahan Province are probably originated from such rock types (see Figs. 6, 7, and 8). According to the petrographic examination on heavy mineral proportion, the pyroxene is a conspicuous heavy mineral (Mohseni *et al.*, 2014a, b). Augite is the most frequent clinopyroxene with a variety of colors including green, brown, and yellowish brown (Figs. 9a, 10). Augite is a common mineral in ultramafic and intermediate rocks, particularly in gabbro, dolerite, andesite basalt and some peridotites (Mange & Maurer, 1992). Pyroxene is normally an unstable heavy mineral and would disintegrate during early stages of weathering and diagenesis. Accordingly, it could only survive in well-durated ancient sediments or very young sediment. It is believed the pyroxene are derived from ultramafics of the Anarak-Khour complex. Although more complementary studies on are required to make sure.

Tectonic setting

Relation depletion in oxides such as Na_2O and CaO (geochemically mobile) versus enrichment of SiO_2 and TiO_2 (mainly immobile element) could point toward tectonic setting of sediments (Khanehbad *et al.*, 2010). The ratios between immobile to mobile elements suggest Oceanic Island Arc (OIA) and Passive Continental Margin (PCM) for the Semnan Province and Isfahan Province respectively (Figs. 11, 12). Although, two samples of the Semnan Province point suggest CIA and PCM.

Source rock

Relative frequency of the elements could reflect various parameters including weathering, transportation from source to depositional environment and digenesis (Paikaray *et al.*, 2008). Concentration of Na, K, Ca, and Mg may fluctuate, whereas Ti and Al are assumed to be considerably constant during these processes, as their oxides are less soluble in aqueous solution at surface temperature (Hayashi *et al.*, 1997). Hence the ratio of Al_2O_3/TiO_2 is a good indicator for interpretation of source of sediments (Paikaray *et al.*, 2008). This ratio suggests that sediments of the Semnan Province have nearly basaltic to granodioritic source whereas those of the Isfahan Province have basaltic to granodioritic source (Fig. 7). This conclusion doesn't confirm provenance setting of the NE Isfahan Province. The apparent discrepancy may be explained by the fact that granitic intrusives in this region (Hatef, 1995 and references cited in) may impel some sediment (particularly in sand size) to the area.

Source sediment

Most samples of the Semnan Province have greywacke composition (Fig. 3 A). Almost all samples of the Isfahan Province have wake, shale and litharenite composition (Fig. 3 A). Lithareintes have potentially high Al_2O_3 content (due to frequent labile rock fragments rich in clay minerals), despite their various chemical composition. In our study, Al_2O_3 increase in most samples with increase in TiO_2 content (Figs. 4, 5). This is probably due to occurrence of TiO_2 inclusion in some mineral (probably titanomagnetite). Positive correlation between Al_2O_3 and K_2O (Figs. 4, 5) may reflect abundance of K-bearing mineral, such as muscovite and illite.

La/Yb ratio varies between 7.47 to 10.08, La/Sm varies between 3.4 to 4.3, Gd/Yb between 1.19 to 1.86 and Ce/La between 0.66 to 0.78 for the sediment samples. These ratios vary between 3.31 to 13.11, 1.92 to 7.52, 0.51 to 1.79 and 0.34 to 0.79 in rock samples collected from the surrounding area. Reasonable similarity between LREE/HREE of sediment and rock samples (3.95 and 3.33 respectively) may imply that sediments could originate (at least in part) from these rocks (Tables 5, 6).

Furthermore, upper continental crust source could be deduced from Zr/Sc vs. Th/Sc cross – plot (suggested by McLennan, 1993), (Fig. 13, Table 7).

