Major and trace element compositions of post-collisional, peraluminous Garam Chashma granite, Hindukush Range, northwestern Pakistan

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The post-collisional Garam Chashma leucogranite with K–Ar (biotite) ages of 20–18 Ma occurs in the Hindukush Range (Trans-Himalayas), northwestern Pakistan. The leucogranite is per-aluminous and shows a restricted range of SiO₂ contents (72–75 wt%). It is different, both in mineralogy and chemical characteristics, from the surrounding pre-collisional granodiorites and post-collisional meta-aluminous to per-aluminous Miocene Baltoro granite from Trans-Himalayas in Northeast Pakistan. The age and chemical trends of Garam Chashma leucogranite are similar to those of the Higher Himalayan granites of Pakistan, India, Nepal and South Tibet, suggesting similar source and/or processes of formation.

Introduction

Most of the post-collisional granites in the Indian–Nepal Himalayas occur in Higher Himalayas (collision zone) and Trans-Himalayas on the southern margin of the Asian plate. The westernmost extension of the Himalayas is situated in the northern Pakistan. The granitic activities in northern Pakistan are more complex than those in the Indian–Nepal Himalayas because of the presence of Kohistan–Ladakh island arc, squeezed between Asian and Indian plates (Fig. 1). The petrological investigations of post-collisional granitic rocks in the northwestern Pakistan would lead us to better understanding of the mountain building processes of Himalayas and adjacent terranes.

The study of per-aluminous (S-type) granitic rocks can help us to determine the P–T conditions at the time of magma genesis using Al-rich minerals such as garnet, cordierite, muscovite and biotite. The per-aluminous

granitic rocks of Higher Himalayas have been investigated by many authors (e.g. Le Fort, 1981; Searle et al., 1988 and 1997; Guillot and Le Fort, 1995; Inger and Harris, 1993). But, post-collisional granitic rocks of the Trans-Himalayas have not been studied in detail.

In Pakistan, post-collisional granites on the southern margin of the Asian plate (Trans-Himalayas) are scarcely distributed and are mostly in the form of small sills and dikes (Searle et al., 1988). Exceptionally, the Baltoro granite (Rex et al., 1988) to the northeast and Garam Chashma granite to the northwest are batholiths (Fig. 1). The Baltoro granitic rocks of 25.5–21.4 Ma (U–Pb zircon) have been investigated by Parrish and Tirrul (1989) and Searle et al. (1992). On the other hand, the Garam Chashma leucogranite has not been studied in detail yet.

In this paper we present the major and trace element chemistry of the post-collisional Garam Chashma granite. A comparison with some pre- and post-collisional granites from southern margin of the Asian plate and Higher Himalayas is also presented.

Tectonics of the northern Pakistan

The main tectonic units of the northern Pakistan include the Asian plate, Indian plate and the Kohistan–Ladakh

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Figure 1. Geological sketch map of the northern Pakistan (after Pudsey, 1985; 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; B, Baltoro; JT, Jutial; TT, Tato; TS, Tarshing.

island arc. The Northern Suture (NS) bounds the island arc to the north and Main Mantle Thrust (MMT) to the south (Fig. 1). The Northern Suture was formed due to the closure of the back-arc around 102 to 75 Ma (Pettersen and Windley, 1985). The Main Mantle Thrust was developed when Indian plate collided with the Kohistan island arc in 55–40 Ma (Tahirkheli, 1982; Coward et al., 1986; Rowley, 1996).

The Kohistan arc was generated as a result of intra-oceanic subduction during Cretaceous (Searle, 1991; Treloar and Izatt, 1993). The arc was then intruded by pre-collisional granitoids of 102 Ma (Pettersen and Windley, 1985). The intra-arc rifting and magmatism of about 40 Ma resulted in the post-collisional calc-alkaline Andean type batholiths (Khan et al., 1993).

