Journal of Sciences, Islamic Republic of Iran 13(3): 249-254 (2002)
National Center For Scientific Research, ISSN 1016-1104

Rb-Sr GEOCHRONOLOGY OF PEGMATITES, PLUTONIC ROCKS AND A HORNFELS IN THE REGION SOUTH-WEST OF ARAK, IRAN

F. Masoudi[1,*], B.W.D. Yardley[2] and R.A. Cliff[2]

[1]Department of Geology, Faculty of Science, Tarbiat Moalem University, Tehran, Islamic Republic of Iran
[2] School of Earth Sciences, University of Leeds, Leeds LS2 9JT, UK

Abstract

In the area SW of Arak, intrusives are emplaced into metasediments of early Mesozoic age. The intrusive rocks vary in morphology, structure and mineralogy, and exhibit various degrees of alterations; Rb-Sr geochronological data have been obtained to constrain their timing. There are three different groups of granitic rocks in the area: (a) the Astaneh intrusion, consisting of granite, biotite granite and granodiorite, intersected by abundant veins of quartz and aplite; (b) the Tavandasht-Gosheh intrusions, occurring as separate, small outcrops and (c) the Borujerd complex, composed of granitic intrusions with a wide range of late magmatic products including pegmatites and quartz veins, and with a well-developed aureole in pelitic country rocks. Rb-Sr data indicate that the first intrusive activity, which postdated low grade regional metamorphism, occurred during early Alpine tectonic movements, in lower Cretaceous times (about 120 Ma). A large elongate granitic intrusion (Older Granites), which occupies most of the Borujerd complex, and the first group of pegmatites (Older Pegmatites) were formed during this stage. Syntectonic intrusive activity associated with continuing Alpine movements, is represented by the Astaneh intrusion, emplaced at 99 Ma. Following this, a series of post-tectonic intrusions (Younger Granites) and pegmatitic veins (Younger pegmatites) were formed during the late Cretaceous-early Paleocene (70-52 Ma).

Keywords: Rb-Sr geochronology; Iran; Sanandaj-Sirjan; Borujerd; Pegmatite

Introduction

The main structures of present-day Iran were created during the Cretaceous movements [2,13,14]. In the Sanandaj-Sirjan zone of metamorphic belt of Iran, the intrusions are well developed and it is possible to determine a relative chronology. In the area SW of Arak, between Arak city and Borujerd city, igneous

* *E-mail: masoudi@saba.tmu.ac.ir*

bodies intrude metasediments of early Mesozoic age. The geology of the region is described by [2,8,10].

There are three different groups of granitic rocks in the area: (a) the Astaneh intrusion, a round intrusion located South-west of Astaneh and consisting of granite, biotite granite and granodiorite, intersected by abundant veins of quartz and aplite; (b) the Tavandasht-Gosheh intrusions, known mainly as isolated, small outcrops and (c) The Borujerd complex, composed of granitic intrusions with aureoles in pelites and wide range of late magmatic products containing pegmatites and quartz veins (Fig. 1).

Prior to this study, the Borujerd complex and the Astaneh intrusion were considered to have formed during one main phase of intrusive activity, during the late Cretaceous [10]. However, these intrusive rocks differ in morphology, structure and mineralogy, and exhibit various degrees of alterations [8]. These differences could reflect emplacement at different times.

In addition, the pegmatites associated with hornfelses and granites also exhibit some differences in mineralogy which could reflect different ages of crystallisation.

The Rb-Sr geochronological data obtained constrain both the timing of different events within the area, and shed light on the time relationship between pegmatites and their host rocks. In this study we report Rb-Sr ages and petrogenetic significance obtained on the initial $^{(87/86)}$Sr ratios are discussed in detail by [8].

Sample Selection and Mass Spectrometry

Eleven samples were selected for Rb-Sr analyses. They encompass all the major varieties of granites, pegmatites, and hornfelses found in the area, including the Astaneh intrusion (FM102), Borujerd complex intrusions (FM14, FM206, FM209, FM47, FM49), pegmatites (FM52, FM40, FM53, FM207), and one hornfels from the Borujerd complex aureole (FM55). Dating of the Gosheh granite was not possible due to low mica concentrations. A simplified map of the location of analysed samples is shown in Figure 1.