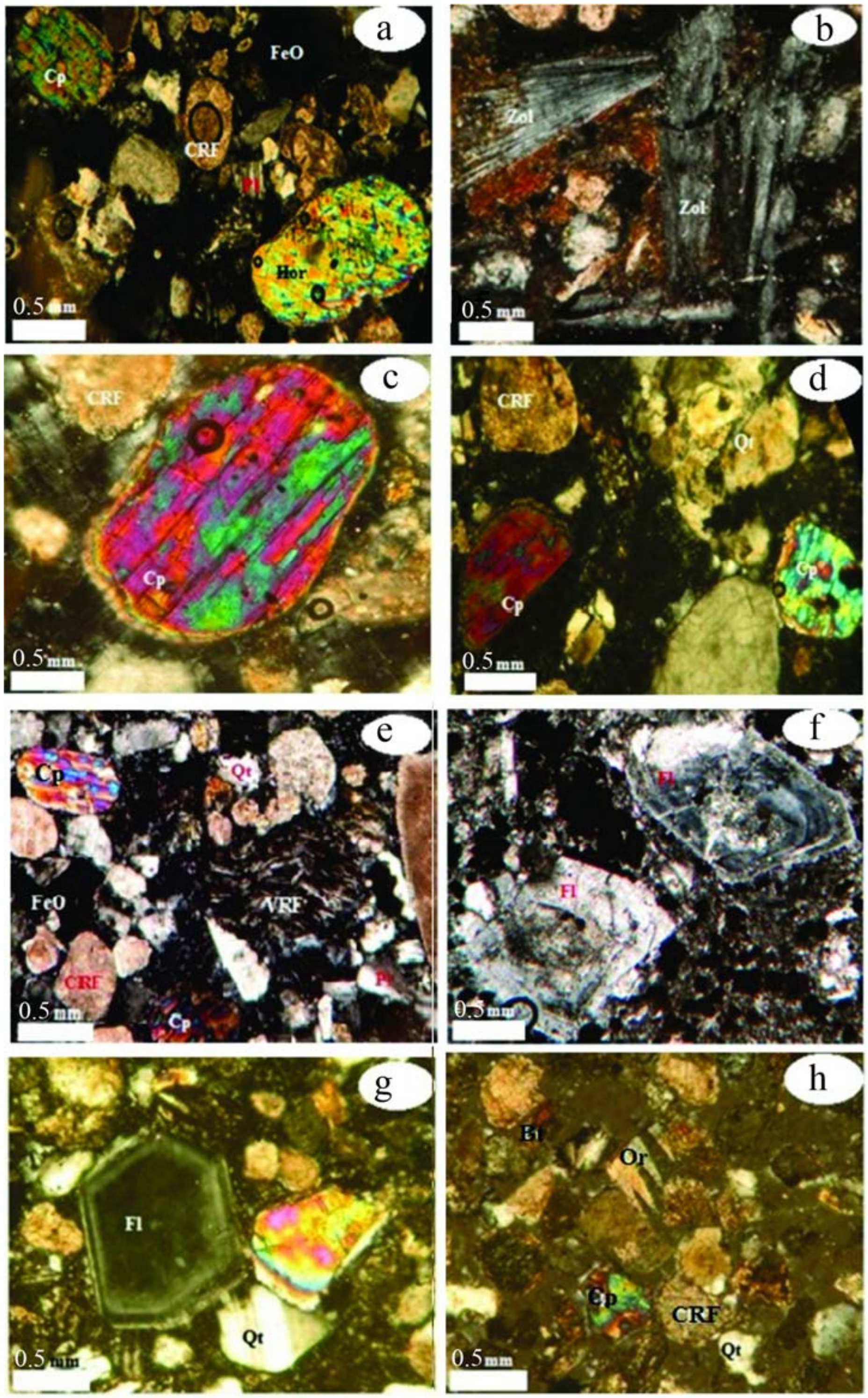


Figure 9. Photomicrographs of heavy minerals under (XPL), a) iron oxide (FeO), clinopyroxene (Cpx), hornblende (Hor), plus carbonate (CRF), b) scapolite surrounding the iron oxide, c) clinopyroxene (Cpx), carbonate rock fragment (CRF), d) clinopyroxene (Cpx), and (CRF), quartz (Qt) (off-wave-type polycrystalline), (c)) clinopyroxene (Cpx), quartz (Qt), volcanic rock fragments (VRF), with (CRF), iron oxide (FeO), d) feldspar (Fl), e) quartz (Qt), feldspar (Fl) and (CRF), clinopyroxene (Cpx), biotite (Bt), quartz (Qt), orthoclase (Ort).