The subduction of the Indian plate under the Kohistan arc and the Asian plate continued even after the collision resulting in thickening of the crust and

Barrovian type of metamorphism with its peak between 40 and 25 Ma (Pudsey et al., 1985). This metamorphism episode was followed by the intrusions of leucogranites ranging in age from 28 to 12 Ma (Le Fort et al., 1986).

The Nanga Parbat-Haramosh Massif (NPHM) represents the western most extension of the Higher Himalayas in Pakistan. The granitic rocks in the massif are fine to coarse-grained tourmaline two-mica leucogranites. Their U-Pb (zircon and monazite) ages range from 19–1 Ma (Zeitler et al., 1993; Schneider et al., 1999a and b).

Geologic setting

The granitic rocks in the Garam Chashma area can be divided into pre-collisional Tirich Mir (TM), Kafiristan (KF) and Birzine (BZ) granodiorites and the post-col-

lisional Garam Chashma granite (GC) (Leak et al., 1989). They occur in the overlying Hindukush metamorphic complex, northwestern Pakistan. The Hindukush metamorphic complex consists of slates, amphibolites, gneisses, quartzite, marbles, biotite–garnet schists, mica schists and graphitic schists (Pudsey et al., 1985; Leak et al., 1989). The metamorphic grade increases towards northwest. Migmatite intercalations in the gneisses are observed to the southwest, towards Afghanistan border. Because of the metamorphism, fossils for age determination are not available in this area. The fossils found in the northwestern unit suggest Jurassic to Devonian age for all the rock units exposed in this area (Pasco, 1923; Calkins et al., 1981; Tahirkheli, 1982; Pudsey et al., 1985).

The pre-collisional Tirich Mir and Kafiristan granitic rocks are composed mainly of hornblende–biotite granodiorites with K–feldspar megacrysts ranging in size from millimeters to a few centimeters. These are strongly foliated and are sometimes described as granodiorite gneisses (Khan, 1986). Tirich Mir granitic rocks are characterized by the presence of 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 granodiorite is exposed to the southwest of Garam Chashma. It occurs within the migmatite zone and is fine to medium-grained granodiorite. Biotite and hornblende sometimes show preferred orientation.

The post-collisional Garam Chashma pluton is located about 30 km northwest of Northern Suture and covers an area of about 300 km². It is composed of fine to coarse-grained homogeneous leucogranite. The granite intrudes into the Hindukush metasediments and yields K–Ar (biotite) ages of 20–18 Ma (Zafar et al., 2000). A U–Pb (monazite) isotope age of 24 ± 0.5 Ma is also reported by Hildebrand et al. (1998). Moderate foliation usually marked by muscovite and biotite can be observed near the contacts of intrusion. Major rock forming minerals include quartz, plagioclase, K–feldspar, muscovite and biotite with subordinate garnet and tourmaline. Aplitic and pegmatitic veins and/or dikes are ubiquitous in the pluton.

The Nanga Parbat–Haramosh Massif, a tectonic half window, is the westernmost extension of the Himalayan mountain chain in northern Pakistan

(Schneider et al., 1999a). It is composed of Precambrian basement, consisting of gneisses, schists and interbedded amphibolites (Chamberlain et al., 1995). The basement rocks are intruded by numerous granitic stocks and dikes, ranging in age from 19 to 1 Ma (Zeitler et al., 1993; Chamberlain et al., 1995; Schneider et al., 1999a and b). The Jutial pluton (JT), located in the northern part of the massif, is composed of two-mica tourmaline granite with a U–Th–Pb (zircon and monazite) age of 9.5 Ma (Schneider et al., 1999a). A fine to coarse-grained garnet tourmaline two-mica Tarshing granite (TS) intrudes into the Rupal Shear zone. The Tato pluton (TT), exposed to the north of Nanga Parbat Mountain, is composed of tourmaline two-mica granite. It gives a U–Pb zircon age of 1 Ma (Zeitler et al., 1993).

