The Age and the Origin of Kashmar Granitoid, NE Central Iran

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Abstract

The Kashmar granitoid is a major plutonic suite occurring in north-Doruneh-Fault magmatic belt of Iran. It intrudes into the Early-Eocene volcanic rocks and crops out as extensive I-type plutons of mainly granitic and granodioritic composition. The plutons show characteristics of low-temperature and low-pressure granites, emplaced in a sub–volcanic environment. Rb/Sr dating on biotite–whole rock pairs from granite, granodiorite and alkali feldspar granite yield ages ranging from 43.5 to 42.4±0.4 Ma which indicate Middle Eocene (Lutetian) times and a short time interval for emplacement of different plutons of the Kashmar granitoid. The Sr and Nd isotopes represent low initial $^{87}Sr/^{86}Sr$, intermediate initial $^{143}Nd/^{144}Nd$ and low, negative εNd values for Kashmar granitoid. Field, geochemistry and isotopic data indicate that magmas of the Kashmar granitoid are relatively similar in source composition and originated from partial melting of quartzofeldspathic rocks of the lower crust (infra-crustal). Also, these magmas have been dominantly evolved through the mechanism of fractional crystallization.

Introduction

The Kashmar granitoid is the largest subvolcanic mass (~200 km^2) occurring throughout the northern parts of the Kashmar area (Fig. 1). It is bordered by the Doruneh Fault to the south and the Rivash Fault to the north; the faults defining the boundaries of Taknar Zone. The Kashmar granitoid intrudes into genetically-related andesitic lavas and pyroclastic rocks (mainly tuff) of Early Eocene age [1]. The granitoid together with associated volcanic rocks constitute the central part

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of the 'north-Doruneh-Fault magmatic belt' that runs from the northern to eastern margins of the Central Iran for a length of ~350 km and width of 15 to 80 km [2]. In this belt, volcanic and plutonic rocks are associated with iron–oxide deposits [3]. Publications directly related to the plutonic rocks are scarce, but general geology, petrography and economic studies of the belt have been carried out by some authors [e.g. 1-3]. The genesis and isotopic ages of these rocks are lacking.

This study presents the first isotopic data for Kashmar granitoid. Due to widespread occurrence of fresh biotite in the rocks studied, the Rb/Sr method on biotite-whole rock pairs was selected for isotope age dating. The significance of this method results from the fact that Rb and Sr are important elements in magmatic processes, as they can provide ideal information, particularly for the petrology of granites. For example, Sr substitutes predominantly in early phase minerals such as apatite and plagioclase, but Rb becomes enriched in residual phase (e.g. biotite). This leads to a large variability in the Rb/Sr ratio during fractionation and, therefore, is used as a control factor on the accuracy of the isochron method and the initial ratio [4].

Sample Preparation and Analytical Techniques

In the present work, 8 samples from major representative plutons of the Kashmar granitoid (Fig. 1) were selected for Rb–Sr and Sm–Nd analyses (Tables 1–2). Biotite flakes was separated from four samples including one alkali feldspar granite, one granodiorite and two granites. The biotites from all dated rocks have been studied using polarizing microscope, followed by electron microprobe analyses. They are homogeneous in composition and represent similar characteristics.

For each sample ~0.1 mg of purified biotite was dissolved in teflon beaker, mixed with a Rb/Sr spike using mixture of HF–HNO_3. Rb and Sr were separated and concentrated for mass spectrometric analyses using standard ion–exchange procedures. Also, representative subset of 8 whole rock powders (0.1 mg) were analyzed for Rb, Sr and Sm, Nd isotope ratios (Tables 1-2), at the School of Geosciences, University of Wollongong, and in CSIRO, Sydney, Australia.