Table 5. Chondrite-normalized REE ratio of sediments sample of Semnan Province and NE Isfahan. Chondrite data from Taylor & McLennan, 1985).

Sample/ Chondrite	M6	M9	M12	M13	M27	M33	M36	M40	Average of AA
La	50.97	69.49	74.27	76.65	71.07	66.03	70.04	64.76	67.91
Ce	36.52	53.46	53.73	59.95	47.51	46.94	54.03	45.89	49.75
Pr	28.74	44.08	46.45	44.16	41.46	37.02	41.59	45.53	41.13
Nd	15.76	30.09	34.04	28.7	27.88	31.89	38.72	33.18	30.03
Sm	11.86	19.29	20.39	20.1	17.94	17.35	20.41	17.83	18.14
Eu	7.38	11.92	12.66	11.97	11.54	11.61	11.06	11.57	11.21
Gd	7.65	13.37	12.07	11.99	11.34	11.41	15.76	11.73	11.91
Tb	9.272	12.36	11.11	10.9	17.58	7.6	12.79	7.92	11.19
Dy	6.64	9.71	8.77	9.78	9.26	7.94	8.47	7.83	8.55
Ho	5.95	9.18	8.23	7.86	7.98	7.06	7.83	8.35	7.81
Er	5.83	9.16	7.49	7.99	7.29	6.29	9.13	6.25	7.43
Tm	5.73	8.92	8.17	9.07	9.73	6.68	9.63	7.58	8.19
Yb	5.95	8.86	8.01	7.59	9.5	6.65	8.44	6.73	7.72
Lu	5.81	8.96	7.41	7.85	8.415	6.95	7.24	14.2	13.2
(La/Yb)n)	8.6	7.8	9.28	10.1	7.48	9.94	8.3	9.62	8.89
(La/Sm)n)	4.3	3.6	3.64	3.81	3.96	3.8	3.43	3.63	3.72
(Gd/b)n	13	1.5	1.51	1.58	1.19	1.71	1.87	1.74	1.55
(Ce/La)n	0.7	0.8	0.72	0.78	0.67	0.71	0.77	0.71	0.75