Petrography

Tirich Mir, Kafiristan and Birzine granodiorites

The Tirich Mir pluton is composed of hornblende biotite granodiorite and biotite granite. Biotite is brown in color and shows strong preferred orientation. Some biotites are bent, sheared and broken into pieces. Laths of biotite surround subhedral to euhedral plagioclase and K–feldspar. Plagioclase crystals are occasionally zoned and contain inclusions of fine-grained biotite and quartz.

The Kafiristan pluton is composed of hornblende biotite granodiorite and biotite granite. Biotite is greenish brown in color and usually shows preferred orientation. Bent, sheared and fractured biotites are also observed. Graphic intergrowths of plagioclase and quartz are observed.

The Birzine pluton is composed of hornblende biotite granodiorite. Hornblende crystals are green in color and euhedral in shape. Biotite shows dark brown color. Bent, sheared and fractured biotites are usually observed.

Garam Chashma granite

The Garam Chashma pluton is composed of fine to coarse-grained two-mica leucogranite. The granite is homogeneous and is characterized by the absence of lithofacies variation. The rocks are composed of muscovite, biotite, plagioclase, K–feldspar and quartz with subordinate garnet and tourmaline. The muscovite is evenly distributed, whilst the ratio of biotite to muscovite is not constant. Muscovite is also found as inclusions in plagioclase and K–feldspar. Muscovite and biotite clots surrounded by plagioclase and K–feld-

spar are also observed. Biotite is brown in color and contains inclusions of zircon and/or sillimanite. Plagioclase is euhedral to subhedral and occasionally contains inclusions of muscovite, biotite and zircon. K-feldspar is usually euhedral to subhedral containing abundant inclusions of muscovite, biotite, and zircon. Perthitic and micrographic intergrowths of K-feldspar and quartz are also observed. Quartz crystals are usually interstitial to the plagioclase and K-feldspar. Subhedral to euhedral almandine garnet crystals are usually fractured. The skeletal frameworks of garnet and quartz are observed, but no reaction rim of garnet is observed. Zircon inclusions are present in garnets. A few scattered anhedral greenish crystals of tourmaline are also observed. It 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 alandite. Pyrrhotite can be observed in a few thin sections.

Nanga Parbat Haramosh Massif

The Jutial, Tarshing and Tato plutons are composed of massive to slightly deformed, fine to coarse-grained tourmaline two-mica leucogranites. Garnet is absent in Jutial granite, whereas in Tarshing and Tato granites it is usually restricted to the biotite abundant lithofacies. The Tato granite is rich in tourmaline as compared to the other two granites. In all the three granites, biotite is usually subhedral, brown in color and rarely contains inclusions of zircon and/or monazite. Plagioclase shows zoning and contains inclusions of muscovite and biotite. Tourmaline is pale-green and sometimes shows zoning and contains inclusions of quartz and plagioclase. The accessory minerals include apatite, cordierite, zircon, monazite and garnet. Garnet is euhedral to subhedral and occasionally contains inclusions of quartz, muscovite and biotite. Accessory zircon and monazite mostly occur as inclusions in plagioclase and K-feldspar.

Major and trace components

The powdered samples were analyzed for major and trace elements (Ce, Cr, Nb, Ni, Pb, Sr, Th, Y, Zr and Ba) at the Naruto University of Education, using a wavelength dispersive X-ray fluorescence spectrometer (Rigaku RIX 2000). Glass beads, from finely ground samples, were prepared with sample to flux ratio of 1:10 and analyzed for major elements using fundamental parameter method, whereas trace elements were deter-

mined using pure press pellets and the empirical calibration curve method (Murata, 1993). The major element data were recalculated to 100 percent. The results of major and trace elements of some representative samples are given in Table 1.