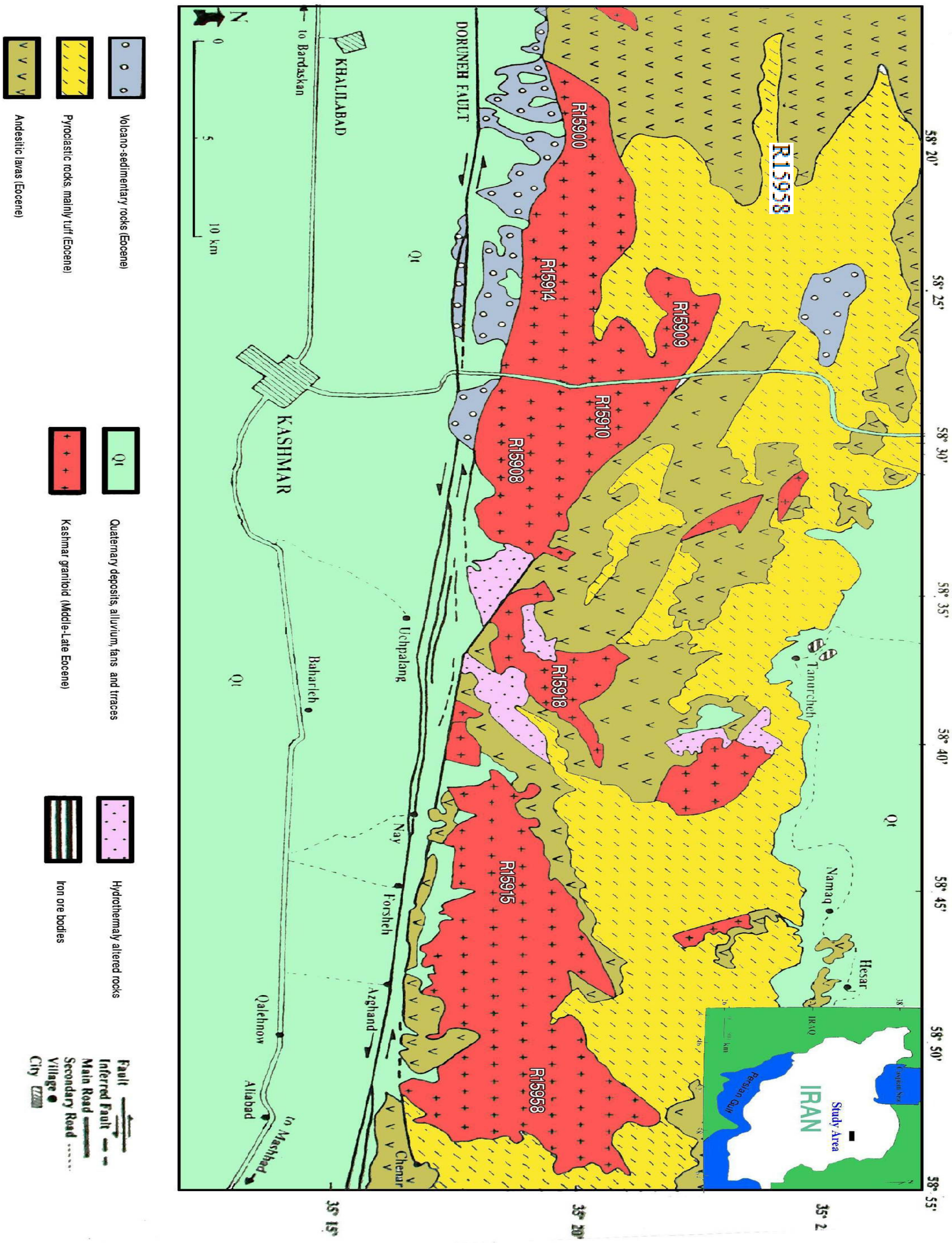


Figure 1. Geological map of the Kashmar granitoid, NE Central Iran.

Isotopic analyses were undertaken on a VG 354 mass spectrometer in CSIRO, Sydney. Replicate analyses of SRM 987 gave $^{86}Sr/^{88}Sr$ = 0.710251±28 (external precision at 2σ, n = 17) and the JM–Nd standard gave $^{146}Nd/^{144}Nd$ = 0.511111±12 (external precision at 2σ, n = 17). $^{87}Sr/^{86}Sr$ normalized to $^{86}Sr/^{88}Sr$ = 0.1194, 2σ analytical uncertainty for $^{87}Sr^{86}Sr$ is ±~0.00005. $^{143}Nd/^{144}Nd$ normalized to $^{146}Nd/^{144}Nd$ = 0.7219, 2σ analytical uncertainty for εNd is ±~0.5 units. Ages, $^{87}Rb/^{86}Sr$, $^{147}Sm/^{144}Nd$, εNd and initial ratios ($^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$), were calculated by the CIS (Center for Isotope Studies) programs, and decay constant (λ) of ^{87}Rb was taken to be 1.42×10^{-11} in reciprocal years. The MSWD, 2σ uncertainty in age and initial $^{87}Sr/^{86}Sr$ were calculated by standard percents of 0.8 and 0.008, respectively for X ($^{87}Rb/^{86}Sr$) and Y ($^{87}Sr/^{86}Sr$) axes.