Sr isotopic analyses and Sr abundance determinations were made in the same run on the automated VG 54E double collector mass spectrometer. Rb was analysed on a manual VG Micromass 30 mass. Analytical methods described in [7,8].

Analytical Results

The analytical results for 8 biotites, 5 white micas and their corresponding feldspar concentrates are given in Table 1.

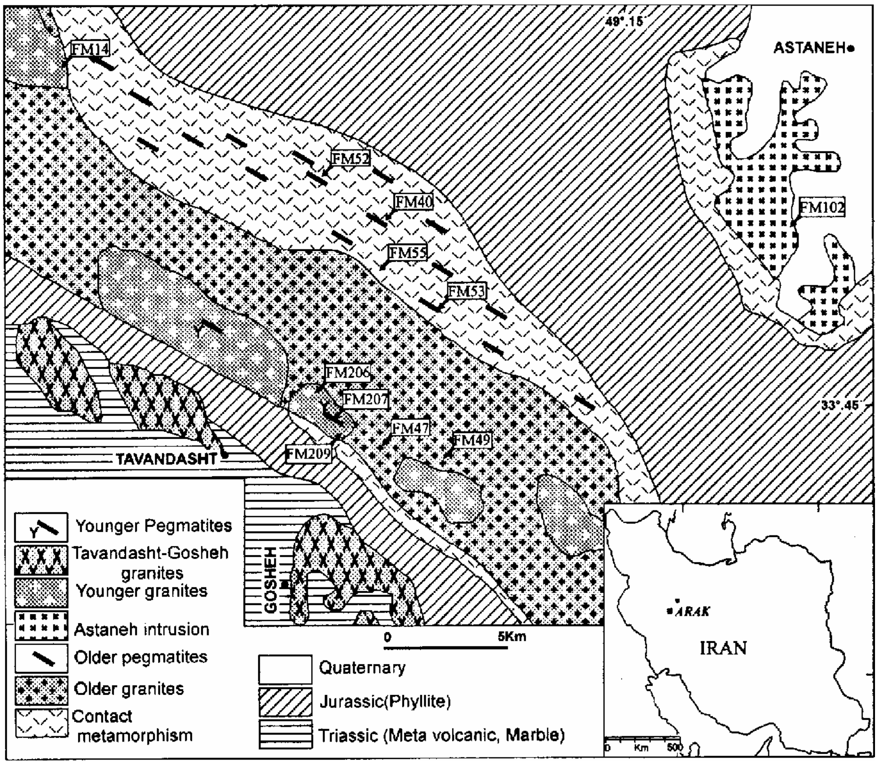

Figure 1. Simplified geological map of the area showing location of analysed samples for geochronology.

