K–Ar biotite ages from Miocene post–collisional Garam Chashma leucogranite, eastern Hindukush Range (Trans–Himalayas), northwestern Pakistan

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Garam Chashma granitic rocks intrude discordantly into the Hindukush metamorphic complex on the southern margin of the Asian plate, Trans–Himalayas, northwestern Pakistan. The rocks are fine to coarse-grained, two-mica leucogranite. K–Ar biotite analyses of four samples from the Garam Chashma pluton yield 18–20 Ma ages. These ages are younger than those of the other post–collisional granitic rocks in Trans–Himalayas of Pakistan and resemble those of the Higher Himalayan granitic rocks.

Introduction

The collision of Indian and Asian plates that occurred around 55–40 Ma (Tahirkheli, 1982; Coward et al., 1986; Rowley, 1996) provoked one of the youngest orogenies in the world, the Himalayan orogeny. Following the collision, continual crustal shortening, thickening and metamorphic events resulted in the anatexis and emplacement of numerous plutons in the collision zone.

The ages of the pre–collisional continental plutons are well established by several authors (Desio et al., 1964; Searle et al., 1991). On the contrary, the post–collisional small and large plutons emplaced during Himalayan orogeny show a wide range of variation from 37 Ma to 1.4 Ma (Searle et al., 1989; Debon et al., 1987; Schneider et al., 1999a, b). It appears necessary to obtain more age data to understand the dynamo–tectonic igneous activities of the region, especially in the

Kohistan arc and adjacent areas. The present authors intend to report here the K–Ar biotite ages of Garam Chashma pluton.

Tectonic setting of the region

In northern Pakistan, the main geologic units include Hindukush–Kararkoram (Trans–Himalayas), Nanga Parbat–Haramosh Massif (Higher Himalayas) and intercalated Kohistan–Ladakh paleo–island arc (Figure 1). The Northern Suture (NS) that separates the Kohistan–Ladakh island arc from the Asian plate was developed in ca. 100 Ma due to the closure of the Neotethys (Pudsey, 1986; Petterson and Windley, 1985). The arc is bounded in the south by Main Mantle Thrust (MMT), which formed as a result of India–Asia collision in 55–40 Ma (Tahirkheli, 1982; Coward et al., 1986; Rowley, 1996).

In the Asian plate of northwestern Pakistan, majority of the granitoids in Hindukush metamorphic complex of Wakhan zone (Gaetani et al., 1996) are pre–collisional in nature. The Garam Chashma pluton is composed of the only noticeable post–collisional, S–type leucogranite (Zafar et al., 1998).

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Figure 1. Geological sketch map of northern Pakistan (after Pudsey, 1986; Hildebrand et al., 1998; Schneider et al, 1999a, b). Inset shows location of the map. NS, Northern Suture; MMT, Main Mantle Thrust; NPHM, Nanga Parbat-Haramosh Massif; KKB, Karakoram batholith; GB, Ghamu Bar; KBZ, Kesu Buni Zom; TM, Tirich Mir; KF, Kafiristan; BZ, Birzine; GC, Garam Chashma; SM, Sumayyar; HD, Hunza Dikes; MG, Mango Gusar; CK, Ching Kang-la; B, Baltoro; JT, Jutial; MP, Mazeno Pass; SC, South Chichi.

Geology of the Garam Chashma area

Pre-collisional granitoids

The pre-collisional Tirich Mir (TM) and Kafiristan (KF) granitoids (Fig. 1) are located in the Hindukush metamorphic complex of Wakhan zone (Gaetani et al., 1996), which shows greenschist to amphibolite facies metamorphism. The pre-collisional granitic rocks are mainly hornblende-biotite granodiorites with K-feldspar megacrysts ranging in size from several millimeters to a few centimeters. They are strongly foliated and are sometimes described as granodiorite gneisses (Khan, 1986). Rocks of the Tirich Mir pluton commonly have quartz and K-feldspar augens. The Tirich Mir pluton yields 117 ± 5 Ma Rb-Sr (biotite) age (Desio et al., 1964), whereas, Kafiristan pluton gives 48 ± 2 Ma K-Ar (biotite) age (Searle, 1991). The 48 ± 2 Ma age of the

Kafiristan pluton may be an erroneous result, because field studies show strong deformation and effects of metamorphism suggesting its intrusion before the formation of the Northern Suture.

The Birzine pluton (BZ), exposed to the southwest of Garam Chashma (GC), is composed of fine to medium-grained granodiorite. The age of this pluton has not been determined yet, but strong deformation and foliation suggest its pre-collisional age. Major and trace element chemistry suggests that it is akin to the Kafiristan pluton (Zafar et al., 1998; Murata et al., 1999).