Discussion

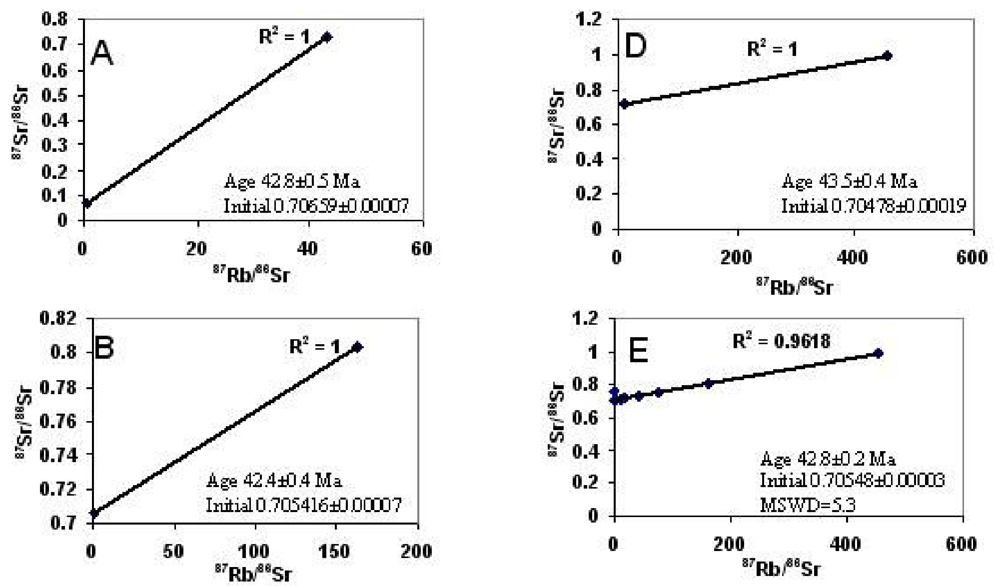
The Rb/Sr biotite–whole rock isochrones (Figures 2A–D) for Kashmar plutons yield isotopic ages ranging from 43.5 to 42.4±0.4 Ma, representing a typical synchronous plutonism in Middle Eocene (Lutetian) for Kashmar granitoid. These ages are essentially indistinguishable with age differences of <1 Ma being negligible for such extensive magmatic suites [cf. 5]. The obtained ages confirm field observations which indicate that the Kashmar granitoid is younger than the host volcanic rocks.

Also, the $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ values for all whole rock and separated biotite analyses define an isochron (Fig. 2E) with a slope that is constrained by biotite samples because they contain significantly higher $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ ratios than whole rock samples. This isochron yields an age of 42.8±0.2 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0.70548±0.00003 both values fall within the range of ages and initial ratios given by biotite–whole rock isochrones. For each pluton, similarities in age and initial $^{87}Sr/^{86}Sr$ values indicate that the total rock Rb/Sr system was closed simultaneously, and that the Rb/Sr system has remained a closed system since the time of emplacement.

The accuracy of the isotopic ages for biotite–whole rock pairs from the Kashmar granitoid depends on the closed-system-behavior of biotite. Although, Late Palaeogene volcanic activity has been reported in this area, the Kashmar granitoid was not subject to isotopic disturbance by younger thermal events. The similarity in isotopic ages from biotite–whole rock pairs clearly records a short duration for the emplacement of different plutons of the Kashmar granitoid in a subvolcanic environment.