Table 1. Rb-Sr analytical results and age of the analysed samples

Sample	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	$(^{87}Sr/^{86}Sr)_i$	Age (Ma)
ASTANEH INTRUSION						
Granodiorite						
FM102, K-feldspar	24.7	189.6	0.3674	0.71027±3		
FM102, biotite	387.3	6.82	168.1	0.94596±8	0.70975	98.9±1.0
BORUJERD COMPLEX						
Granite						
FM14, K-feldspar	17.14	500.9	0.0990	0.70700±3		
FM14, biotite	484.7	31.67	44.47	0.75120±7	0.70690	70.1±0.7
FM14, biotite	467.9	30.96	43.91	0.75032±6	0.70690	69.6±0.7
Granite						
FM206, K-feldspar	16.84	275.8	0.1767	0.70897±3		
FM206, biotite	485.6	21.07	67.07	0.76767±5	0.70882	61.8±0.6
Granodiorite						
FM209, K-feldspar	6.8	450.9	0.0436	0.70754±3		
FM209, biotite	458.3	8.698	154.6	0.85274±7	0.70750	66.1±0.7
Granite						
FM47, K-feldspar	101.1	78.64	3.7355	0.71634±3		
FM47, muscovite	296.6	14.39	60.29	0.82083±8	0.70944	130.0±1.4
Granodiorite						
FM49, K-feldspar	2.39	349.2	0.0198	0.70614±3		
FM49, biotite	359.1	12.56	83.81	0.84218±7	0.70611	114.2±1.1
FM49, biotite	363.4	12.97	82.14	0.84293±7	0.70611	117.2±1.2
HORNFELS						
FM55, K-feldspar	48.47	192.1	0.7308	0.71845±3		
FM55, biotite	514.1	13.7	37.53	0.90406±7	0.71722	118.8±1.2
PEGMATITES						
Pegmatite						
FM52, K-feldspar	16.98	60.88	0.8077	0.71672±3		
FM52, muscovite	504.5	4.53	340.82	1.29770±1	0.71534	120.2±0.7
Pegmatite						
FM40, K-feldspar	24.97	4.87	14.9184	0.76523±3		
FM40, muscovite	938.3	2.025	1762.81	3.92730±6	0.73824	127.3±1.3
Pegmatite						
FM53, K-feldspar	392.5	25.48	45.0549	0.81910±3		
FM53, muscovite	693.3	2.365	990.26	2.42013±11	0.74278	119.2±1.3
Pegmatite						
FM207, K-feldspar	44.04	223.4	0.5704	0.70866±3		
FM207, muscovite	226.4	22.5	29.17	0.72990±3	0.70824	52.3±0.5