Tirich Mir, Kafiristan and Birzine granodiorites

The SiO₂ contents of Tirich Mir and Kafiristan granitic rocks range from 65 to 74 wt% and from 64 to 76 wt%, respectively. The aluminum saturation index (ASI = molar Al₂O₃/[CaO+Na₂O+K₂O]) ranges between 0.92 and 1.16, representing their metaluminous to peraluminous character. Irrespective of their similar SiO₂ ranges, both rocks show different chemical trends on the SiO₂ vs. Al₂O₃ and SiO₂ vs. Fe₂O₃ plots (Figs. 2a and b). Only two analyzed samples of Birzine granodiorites show a possible extension of the chemical trend described for Tirich Mir granitic rocks. All the three pre-collisional granitic rocks of this area plot in the volcanic arc granite (VAG) field of the trace element discrimination diagrams (Figs. 2c and d) of Pearce et al. (1984).

Garam Chashma granite

The Garam Chashma granite shows a narrow SiO₂ range, 72 to 75 wt% (Table 1). The aluminum saturation index (ASI) ranges from 1.03 to 1.25, thereby representing its peraluminous character (Table 1). The K₂O/Na₂O is also higher than 1.0.

Nanga Parbat Haramosh Massif

The major and trace element characteristics of the three leucogranites from the Nanga Parbat Haramosh Massif are similar to those of the Garam Chashma granite. They also show a narrow SiO₂ range (73–77 wt%) and K₂O/Na₂O ratios higher than 1.0. The aluminum saturation index varies from 1.01 to 1.35, showing their peraluminous nature (Table 1).

Discussion

In this section we make a comparison of Garam Chashma leucogranite with post-collisional plutons from the Trans- and Higher Himalayas.

Comparison with Trans-Himalayan Baltoro granite

The Baltoro pluton is located in the Karakoram Range on southern margin of the Asian plate, northeastern Pakistan (Fig. 1). The 25.5–21.4 Ma (U–Pb zircon) age

Table 1. Representative Chemical compositions of granitic rocks from the Garam Chashma and NPHM areas

