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Petrogenesis of the augen gneisses from Mahesh Khola section, Central Nepal

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ABSTRACT

In Mahesh Khola section, Central Nepal the augen gneisses are exposed within the rocks of the Kulikhani Formation of the Bhimphedi Group, Kathmandu Complex. Major and trace element were analysed in this study. The gneisses show peraluminous S-type nature with high mol. A/CNK ratios. Mantle normalised trace element patterns have similar character with the Early Paleozoic S-type granite of the Lachlan Fold Belt of Australia and the Paleozoic granites of the Tso-Morari Crystalline Complex, Lakadh, India. Hence most probably the protoliths of these gneisses are the porphyritic S-type granite that intruded in the rocks of the Bhimphedi Group during Caledonian Orogeny. However the granite is sheared, deformed and metamorphosed.

INTRODUCTION

The problem of origin and age of the augen genisses that occur in the Lesser Himalaya, Nepal is the most debated topic in petrogenesis (Pechêr and Le Fort 1977; Arita 1983; Kano 1984, 2004). However, there is no controversy about the composition of these gneisses. Many detail studies have been made by several authers regarding geochemistry and geochronology of the granites of the Kathmandu Crystalline Nappe (Le Fort et al. 1981, 1983; Sharma 1982; Scharer and Allegre 1983; Sharma 1992; Le Fort and Rai 1999), but such studies of augen gneisses of the Mahesh Khola section (also known as the Sheopuri Injection Gneisses), are limited (Johnson et al. 2001). U-Pb zircon chronology of these augen gneisses revealed an age of 471±12 Ma (Johnson et al. 2001). This paper deals with the major and trace element geochemistry of the selected samples of the augen gneisses from the Mahesh Khola section to find their petrogenesis.

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The study area is located in Central Nepal Higher Himalaya (Fig. 1). The mapping from the confluence of the Mahesh Khola and the Trisuli River towards upstream was carried out (Fig. 2) and selective sampling was made.

GEOLOGICAL SETTING

The geology of the Central Nepal has been well defined by Arita et al. (1973), Stocklin (1980), Rai et al. (1998), Rai (2001), Johnson et al. (2001), Gehrels et al. (2003) and others. According to Arita et al. (1973) the augen gneisses exposed along the Mahesh Khola section belong to the Sheopuri Injection Gneiss Zone (SIGZ) that is bounded by the Trishuli-Likhu Fault in the north and the Kalpu-Dhanr Fault in the south. They described the SIGZ as a tectonic zone extending nearly east-west along the northern margin of the Kathmandu Valley from the Trisuli River to the Sunkoshi Tectonic Zone in the east. The SIGZ is terminated by the Thaple Fault in the west. The rock succession in the study area belongs to the Bhimphedi Group (Precambrian rocks) of the Kathmandu Complex, and the augen gneisses were