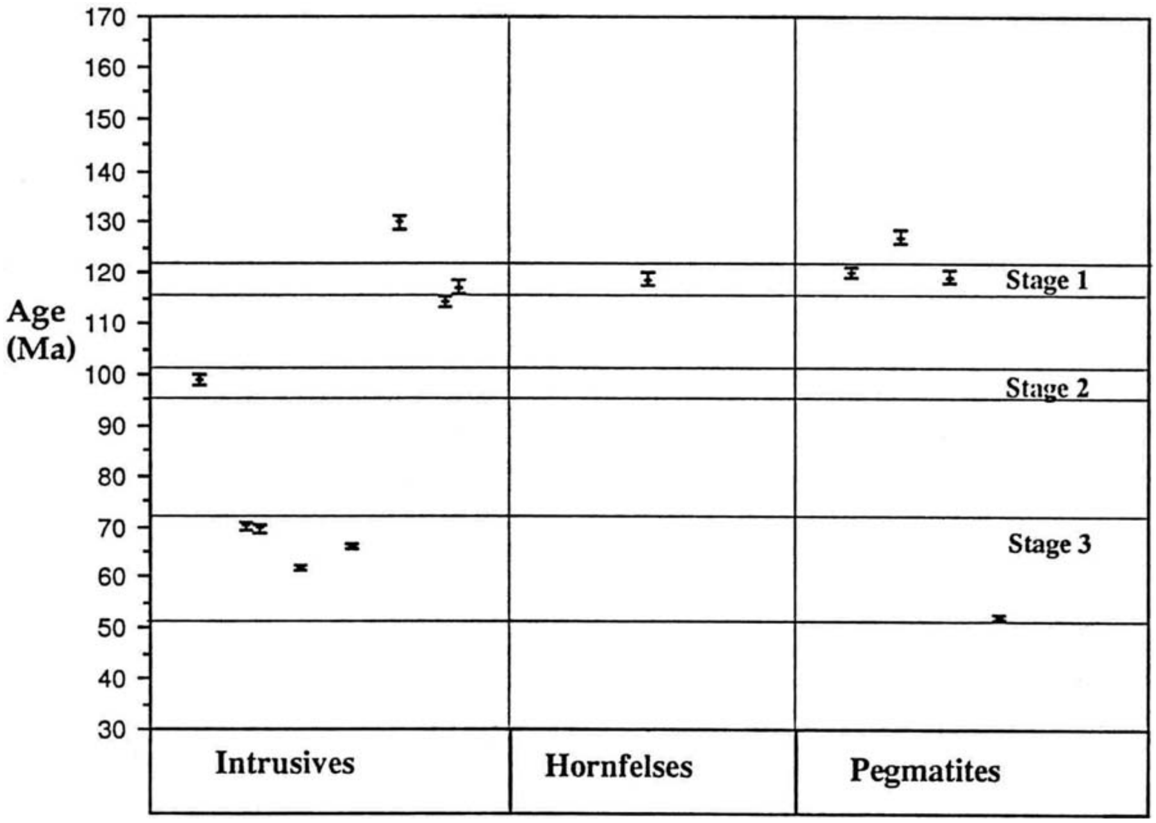

Figure 2. The mineral ages of analysed samples *vs.* their rock types.

The analytical errors on the biotite ages were examined by running duplicates for samples FM14 and FM49 (Table 1). White mica was very sensitive to the analytical procedures and for two samples the range of error was significantly more than the estimated analytical errors. Therefore the analytical procedures were repeated for these samples (FM52 and FM40). In general the radiogenic increase in $^{87}Sr/^{86}Sr$ is much smaller in white mica than in biotites and, as a consequence, their ages are more sensitive to uncertainties in initial isotopic composition [4].

Rb-Sr Mineral Ages

The mineral age of analysed samples versus their rock types is given in Figure 2. The distribution of data demonstrates the existence of three important stages in the evolution of investigated samples.

Stage One (>114 Ma)

Analyses of intrusive rocks of the Borujerd Complex yield ages of 114.2 and 117.2 Ma for sample FM49, and 130.0 Ma for sample FM47. With one exception, the age of pegmatites is in the range of 119.2 to 127.3 Ma (Fig. 2), while the hornfels yields an age of 118.8 Ma. Considering the errors associated with these ages (Table 1), with two exceptions, both muscovite ages, intrusions, hornfelses and pegmatites all yield ages in the range of 117-120 Ma.

The older age of pegmatite FM40 probably results from the sensitivity of the muscovite age to uncertainties in analytical procedure, particularly since there is no independent reason for supposing that pegmatite FM40 is the oldest among analysed pegmatites.

In considering the mechanisms for distribution of ages (Fig. 2) and the initial $^{(87/86)}Sr$ ratios (Table 1) of intrusive rocks (FM47 and FM49), three possible explanations can be offered:

Case A

Large intrusive bodies such as this one are often accumulations of successive smaller intrusions. In such a case, the intrusive mass can be regarded as a single geological unit but with slightly different age [9]. In this case granite FM47, which has an initial $^{(87/86)}$Sr ratio different from granodiorite FM49 (Table 1), could have been formed in an earlier stage of intrusive activity, and the apparent difference in ages is real.

Case B

During the formation of younger granites and pegmatites, some radiogenic Sr could have been introduced into the older rocks (e.g. FM47). Hence, the calculated age is older than the real age.

Case C

Incomplete Sr homogenisation within the sampling area could have caused a scattering of points in the diagram [5], leading to random uncertainty in all mineral ages.

By comparison with the other data, the age of 117.2 Ma is the preferred value for sample FM49, The younger age of 114.2 Ma for this sample could be a result of analytical errors.

Stage Two (99 Ma)

Stage two is represented by only one sample, this giving an age of 98.9 Ma. However, it can be regarded as the age of Astaneh intrusion to a first approximation.

Stage Three (52.3 to 70.1 Ma)

A series of small intrusions (FM206, FM209, FM14) with an initial $^{(87/86)}$Sr ratio of 0.707±1 formed between 61.8 to 70.1 Ma from a rather uniform source. This age broadly corresponds with the formation of pegmatite FM201 at 52.3 Ma. This pegmatite (FM207) is mineralogically distinct from the older ones and has an initial $^{(87/86)}$Sr ratio of 0.70824, i.e. lower than that of pegmatites formed during stage one (Table 1). This suggests a different origin for the younger pegmatites formed during this stage from those of stage one.