Location	Sample	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	ASI	Ce	Cr	Nb	Ni	Pb	Rb	Sr	Th	Y	Zr	Ba
Garam Chashma pluton	001'	73.71	0.11	14.99	1.09	0.01	0.15	0.78	3.84	5.03	0.29	1.14	6.8	trace	13.5	trace	49.7	263	50.2	7.7	21.8	37.1	99
	004C	73.16	0.18	15.04	1.35	0.02	0.20	0.97	3.66	5.12	0.31	1.13	30.3	trace	11.3	trace	52.0	287	66.6	9.2	23.4	62.9	131
	004D	73.73	0.12	14.92	1.09	0.02	0.15	0.74	4.06	4.96	0.22	1.11	20.6	trace	8.6	trace	42.1	266	46.3	6.5	20.3	40.5	115
	005A	73.30	0.16	14.97	1.20	0.02	0.21	0.88	3.67	5.36	0.23	1.11	27.1	trace	7.0	trace	45.0	286	60.1	9.0	20.9	51.9	167
	005C	73.36	0.15	14.95	1.11	0.02	0.19	0.83	3.55	5.59	0.27	1.12	23.7	trace	7.6	trace	44.9	282	55.8	7.4	20.9	49.5	143
	008A	72.86	0.23	14.80	1.67	0.02	0.32	1.30	4.11	4.49	0.20	1.06	42.1	3.5	8.3	trace	49.8	193	131.5	15.9	20.1	137.2	297
	008B	73.13	0.19	14.86	1.05	0.01	0.19	1.03	3.36	5.97	0.21	1.07	21.9	trace	7.2	trace	45.8	226	121.9	10.4	19.3	58.3	313
	009A	73.88	0.21	14.67	1.30	0.01	0.25	1.28	3.67	4.59	0.14	1.10	40.8	trace	6.5	trace	55.4	184	163.7	13.3	19.0	111.5	401
	009C	73.26	0.14	14.80	1.12	0.02	0.16	0.97	2.94	6.23	0.37	1.11	36.8	trace	17.6	trace	53.7	268	82.4	10.3	26.4	142.8	290
	011B	73.95	0.17	14.43	1.35	0.02	0.20	1.15	3.63	5.04	0.07	1.07	51.8	trace	11.0	trace	50.0	238	107.4	20.7	19.2	105.3	404
	012B	73.02	0.19	14.84	1.43	0.02	0.29	1.09	3.38	5.51	0.23	1.10	42.0	trace	15.2	trace	57.8	235	129.5	18.1	23.0	118.0	401
	017A	73.65	0.14	14.58	1.19	0.03	0.16	1.20	4.05	4.93	0.08	1.03	38.6	trace	9.6	trace	41.1	223	247.8	9.0	18.9	87.5	600
	018A	74.12	0.14	14.49	1.15	0.02	0.17	1.08	3.35	5.42	0.06	1.09	35.4	trace	8.5	trace	58.4	194	335.3	11.6	18.9	85.9	859
	019A	73.73	0.13	14.94	0.96	0.02	0.16	0.96	3.78	5.17	0.15	1.10	28.6	6.9	11.1	trace	53.3	313	90.9	10.8	23.0	51.6	183
	020A	74.25	0.09	14.88	0.87	0.02	0.08	0.84	4.38	4.51	0.07	1.09	31.3	trace	16.3	trace	41.3	328	58.5	13.3	22.5	38.4	199
	020B	74.19	0.09	14.80	0.86	0.03	0.09	0.75	3.92	5.15	0.11	1.11	27.9	trace	15.9	trace	45.0	361	54.1	10.3	25.3	40.1	141
	021A	74.17	0.22	15.22	1.40	0.01	0.27	1.29	3.27	4.11	0.06	1.25	48.1	6.3	5.4	trace	37.2	131	398.7	15.5	15.5	144.6	920
Nanga Parbat Haramosh Massif	102A	74.63	0.11	14.15	0.85	0.01	0.11	1.35	3.36	5.39	0.06	1.02	34.8	trace	5.4	trace	62.5	254	100.0	12.8	21.8	13.7	315
	102B	74.19	0.06	14.91	0.57	0.01	0.09	1.69	4.18	4.32	trace	1.02	22.2	trace	9.1	trace	117.0	189	167.0	6.3	18.5	43.1	413
	102C	76.56	0.05	13.78	0.47	0.01	0.03	1.38	3.45	4.23	0.03	1.08	27.2	trace	5.3	trace	66.0	250	70.0	7.7	33.1	20.9	59