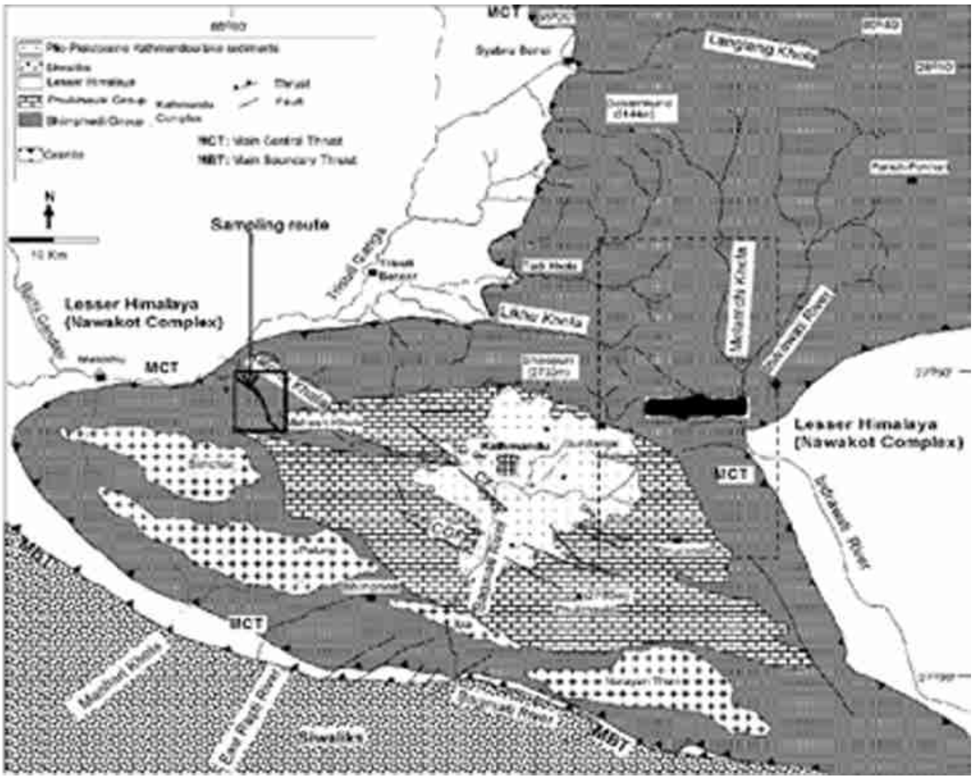

Fig. 1 Geological map of Central Nepal modified after Stocklin (1980) and location of the study route

injected in the rocks of the Kulekhani Formation. Upreti and Le Fort (1999) consider these augen gneisses as the Gosainkund Crystalline Nappe that are equivalent to the Higher Himalayan Crystallines in the north. According to Gehrels et al. (2003), the Lesser Himalayan rocks of the Central Nepal are overlain by the Higher Himalayan rocks (Formation I, II and III), the boundary being the Main Central Thrust (MCT). The Formation III consists basically of Cambro-Ordovician augen gneisses and is analogous with the Palung and related granites in the Kathmandu Nappe. They have interpreted the sill-like augen gneisses of the Formation III to be emplaced along with the Early Paleozoic Thrust. Considering the interpretation of Gehrels et al. (2003), the augen gneisses of the Mahesh Khola section are related with the Formation III gneisses (Upreti and Le Fort 1999). Similarly, according to Rai et al. (1998), the augen gneisses of the studied section belong to the SIGZ of the Kathmandu, i.e., to the MCT sheet, and are bounded to both north and south by the MCT. The location of the MCT in the vicinity of the study area is also a matter of discussion. Upreti and Le Fort (1999) consider the existence of a number of sub-MCT sheets, whereas Johnson et al. (2001) consider the basal thrust of the Kathmandu Nappe locally known as the MT ast the southern continuation of the MCT of the Higher Himalaya.

Along the Mahesh Khola route, rock successions of the Kalitar Formation, Chisapani Quartzite, Kulikhani Formation and the Markhu Formation are exposed from the NW to the SE (Fig. 2). The Kalitar Formation comprises two mica schist (sometimes with sillimanite) and micaceous quartzite with bands of amphibolite. The Chisapani Quartzite comprises thin to thick bedded white quartzites. The Kulikhani Formation consists of garnetiferous schist and green-grey to light green micaceous quartzite. The Markhu Formation is characterised by dark grey biotite schist and quartzites with bands of marble and actinolite schists. In this formation a kyanite-bearing pegmatite