Discussion

In the studied area pegmatites are very coarse grain which makes it susceptible to alteration and causes difficulties on a representative homogeneous sample. Granitic rocks are mainly hydrothermaly altered and metasomatic features are well developed in hornfelses. Generally Rb-Sr whole rock (WR) isochron is fairly resistant to resetting during metasomatism and alteration, so Sr isotope homogenisation proceeds with difficulty. In order to avoid the consequences of hydrothermal alterations affect in granites and pegmatites and metasomatism in hornfelses, this study has involved Rb-Sr analyses of selected minerals from pegmatites, granites, and hornfels.

Selected samples contain both biotite or muscovite and K-feldspar, all of which can be detected by the Rb-Sr method. However the obtained results are 2- point isochrons and the precaution should be made in using of the ages. On the other hand the field and microscopic studies are concordant with obtained data, which increase the confidence on the obtained results.

The results of Rb-Sr mineral dating (Table 1) indicate that the Astaneh intrusion and the Borujerd complex were emplaced in different episodes. The Astaneh intrusion formed during the late Albian (98.9±1 Ma), while the Borujerd complex, which is composed of granitic intrusions, may have formed during two main periods.

i) Diorites and granites formed in the Aptian (117±1.2 Ma) occupy most of the Borujerd complex. It is possible that some granites are significantly earlier (130±1.4 Ma) within this event. These rocks are termed as the Older granites.

ii) Dioritic and granitic rocks also formed as minor intrusions during the late Cretaceous and early Palaeocene (70.1±0.7 to 61.8±0.6 Ma). They are named here as the Younger granites. Intrusive bodies appear to have evolved from diorite to granite in composition from the late Cretaceous to the early Palaeocene, but the length of this episode is subject to large uncertainties.

On the basis of the age given by sample FM55, an age of 118.8±0.7 has been taken for the Borujerd complex aureole. This implies that the major phase of magmatism was during stage 1.

The interpretation of ages in metamorphic rocks is critically dependent on knowledge of the behaviour of isotopic systems in minerals during heating and recrystallisation [6]. The more complete our understanding of the processes involved in a rock's history, the better the interpretation of its "age" is likely to be.

At the simplest level, a radiometric age is the result of measuring the amount of radioactive decay of isotope in a system since the system became closed to the diffusion of both parent isotope and daughter product. During contact metamorphism, where crystallisation of metamorphic minerals (e.g. biotite, feldspar) has occurred, the system behaviour begins at approximately the peak temperature of metamorphism, and hence ideally a radiometric age calculated in this study for hornfelses will date the metamorphic peak.

The older intrusive rocks with an age of 117.2±1.2 Ma in the Borujerd complex are believed to be responsible for the main high grade metamorphism of associated country rocks. This conclusion is supported by the location of the sillimanite zone, which occurs only at the northern margin of the complex, where the Older granite is present in abundance.

Two major groups of pegmatites can be distinguished (Table 1). One group gives lower Cretaceous ages between 119.2±1.3 to 127.3±1.3 Ma (Barremian-Aptian) and are termed the Older pegmatites. The second group date from the early Palaeocene (52.3±0.5 Ma) and are termed the Younger pegmatites. This second group is represented by sample FM207.

The Older pegmatites occur in the Borujerd complex aureole, while Younger pegmatites are mainly hosted by Younger granites. The Older pegmatites and the Younger pegmatites also present different mineralogical features and fluid inclusions. The Older pegmatites are characteristically composed of quartz, feldspar, muscovite, tourmaline, garnet, andalusite and apatite, while the Younger pegmatites contain mainly feldspar, albite, quartz, biotite, tourmaline and muscovite. The presence of biotite and lack of garnet distinguish Younger pegmatites from Older pegmatites. The CO_2-H_2O type inclusions occurs in Older pegmatites, while H_2O-low salinity inclusions are common in Younger pegmatites.

The Older pegmatites (119.2±1.3 Ma and 120.2±1.2 Ma) appear to have formed during the same period as their host contact metamorphic rocks (118.8±1.2 Ma).