Infra-Crustal Origin

Isotopic data from different plutons of the Kashmar granitoid (Tables 1–2) show low initial $^{87}Sr/^{86}Sr$ (0.70471–0.70569), intermediate initial $^{143}Nd/^{144}Nd$ (0.512488–0.512548) and negative εNd (–0.70 to –1.86) values which are typically within the range of Sr–Nd isotopic signature of I–type granites, suggesting infra–crustal source rocks (Fig. 2F) which tend to occur along the continental margins [6]. The εNd values show a narrow range, and for most samples these values are indistinguishable within the 2σ analytical uncertainties (±~0.5 units). For each pluton differences between initial $^{87}Sr/^{86}Sr$ ratios are small but are slightly larger than 2σ analytical uncertainty (±~0.00005). Consequently, a model of simple fractional crystallization of any isotopically uniform melt for the generation of each pluton is unlikely. The isotopic signature of Kashmar granitoid is consistent with low–temperature feature [7, 8] which is mainly distinguishable by presence of zircon crystals in rocks with different SiO_2 contents from each pluton. This implies that zircon was not homogenized in the magma due to the low–temperature condition. Such magmas may be produced by partial melting of quartzofeldspathic source rocks and evolve through the mechanism of fractional crystallization [e.g. 9a, 9b].



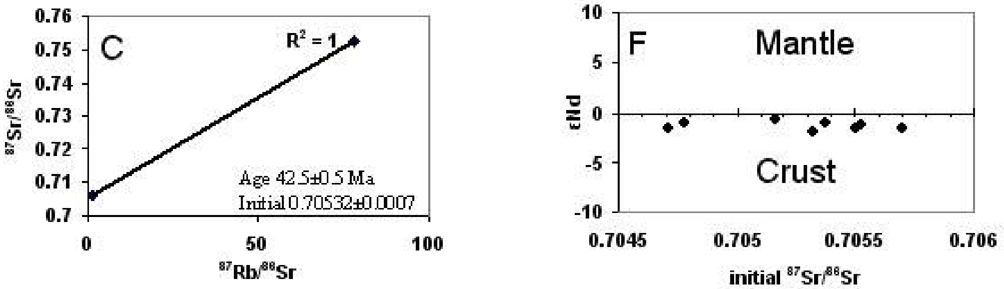


Figure 2. Rb–Sr biotite–whole rock isochrones and Sr–Nd isotopic composition of Kashmar granitoid, northeastern CIP, Iran. A = Sample R15915 (granodiorite); B = R15910 (granite); C = R15918 (granite); D = R15900 (alkali feldspar granite); E = all analyses (8 whole rocks and 4 biotites); F = initial $^{87}Sr/^{86}Sr$ vs. εNd diagram showing the boundary between mantle and crustal sources.

Table 1. Rb–Sr isotope data for biotite–whole rocks of the Kashmar granitoid, northeastern CIP, Iran.

Sample	Lithology	Rb	Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$ initial	$^{87}Sr/^{86}Sr$	Age (Ma)
R15915	granodiorite*	62	273	0.672	0.70569±0.00007	0.70610	42.8±0.5
	biotite	346	23	43.115		0.73193	
R15908	granodiorite	59	342	0.511	0.70552±0.00003	0.70583	42.8±0.2 (A)
R15910	granite*	103	315	0.968	0.70516±0.00007	0.70574	42.4±0.4
	biotite	441	8	162.759		0.80313	
R15918	granite*	88	288	1.382	0.70532±0.00007	0.70615	42.5±0.5
	biotite	398	15	77.998		0.75235	
R15909	granite	145	188	2.282	0.70537±0.00003	0.70675	42.8±0.2 (A)
R15958	granite	80	269	0.880	0.70550±0.00003	0.70603	42.8±0.2 (A)
R15900	AF granite*	200	50	11.873	0.70478±0.00019	0.71209	43.5±0.4
	biotite	690	5	452.424		0.98461	
R15914	AF granite	207	36	16.990	0.70471±0.00003	0.71504	42.8±0.2 (A)

Table 2. Sm–Nd isotope data for the Kashmar granitoid, northeastern CIP, Iran.

Sample	Lithology	Sm	Nd	$^{143}Nd/^{144}Nd$ initial	$^{143}Nd/^{144}Nd$	$^{147}Sm/^{144}Nd$	εNd
R15915	granodiorite*	3.9	17.6	0.512507	0.512544	0.13396	−1.49
R15908	granodiorite	4.0	17.4	0.512521	0.512560	0.13898	−1.21
R15910	granite*	4.2	20.0	0.512548	0.512583	0.12696	−0.70
R15918	granite*	4.0	18.2	0.512488	0.512525	0.13287	−1.86
R15909	granite	3.3	15.8	0.512532	0.512567	0.12627	−1.00
R15958	granite	3.4	20.5	0.512502	0.512530	0.10027	−1.58
R15900	AF granite*	5.0	27.5	0.512532	0.512563	0.10992	−0.98
R15914	AF granite	4.3	23.5	0.512510	0.512541	0.11062	−1.42