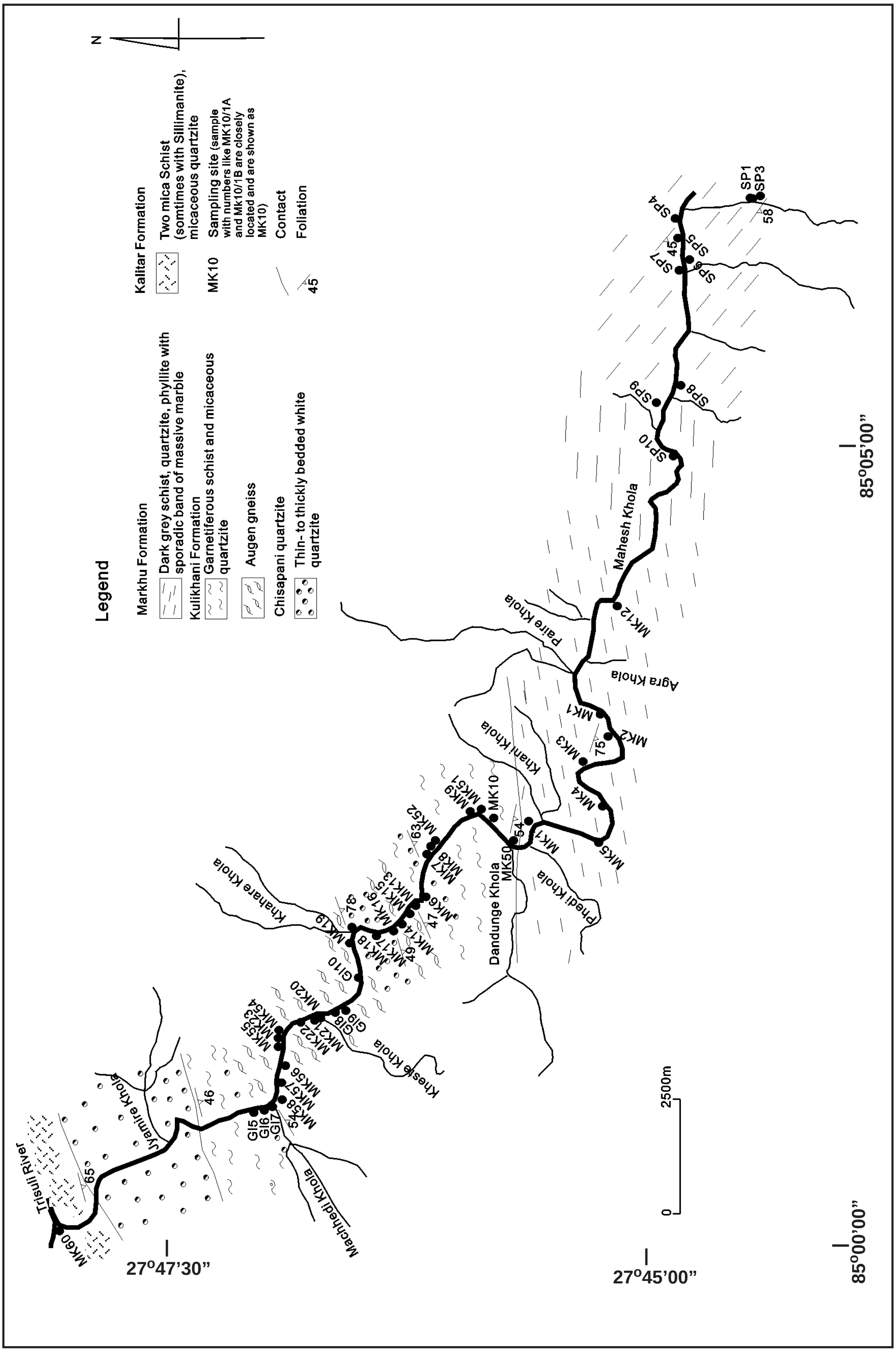

Fig. 2 Route map along the Mahesh Khola with simpling site

having discordant relationship with the schistocity was observed in location Sp7. The augen gneisses were intruded in the rocks of the Kulikhani Formation. The augen gneisses had concordant relationship with country rocks and were seen like sills.

PETROGRAPHY OF AUGEN GNEISSES

The augen gneisses in the study route are light grey. Many tourmaline bearing pegmatites and quartz veins, both concordant and discordant with folication of the gneisses are present. Plagioclase, K-feldspar, quartz, muscovite and biotite were the major constituents of these gneisses, whereas sphene, tourmaline, apatite, zircon, monazite, opaque mineral, and garnet were the accessory minerals. Staurolite with penetrating twinning was observed in MK 23. K-feldspar was mainly orthoclase with minor perthitic and myrmekitic intergrowths that were spradically sericitized, and frequently includes muscovite, biotite and quartz. Augens upto 40 mm in diameter were represented by K-feldspars.

GEOCHEMISTY OF AUGEN GNEISSES

Major and trace elements from the 17 selected rock samples (Table 1) were analysed using Philips PW1404 X-ray fluorescence spectrometer with Rh side-window tube at the geochemical laboratory of Hokkaido University, Japan in 1999. The details of analytical method, accuracy and precision of analysis are given in Tanaka and Orihashi (1995). Analytical error of the instrument is ±0.2% for the major elements and ±5% for trace elements. Two or more chips of rock samples, cut normal to foliation were powdered and used for analysis. Powder of the rock samples was heated upto 1000^{o}C for 3 hours to determine the ignition loss, which was found to be less than 1 wt%, and was discarded from further consideration.