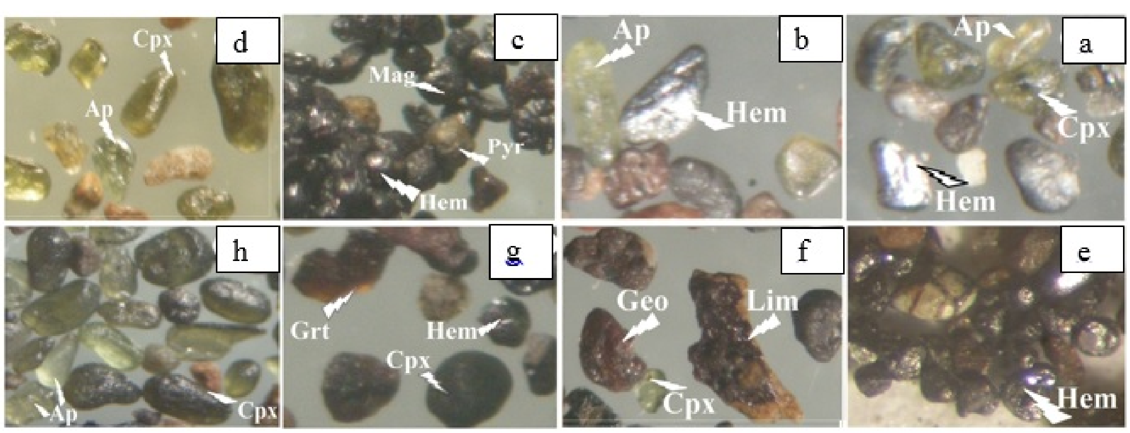


Figure 10. Images of sediment samples in the area Semnan Province and NE Isfahan Province.Cpx = clinopyroxene, Geo = goethite, Mag = magnetite, Hem = hematite, Pyr = pyrite, Lim = limonite, Grt = Ap = garnet and apatite. Minerals such as hematite and magnetite are frequent in 125 microns size fraction.

Table 6. Chondrite-normalized REE ratio of rock sample of the Semnan Province and NE Isfahan. Chondrite data from Taylor & McLennan, 1985).

Sample/ Chondrite	A1	A2	A3	A4	A5	A6	A7	A8	Average of samples
La	43.43	12.19	27.69	10.05	11.15	3.53	74.28	41.96	28.03
Ce	35.5	5.95	22.04	3.47	5.9	1.87	54.72	27.42	19.61
Pr	27.76	7.49	21.35	4.75	8.41	4.35	41.05	24.51	17.46
Nd	19.71	4.09	19.31	2.21	3.45	1.17	23.34	19.38	11.58
Sm	14.01	3.12	14.88	1.34	2.28	0.59	17.85	10.93	8.12
Eu	8.22	1.72	11.88	0.78	1.53	0.45	11.28	5.98	5.23
Gd	9.61	2.43	11.94	1.158	1.46	0.46	10.79	6.62	5.56
Tb	8.25	2.12	12.82	0.87	1.24	0.34	9.82	6.77	5.28
Dy	5.14	1.65	10.63	0.77	1.09	0.33	7.52	5.67	4.1
Ho	4.98	1.57	10.91	0.87	1.08	0.47	7.34	5.28	4.06
Er	4.32	1.46	9.54	0.74	0.97	0.45	6.35	5.51	3.67
Tm	6.22	1.76	10.1	0.84	1.48	0.32	7.23	5.25	4.15
Yb	5.29	1.34	8.41	0.77	1.06	0.91	7.08	5.69	3.82
Lu	5.67	0.79	7.82	0.52	0.79	1.05	7.22	5.42	3.66
(La/Yb)n	8.21	9.11	3.31	13.11	10.51	3.92	10.51	7.42	8.23
(La/Sm)n	3.11	3.91	1.92	7.52	4.89	5.9	4.16	3.79	4.39
(Gd/Yb)n	1.79	1.79	1.39	1.51	1.38	0.51	1.52	1.21	1.39
(Ce/La)n	0.79	0.49	0.79	0.34	0.53	0.51	0.74	0.69	0.61

Table 7. Elemental ratio (Th, Zr and Sc) of sediment and rock samples of the Semnan Province and NE Isfahan.

Sample No.	Sc	Th	Zr	Zr/Sc	Th/Sc	Sample No.	Sc	Th	Zr	Zr/Sc	Th/Sc
M6	6.14	5.09	76.4	12.44	0.83	A1	13.1	7.03	68.9	5.26	0.54
M9	11.2	8.60	101	9.01	0.76	A2	0.50	0.51	4.29	8.57	1.02
M12	12.4	8.05	97.7	7.85	0.65	A3	42.6	1.05	33.0	0.77	0.02
M13	12.3	7.62	92.8	7.56	0.62	A4	0.50	0.17	2.94	5.89	0.35
M27	19.9	12.1	111	5.59	0.61	A5	0.50	0.90	6.84	13.68	1.79
M33	10.9	6.28	65.0	5.97	0.58	A6	0.50	0.09	2.70	5.39	0.18
M36	13.0	8.85	88.0	6.77	0.68	A7	9.76	6.90	53.3	5.47	0.71
M40	12.1	7.76	79.0	6.54	0.64	A8	6.26	4.18	62.6	10.01	0.67

This also confirms the same conclusion obtained by Figure 7, which show basaltic – granodioritic source, characteristic of upper continental crust as well.