Post-collisional Garam Chashma pluton

The post-collisional Garam Chashma pluton is located about 30 km northwest of the Northern Suture, and covers an area of about 300 km² (Fig. 2). It intrudes discordantly into the metasedimentary rocks and consists

Figure 2. Geologic sketch map of the Garam Chashma area showing sample localities (modified after Khan, 1986). HMC, Hindukush Metamorphic Complex; GC, Garam Chashma; BZ, Birzine.

of fine to coarse-grained leucogranite with little change in lithofacies. It is generally massive, but shows foliation along the intrusive contacts. Aplitic and pegmatitic veins and/or dikes are widespread through the pluton. Hildebrand et al., (1998) reported U-Pb (monazite) age of 24 ± 0.5 Ma for the Garam Chashma leucogranite. They speculated that this age possibly represents crustal melting or the upper limit on the age of regional metamorphism.

Petrography

The Garam Chashma leucogranite is composed of muscovite, biotite, plagioclase, K-feldspar and quartz with subordinate garnet and tourmaline. The ratio of biotite to muscovite is not constant. Muscovite is evenly distributed. It is also found as inclusions in plagioclase and K-feldspar. Biotite is brown and contains inclusions of zircon and/or sillimanite. Plagioclase is euhedral to subhedral and contains inclusions of muscovite, biotite, and zircon. K-feldspar is usually subhedral and contains abundant inclusions of muscovite, biotite, and zircon. Micrographic intergrowths of K-feldspar and quartz are observed in aplitic rocks.

Quartz crystals are usually interstitial to both plagioclase and K-feldspar. Subhedral to euhedral almandine garnet crystals are usually fractured and contain zircon inclusions. The skeletal frameworks in garnet contain quartz. No reaction rims of garnets are observed. A few scattered anhedral greenish crystals of tourmaline are also observed. Tourmaline shows light to dark green optical zonation and is devoid of any inclusions. Among the accessory minerals apatite is the most abundant. Other accessory minerals include zircon, sillimanite and allanite. Ilmenite and pyrrhotite are also observed.

K-Ar age determination

Four representative fresh samples were selected for K-Ar age determination. The sampling sites are indicated in Figure 2. The samples were crushed in a mortar and sieved. Only 100–150 mesh size fractions were used to separate biotite by isodynamic magnetic separator. The biotite grains were further purified using heavy liquid (Thallium Formate-Malonate). Potassium was analyzed by flame photometry (Nagao et al., 1984). ^{40}Ar was determined by the isotope dilution method with ^{38}Ar spike using the mass spectrometer (Nagao and Itaya, 1988; Itaya et al., 1991) at the Hiruzen Institute for Geology and Chronology. K-Ar age was calculated using the physical constants, $\lambda_e = 0.581 \times 10^{-10}/\text{y}$, $\lambda_\beta = 4.962 \times 10^{-10}/\text{y}$, $^{40}\text{K}/\text{K} = 0.0001167$ (Steiger and Jäger, 1977). The results for Garam Chashma leucogranite range from 18.05 Ma to 19.85 Ma (Table 1).

Results and Discussion

The K-Ar biotite ages of 18–20 Ma (Table 1) of the Garam Chashma leucogranite indicate that it is probably the youngest post-collisional granitic body in the Trans-Himalayas of northwestern Pakistan. A comparison of post-collisional granitoids in the Trans- and Higher Himalayas of the Pakistan, India and Nepal is given in Table 2.

In the Trans-Himalayas of northeastern Pakistan, the other known post-collisional granites yield ages from 21 to 37 Ma. These include Mango Gusar (MG), Ching Kang-la (CK), Hunza dikes (HD), Sumayar (SM) and Baltoro (B) plutons (Fig. 1). The Mango Gusar pluton is composed of a non-foliated, medium-grained, two-mica granite-granodiorite and yields U-Pb (zircon) age of 37 ± 0.8 Ma (R. Parrish data in Searle, 1991). The Ching Kang-la pluton is composed of pyroxene-hornblende-biotite granite with a K-Ar (hornblende) age of 34 ± 1.0 Ma (Searle et al., 1989). The Baltoro

Table 1. K-Ar biotite ages for Garam Chashma leucogranite

Sample No.	K (wt%)	Rad. ^{40}Ar (10^{-8}ccSTP/g)	K-Ar age (Ma)	Non. Rad. Ar(%)
8A	7.109 $\pm$ 0.142	502.2 $\pm$ 6.0	18.11 $\pm$ 0.42	13.9
		500.5 $\pm$ 6.1	18.05 $\pm$ 0.42	14.0
12B	7.118 $\pm$ 0.142	512.4 $\pm$ 5.9	18.46 $\pm$ 0.42	12.6
		506.8 $\pm$ 5.9	18.26 $\pm$ 0.42	12.3
18A	6.933 $\pm$ 0.139	510.1 $\pm$ 5.9	18.86 $\pm$ 0.43	12.7
		505.1 $\pm$ 5.9	18.68 $\pm$ 0.43	13.1
21A	6.733 $\pm$ 0.135	518.1 $\pm$ 6.1	19.72 $\pm$ 0.46	13.7
		521.5 $\pm$ 6.2	19.85 $\pm$ 0.46	13.9