Notes for Tables 1 and 2: * means biotite was separated. AF = alkali feldspar. (A) = the average age of biotite–whole rock pairs, was assumed for calculation of initial $^{87}Sr/^{86}Sr$ ratios in whole rock samples of the Kashmar granitoid. The $^{87}Sr/^{86}Sr$ normalized to $^{86}Sr/^{88}Sr = 0.1194$; 2σ analytical uncertainty for initial at (42.8 Ma) $^{87}Sr/^{86}Sr$ is ± ~0.00003.

Associated Volcanic Rocks

The only isotopic age data for the host volcanic rocks to the north of Kashmar city have been reported by [1], giving K/Ar ages of 57.2±3.7 and 43.7±1.7 Ma on hornblende and biotite, respectively. A significant difference is observed between the given isotopic ages of hornblende and biotite. As hornblende has the capacity to be more retentive with respect to ^{40}Ar than biotite, the age of hornblende is interpreted as the emplacement time of host volcanic rocks, whereas the younger age for biotite may be the result of loss of ^{40}Ar due to the later thermal event caused by volcanic activity or intrusion of the Kashmar granitoid.

Tertiary volcanic rocks occur in the Gonabad and Bejestan areas, located to the southern parts of the Kashmar granitoid. Bina *et al*. [10] determined whole rock K/Ar ages of 61±2 and 54±2 Ma for andesitic rocks of the Gonabad and Bejestan areas, respectively. The latter age (54±2 Ma) which corresponds to the Bejestan Andesite is very similar to the isotopic age of hornblende from the host volcanic rocks of the Kashmar granitoid. The age of 57.2±3.7 Ma for hornblende reported by [1] is within the 2σ analytical uncertainty of the isotopic ages of Gonabad and Bejestan Andesites. These isotopic data confirm that Early Eocene volcanic activity occurred prior to the emplacement of Kashmar granitoid.

Eocene Magmatism in NE Central Iran

In view of the field data, the ages obtained for the Kashmar granitoid support a close genetic link between host volcanic rocks and granitoid emplacement. According to the isotopic ages, volcanic activity in the Kashmar area is believed to have been started approximately 57.2±3.7 Ma ago, continued through the Early to Middle Eocene and was followed by intrusion of the Kashmar granitoid at 42.8±0.5 Ma, suggesting that magmatic activity occurred over a time interval of ~15 million years. Such a period for intense magmatic activity is not unusual [e.g. 5, 11]. The precise Rb/Sr ages of the Kashmar granitoid, when taken together with the few reliable published isotopic ages for the host volcanic rocks (57–43 Ma) suggest that these subvolcanic plutons were emplaced after or contemporaneous with widespread volcanic extrusions (mostly andesite) during the Middle Eocene in NE Central Iran. The east–west distribution (~350 km) of volcanic and plutonic rocks along the northern parts of the Doruneh Fault may be interpreted to be related to extensional magmatism resulting from the upwelling of large volumes of magma being focused along the major structural discontinuity (*i.e.,* Doruneh Fault) in the NE Central Iran.

Conclusions

Rb–Sr and Sm–Nd isotopic data suggest that the Kashmar granitoid emplaced in 43.5 to 42.4±0.4 Ma, corresponding to Middle Eocene (Lutetian Stage) plutonism that extensively occurred in Iran. Close isotopic ages of different plutons are resulted from several criteria including precise sampling, accurate laboratory works, sensitive technical equipment, appropriate dating system, consanguineous plutons, closed system behavior of biotite and no isotopic disturbance after emplacement. The isotopic data for Kashmar granitoid show low initial $^{87}Sr/^{86}Sr$ (0.70471–0.70569), intermediate initial $^{143}Nd/^{144}Nd$ (0.512488–0.512548) and negative εNd (–0.70 to –1.86) values which are typically within the range of Sr–Nd isotopic signature of I–type granites which originated from partial melting of quartzofeldspathic rocks of lower continental crust (infra-crustal) and evolved dominantly through the mechanism of fractional crystallization. The similarity between isotopic ages and initial ratios indicate synchronous intrusions and genetically–related plutons for the Kashmar granitoid.

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