Conderite – normalized (McLennan and Taylor, 1983) REE content of the samples revealed that LREE are relatively enriched in compare to HREE (Fig. 14). Eu has an average value of 11.21 ppm. This may reflect felsic sediments (Gu *et al.*, 2002), (see Figs. 15 and 16). Composition between two study areas reveals their overall similarity.

Condrite-normalized REE pattern revealed relatively higher LREE in compare to HREE and depleted Eu anomaly in both areas. Such trends could suggest acidic and highly oxidized mafic igneous rock with $Fe_2O_3/FeO>1$ origin for these sediments (Rostami *et al.*, 2014). Furthermore, apatite occurrence in sediments of the study areas support possible contribution of Mesozoic granitoids and associated aplitic dikes, stocks and pegmatite in the Anarak-Khour area.

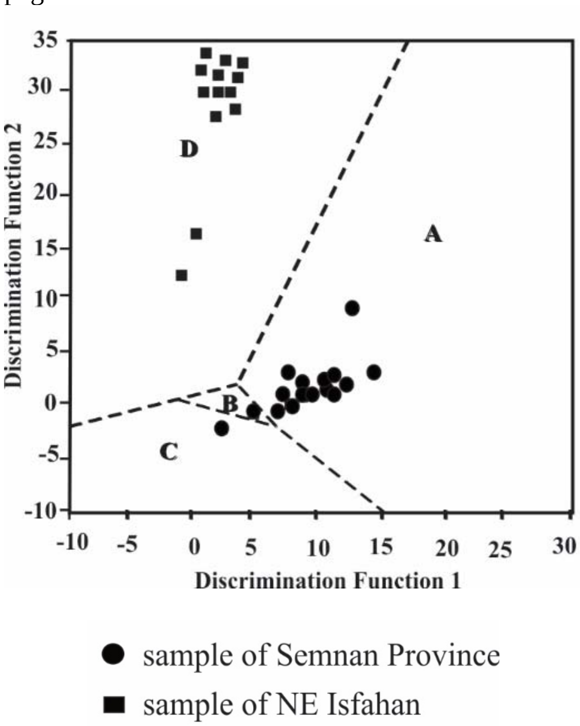
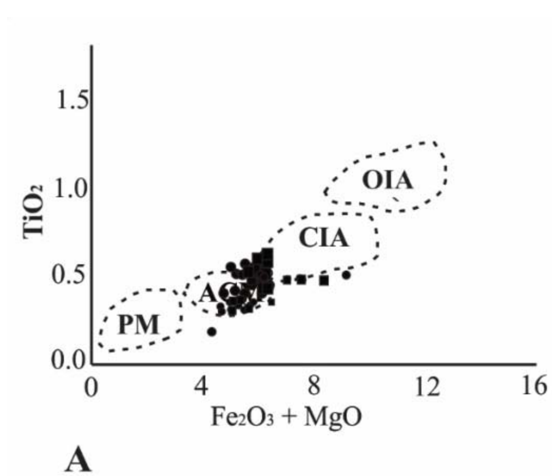


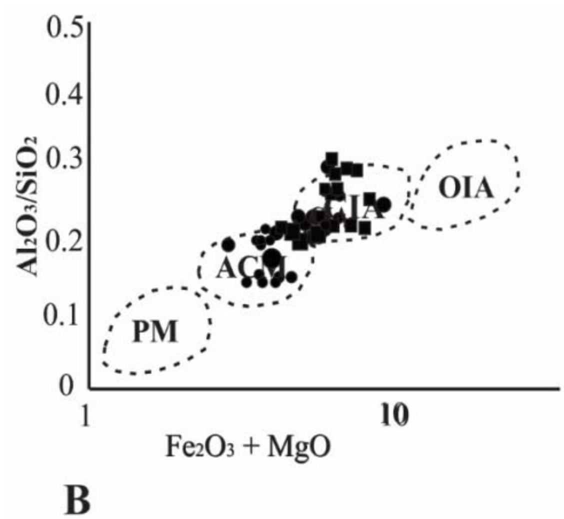
Figure 11. Discrimination Function plots (Bahatia, 1983), NE Isfahan and Semnan Province.