Table 2. Post-collisional granitoids in the Trans- and Higher Himalayas of Pakistan, India and Nepal

	Rock Type	Age (Ma)
Trans-Himalayas		
Garam Chashma pluton (this study)	Two-mica leucogranite	18-19
Mango Gusar pluton (1)	Two-mica granodiorite-granite	37 $\pm$ 0.8
Chingangk-la pluton (2)	Px-Hb-Bt granite	34 $\pm$ 1
Baltoro pluton (3)	Monzogranite-leucogranite	21.4-25.5
Hunza dikes (4)	Granodiorite-leucogranite	Mid-Miocene
Sumayar pluton (5)	Leucogranite	< 37
Higher Himalayas		
A: India Himalayas		
Gangotri pluton (6)	Tourmaline-biotite leucogranite	22.4
B: Nepal Himalayas		
Manaslu pluton (7)	Two-mica granite	19-22.4
C: Nanga Parbat Haramosh Massif		
South Chichi pluton (8)	Leucogranite	18-19
Jutial pluton (9)	Two-mica granite	9.5
Mazeno Pass pluton	Two-mica granite	1.4

1, R. Parrish data in Searle, 1991; 2, Searle et al., 1989; 3, Searle et al., 1991 and Parrish and Tirrul, 1989; 4, Debon et al., 1987; 5, Searle et al., 1989 and Crawford and Searle, 1993; 6, Scaillet et al., 1990 and Harrison et al., 1997; 7, Coleman and Parrish, 1995 and Harrison et al., 1995; 8, Schneider et al., 1999b; 9, Schneider et al., 1999a.

pluton is the largest of all and is composed of monzogranite-leucogranite (Searle et al., 1992), which gives U-Pb (zircon) age of 21.4-25.5 Ma (Parrish and Tirrul, 1989). The Hunza dikes comprise leucogranites, granodiorites, monzogranites, pegmatites and aplites. No radiometric age is available for these dikes. However, Debon et al. (1987) suggested a Mid-Miocene age. The Sumayar pluton, composed of a homogeneous leucogranite, is presumably younger than 37 Ma, because it cuts the metamorphic structures, which formed during the Barrovian type metamorphism with its culminating age of 37 Ma (Searle et al., 1989; Crawford and Searle, 1993).

Majority of the Higher Himalayan post-collisional granites range from 19 to 24 Ma in age and suggest younger plutonism (Harrison et al., 1997). The Gangotri and Manaslu plutons represent granitic rocks from the India and Nepal Himalayas, respectively. The Gangotri pluton comprises fine-grained tourmaline muscovite $\pm$ biotite leucogranite (Scaillet et al., 1990) with Th-Pb (monazite) age of 22.4 Ma (Harrison et al., 1997). The Manaslu pluton, composed of two-mica granite with occasional tourmaline and garnet, yields 19 Ma U-Pb (Coleman and Parrish, 1995) and 22.4 Ma Th-Pb (monazite) (Harrison et al., 1995) ages.

The Nanga Parbat-Haramosh Massif (NPHM)

represents the westernmost extension of the Higher Himalayas in Pakistan. The South Chichi granite of the NPHM (Fig. 1) is composed of fine-grained leucogranite and gives Th-Pb (monazite) ages of 18–19 Ma (Schneider et al., 1999b). The Jutial and Mazeno Pass plutons, to the north of South Chichi granite, represent even much younger plutonic activities in the Nanga Parbat area. The Jutial pluton is largely undeformed, two-mica $\pm$ tourmaline granite with U-Th-Pb (zircon and monazite) age of 9.5 Ma, whereas the Mazeno Pass pluton is composed of fine-grained, two-mica granite and yields U-Th-Pb (zircon and monazite) age of 1.4 Ma (Schneider et al., 1999a).

The K-Ar biotite ages of Garam Chashma leucogranite range from 18 to 20 Ma. These ages are comparable to most of the Higher Himalayan post-collisional granites. The Higher Himalayan granites are characterized by tourmaline-muscovite-biotite mineral assemblage and restricted SiO₂ range. The Garam Chashma two-mica leucogranite is also similar in mineral assemblage and chemistry to the Higher Himalayan granites (Murata et al., 1999 and Zafar et al., in prep.). In conclusion, the Garam Chashma leucogranite is younger than the other post-collisional granites in the Trans-Himalayas of northern Pakistan and is considered to be akin to the Higher Himalayan granites in terms of age, mineralogy and chemical characteristics.

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