	106A	76.78	0.08	12.72	0.70	0.01	0.06	0.45	2.51	6.49	0.21	1.06	18.3	trace	4.9	trace	32.7	328	39.2	3.5	24.3	14.0	93
	106C	75.04	0.11	15.04	0.98	0.01	0.27	0.81	2.79	4.70	0.24	1.35	18.0	6.7	7.5	trace	34.1	277	103.0	3.8	23.6	51.1	383
	106E	73.49	0.13	14.04	1.19	0.01	0.45	1.23	3.21	5.87	0.36	1.01	22.7	19.2	6.7	3.0	43.1	253	142.0	3.2	24.9	59.5	808
	106F	75.75	0.10	13.71	0.96	0.01	0.15	0.60	2.71	5.75	0.26	1.16	23.6	trace	8.3	trace	31.9	286	73.1	4.2	23.8	43.0	172
	118B	74.39	0.09	14.36	1.05	0.03	0.05	1.32	3.65	5.02	0.04	1.04	43.1	trace	10.1	trace	92.2	446	66.1	20.1	42.3	67.0	181
	118C	74.78	0.07	14.70	0.98	0.03	0.04	1.09	3.44	4.82	0.05	1.14	26.5	2.8	9.1	trace	87.4	420	55.2	21.1	41.2	57.2	146
	118H	74.55	0.08	14.27	1.09	0.03	0.07	1.26	3.52	5.09	0.05	1.05	34.2	trace	10.2	trace	80.4	399	62.7	21.8	47.3	57.8	190
	118J	74.54	0.08	14.43	1.08	0.03	0.05	1.16	3.58	4.99	0.06	1.08	25.6	trace	9.7	trace	84.1	416	55.2	20.7	41.5	60.6	152
Pre-collisional plutons	Tirich Mir	74.02	0.20	14.09	1.61	0.03	0.39	1.03	3.52	4.98	0.12	1.08	37.1	7.6	10.4	trace	41.3	217	109.5	10.2	22.5	78.7	279
	024A	66.83	1.05	15.02	5.77	0.09	1.35	2.74	3.80	3.09	0.27	1.03	50.1	19.4	16.0	3.2	24.5	198	154.4	13.6	26.2	233.5	368
	024B	70.03	0.42	15.51	2.66	0.05	0.88	2.37	4.38	3.49	0.21	1.01	55.3	6.2	13.2	2.5	32.2	184	210.0	13.2	21.1	142.0	343
	024D	65.96	0.66	16.81	3.90	0.06	1.41	2.86	4.29	3.71	0.34	1.03	63.9	18.7	14.8	11.5	29.3	254	264.4	15.3	23.9	200.9	691
	025'	73.87	0.04	15.13	0.56	0.01	0.07	0.57	3.20	6.21	0.34	1.16	18.6	trace	12.8	trace	34.7	359	28.6	1.4	24.1	23.5	81
	026'	72.77	0.23	15.12	1.51	0.03	0.36	1.54	4.53	3.79	0.12	1.05	21.8	4.7	10.2	trace	33.3	201	85.4	9.2	19.0	71.7	165
	029A	75.72	0.13	12.95	1.27	0.04	0.10	0.55	3.31	5.92	0.03	1.01	48.5	trace	14.0	trace	26.2	370	30.8	18.8	39.5	74.8	157
	029B	71.81	0.43	13.67	3.23	0.05	0.43	1.95	3.38	4.93	0.12	0.95	89.5	trace	13.6	trace	19.2	156	115.1	16.1	29.8	235.1	626
	029C	75.02	0.16	13.44	1.31	0.06	0.20	0.87	3.36	5.51	0.07	1.03	50.0	trace	11.0	trace	23.1	224	62.9	16.7	30.9	91.0	385
	029D	64.31	0.82	15.92	5.92	0.08	1.94	4.59	4.07	2.18	0.16	0.92	50.7	23.3	7.4	12.1	13.0	89	335.8	6.3	23.0	175.5	410
	029J	66.56	0.72	15.77	5.38	0.08	1.59	3.66	3.58	2.52	0.15	1.03	44.8	11.1	7.5	4.3	14.3	86	275.6	8.0	22.6	168.4	506
	029K	64.26	0.80	16.28	5.87	0.09	2.07	4.97	3.85	1.69	0.14	0.95	41.1	25.5	6.7	9.5	11.2	56	242.2	5.6	19.5	142.0	408
	013A	62.67	0.74	18.09	5.52	0.07	1.95	5.06	3.43	2.30	0.16	1.04	65.8	14.2	8.9	2.4	21.6	110	395.9	15.0	18.6	134.2	513
	013B	62.79	0.63	17.56	5.61	0.09	2.22	5.50	3.60	1.87	0.13	0.98	41.4	22.2	7.1	trace	25.1	93	421.4	8.6	18.6	108.6	440