A = oceanic island arc, B = continental island arc, C = active continental margin and D) passive margin.

Discrimination Function 1: - 0.0447 SiO_2 - 0.972 TiO_2 + 0.008 Al_2O_3 - 0.267 Fe_2O_3 - 3.082 MnO + 0.140 MgO + 0.195 CaO + 0.719 Na_2O - 0.032 K_2O + 7.51 P_2O_5 + 0.303

Discrimination Function 2: - 0.421 SiO_2 + 1.988 TiO_2 - 0.526 Al_2O_3 - 0.551 Fe_2O_3 - 1.610 FeO + 2.720 MnO + 0.881 MgO + 0.907 CaO + 0.177 Na_2O - 1.84 K_2O + 7.244 P_2O_5 + 43.57





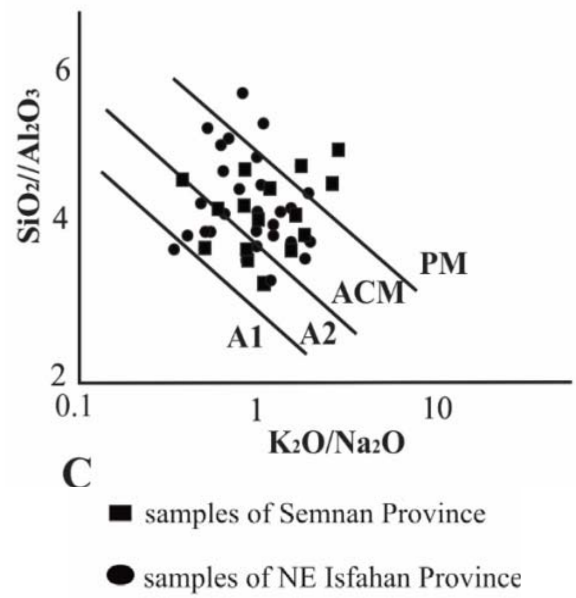


Figure 12. A) TiO_2-Fe_2O_3+MgO (Bahatia, 1983), of samples which show continental island arc and active continental margin. B) Al_2O_3/SiO_2-Fe_2O_3+MgO (Bhatia, 1983) continental island arc and active continental margin, C) Al_2O_3/SiO_2-K_2O/Na_2O (Roser and Korsch, 1988) arc setting, basaltic and andesitic detritus (A1), evolved arc setting, felsic – plutonic detritus (A2), active continental margin (ACM) and passive margin (PM).

ACM = active continental margin, PM = passive margin, CIA = continental island arc, OIA = oceanic island arc, A1 = arc setting, basaltic and andesitic detritus, A2 = evolved arc setting, felsitic – plutonic detritus

Conclusion

Volcanic rocks exposed in the southern part of the Attari fault are mainly basic, acidic and intermediate, of which the last type is dominant, which is reasonably correspond to suggested

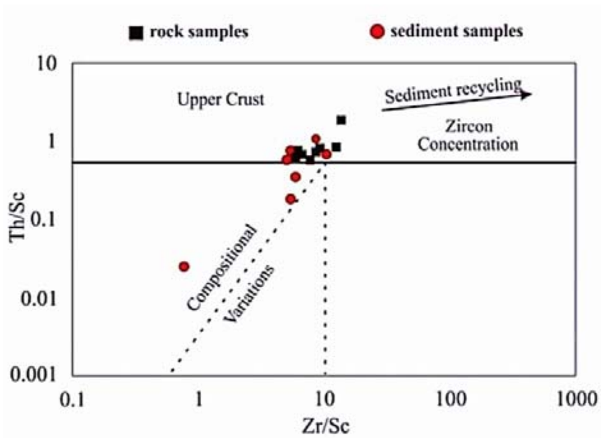


Figure 13. Th/Sc versus Zr/Sc diagram representing reworking and upper crust input (after McLennan *et al.*, 1993).