It is believed that Older pegmatites formed during the peak of contact metamorphism. This is based on textural features of tourmalinisation. In the hornfelses from the Borujerd complex aureole, tourmalinisation accompanies the metamorphic growth of andalusite. Tourmalines with a comparable composition to those in pegmatites frequently occur included along the margins of andalusite crystals but are lacking from their cores. This suggests that the tourmaline formed during the peak of metamorphism.

Conclusion

The results obtained so far provide useful controls on the absolute timing of events and the history of the area and demonstrate a prolonged history of Alpine Calcalkaline magmatism. [1] stated late Jurassic to early Cretaceous time for regional metamorphism. This study shows, the first intrusive activity occurred after regional metamorphism and during the early Alpine tectonic movements, in lower Cretaceous times (about 120 Ma). A large elongate granitic intrusion (Older Granite), which occupies most of the Borujerd complex, and the first group of pegmatites (Older Pegmatites) formed during this stage.

The Astaneh intrusion was emplaced during the Albian, during syntectonic intrusive activity associated with continuing Alpine movements. Following this, the Younger Granites and Younger Pegmatites formed as a series of post tectonic intrusions and veins during late Cretaceous-early Palaeocene (70-52 Ma).

References

1. Bellon H. and Braud J. Donnés nouvelles le domaine métamorphique du Zagros (Zone de Sanandaj-Sirjan) au niveau de Kermanshah-Hamadan (Iran); Nature, áge et interprétation des séries métamorpgiques et des intrusion, évolution structural: Fac, Sci. d'orsay, Paris, 14 p. (1975).
2. Berberian M. and King G.C.P. Toward a paleogeography and tectonics of Iran. *Can. J. Earth Sci.*, **18**: 210-265 (1981).
3. Berthier F., Billiault J.P., Halbrown B. and Maurizot P. Etude Stratigrapgique et structural de la region de Khorramabad (Zagros-Iran): Ph.D de Grenoble, France (1974).
4. Cliff R.A., Droop G.T.R. and Rex D.C. Alpine metamorphic in the south-east Tauern Window, Austria: 2. Rates of heating, cooling and uplift. *J. Metamorphic Geol.*, **3**: 403-415 (1985).
5. Faure G. Principles of isotope geology. 2nd edition, John Wiley, New York, USA (1986).
6. Heier K.S. and Compston W. Interpretation of Rb-Sr age patterns in high-grade metamorphic rocks, north Norway. *Norsk Geologisk Tidsskrift*, **49**(3): 257-283 (1969).
7. Inger S. and Cliff R.A. Timing of metamorphism in the Tauern Window. Eastern Alps. Rb-Sr ages and fabric formation. *J. Metamorpg. Geol.*, **12**: 695-707 (1994).
8. Masoudi F. Contact metamorphism and pegmatite development in the region SW of Arak, Iran. PhD thesis, The university of Leeds, UK (1997).
9. Nakajima T., Shirahase T. and Shibata K. Along-arc lateral variation of Rb-Sr and K-Ar ages of Cretaceous granitic rocks in southwest of Japon. *Can. Mineral. Petrol.*, **104**: 381-389 (1989).
10. Radfar J. Petrology of granitic rocks from Astaneh area, Iran. MSc thesis (in Farsi), Tehran University, Iran (1987).
11. Schreiner G.D.L. Composition of the Rb-87/Sr-87 age of the Red granite of the Bushveld complex from measurements on the total rock and separated mineral fractions. *Proc. Roy. Soc. Ser. A*, **245**: 112-117 (1958).
12. Steiger R.H. and Jäger E. Subcommission on geochronology: convention on the use of decay constants in geo- and cosmo-chronology. *Earth Planet. Sci. Lett.*, **36**: 359-362 (1977).
13. Stöcklin J. Structural history and tectonics of Iran: A review. AAPG, 1229-1258 (1968).
14. Stoneley R. The Arabian continental margin in Iran during the Late Cretaceous. In: Robertson A.H.F., Searie M.P. and Ries A.C. (Eds.), *The Geology and Tectonics of the Oman Region*. Geological Society Special Publication, No. 49, pp. 787-795 (1990).