Trace element in ppm; Total iron as Fe₂O₃.

Figure 2. Representative major elements versus SiO_2 (a, b) and trace element discrimination plots (c, d) of the pre-collisional granodiorites from the Garam Chashma area.

Syn-COLG, Syn-collision granites; VAG, volcanic arc granites; WPG, within plate granites; ORG, ocean ridge granites.

has been assigned to this pluton (Parrish and Tirrul, 1989). The Baltoro pluton has been lithologically divided into monzogranite and leucogranite lithofacies. These rocks are metaluminous to peraluminous ($\text{ASI} = 0.90\text{--}1.14$) and their SiO_2 range lies between 67 and 77 wt% (Searle, 1991). Some major and trace element plots of representative samples are shown in Fig. 3. Detailed compositional diagrams can be seen in Murata et al. (1999). These plots are depicting linear trends suggesting that the monzogranitic part is the least evolved one and acted as a parent magma to generate the leucogranitic part by fractional crystallization (Searle et al., 1992).

The Garam Chashma granite has a restricted SiO_2 range as compared to the Baltoro granitic rocks. It has higher Al_2O_3 , K_2O and Y contents and lower Na_2O content than the Baltoro granite (Fig. 3). We conclude that the Garam Chashma granite is different from the Baltoro granite in mineral assemblage and chemistry.

Comparison with Higher Himalayan granites

As the Garam Chashma granite is considered to be different from the post-collisional Baltoro granite of the eastern Karakoram Range in Pakistan, we attempt to compare it with post-collisional Higher Himalayan granites from Pakistan, India, Nepal and South Tibet.

The Nanga Parbat-Haramosh Massif is the westernmost extension of the Higher Himalayas in northern Pakistan (Schneider et al., 1999a). The Jutial, Tarshing and Tato plutons of the massif are tourmaline two-mica leucogranites. All three leucogranites are characterized by a restricted SiO_2 range (73–77 wt%, Table 1) and the absence of lithofacies variation. Their major element variation plots (Fig. 4) show similar trends to the Garam Chashma ones. On the basis of mineralogical and chemical data, we conclude that the Higher Himalayan granites from northern Pakistan resemble to the Garam Chashma granite.

The Miocene Higher Himalayan granitic rocks are

Figure 3. Representative major and trace elements versus SiO_2 plots of the post-collisional granitic rocks from the Asian Plate, northern Pakistan.

Figure 4. Representative major and trace elements versus SiO_2 plots of the post-collisional granitic rocks from Garam Chashma and Higher Himalayas of Pakistan, Indian, Nepal and South Tibet.

ubiquitously distributed in India, Nepal, Bhutan and South Tibet. However, only a few of them have been thoroughly studied. Also their data published are inadequate and variable. We have selected three Higher Himalayan granites that have been studied relatively in detail. These include Gangotri pluton from India (Scaillet et al., 1990), Langtang pluton from Nepal (Inger and Harris, 1993) and Shisha Pangma pluton from South Tibet (Searle et al., 1997). These plutons are composed of tourmaline two-mica leucogranites. The radiometric ages of the Gangotri pluton range from 21 to 18 Ma (Stern et al., 1989), whereas Shisha Pangma pluton yields 20–17 Ma ages (Searle et al., 1997). Their representative major elements versus SiO_2 plots (Fig. 4) depict similar trends to those of the Garam Chashma and Nanga Parbat Haramosh Massif granites. However, Fe_2O_3 contents of Gangotri granite are slightly lower than those of the Garam Chashma and other Higher Himalayan granites. The similar age, mineral assemblage and chemical trends reveal that the Garam Chashma granite resembles to Higher Himalayan leucogranites.

Conclusions

The Garam Chashma leucogranite is located in the Hindukush Range (Trans-Himalayas) on the southern margin of the Asian plate. It differs in age, mineral assemblage and chemistry from the surrounding pre-collisional granitoids (Tirich Mir, Kafiristan and Birzine) and post-collisional Baltoro granite in the eastern Karakoram Range. However, it resembles to the Higher Himalayan granites from Pakistan, India, Nepal and South Tibet. From the aforementioned data we infer that the Garam Chashma granite was probably developed from the similar source and/or processes of evolution as those of the Higher Himalayan granites. The oxygen isotopes of the Garam Chashma rocks will appear in another paper to discuss its source.

Acknowledgments

One of the authors (M. Zafar) is thankful to Ministry of Education, Japan, for providing him an opportunity to work at the Naruto University of Education. We are also indebted to Mr. S.H. Gauhar, Director General, Geological Survey of Pakistan, for his continuous support. The manuscript was improved by valuable reviews and comments of Profs. S. Arai and S. Hara-yama.

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Manuscript received; 17 March, 2000

Manuscript accepted; 30 October, 2000