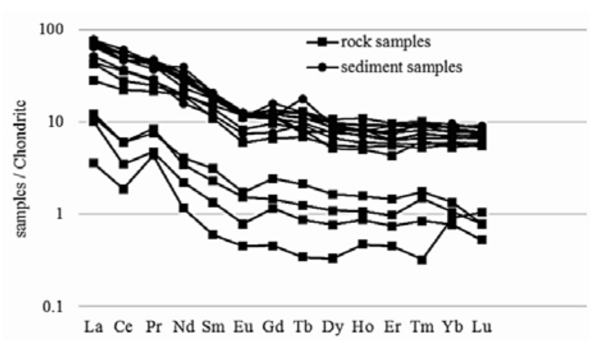


Figure 14. Chondrite-normalized REE patterns of sediment (circle) and rock samples (square) in the Semnan Province and NE Isfahan, Chondrite data from Taylor & McLennan, 1985).

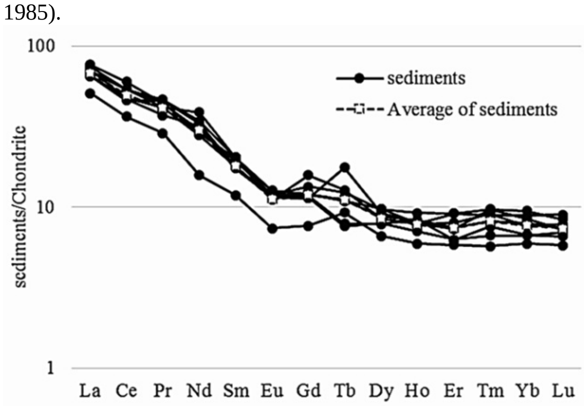


Figure 15. Chondrite-normalized REE patterns of sediment samples of the Semnan Province and NE Isfahan. Chondrite data from Taylor & McLennan, 1985)

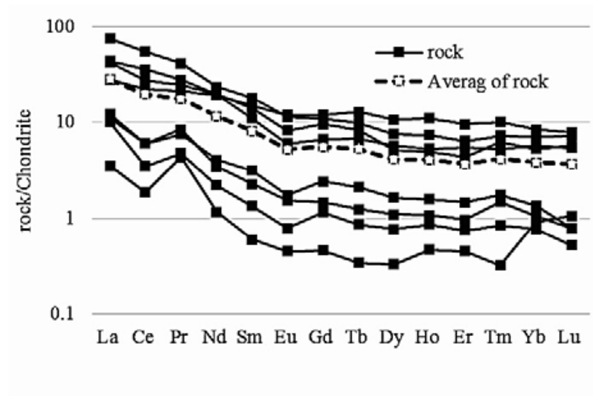


Figure 16. Chondrite-normalized REE patterns of rock samples of the Semnan Province and NE Isfahan, Chondrite data from Taylor & McLennan, 1985).

possible origin for sediments in the Semnan province. For the NE Isfahan, a vide rage of rocks are responsible, which could be explained by the various rock types exposed around the area.

Al_2O_3/ TiO_2 ratio suggest basaltic provenance for Sediments of the Semnan Province, while those of the NE Isfahan Province revealed basaltic to granodiorite provenance.

Depleted Ce anomaly in REE of both areas might reflect intermediate igneous rocks.

Zr/Sc vs. Th/Sc suggests upper crust and compositional origin for both of the study areas.

Condrite normalized REE pattern of the sediments from both areas revealed high LREE and depleted Eu anomaly. Such trends may show acidic igneous rocks including granitoids and highly oxidized mafic rocks.

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