The variation in SiO_2 content was from 65.13 to 73.7 wt%, whereas the total alkali content ranged from 6.14 to 8.04 wt%. The gneisses had high K_2O content with K_2O/Na_2O ratios exceeding 1 except for the samples MK23/1A, MK23/1B and MK18/1A. These samples had higher molar A/CNK ratio (where, A = Al_2O_3, C = CaO, N = Na_2O, K = K_2O) indicating their peraluminous nature (Fig. 3).

Most of the major elements such as Al_2O_3, TiO_2, Fe_2O_3, MnO and MgO had negative correlation with SiO_2 (Fig. 4). Very poor correlation existed between SiO_2 and K_2O, Na_2O, CaO or P_2O_5. These trends are controlled by crystallisation of the major rock forming minerals, particularly Kf + Pl + Bt ± Ms assemblage.

The gneisses had high Rb and low Sr contents (Table 1). Correlation patterns of selected trace elements with Zr are shown in Fig. 5 to check fractionation of Kf + Pl + Bt ± Ms assemblage. Rb content decreases with increasing Zr. Positive correlations are shown by Nb, Sr, Ba, La and Ni with Zr. Zr has poor correlation with Y, Th, Ga and Zn.

DISCUSSIONS

The augen gneisses mostly plot in monzogranite field (Fig. 6), except one sample that plots in granodiorite field based on granitoid classification of Streckeisen (1976). These gneisses exhibit narrow range of SiO_2/Al_2O_3 ratio which supports partial melting. There was no metasomatism and solid-state segregation which would have otherwise yield variable ratio. The role of partial melting is also supported by the presence of migmatites that are abundant in the study area.

Zr which is the most immobile element decreases with SiO_2. Decrease of Rb and Zr, and increase of Nb, Sr, La, Ni and Ba with SiO_2 content are controlled

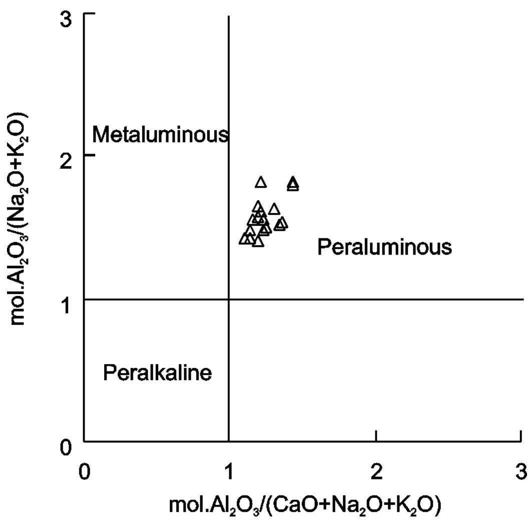

Fig. 3 Shand's (1946) Index of the augen gneisses from the Mahesh Khola section

Table 1: Major (wt %) and trace (ppm) elements of the augen gneisses from the Mahesh Khola section

Sample Name	*Mk16/1A*	*Mk22/1B*	*Mk20/1A*	*Mk23/1A*	*Mk23/1B*	*Mk18/1A*	*Mk15/1A*	*Mk15/1B*	*Mk22/1A*	*Mk19/1A*	*Mk54/3A*	*MK16/1B*	*MK54/3B*	*MK20/1B*	*MK19/1B*	*99112401Z*	*99122601Z*
Major elements (wt%)																	
SiO_2	71.90	70.32	71.15	69.80	69.87	70.94	73.71	73.36	70.53	72.95	68.55	71.88	68.05	70.72	72.75	69.39	65.13
Al_2O_3	13.49	13.48	15.74	13.52	13.30	13.75	13.53	13.53	13.52	13.10	14.49	13.41	14.87	16.14	13.07	14.09	16.46
TiO_2	0.61	0.78	0.39	0.90	0.92	0.54	0.45	0.04	0.78	0.61	0.92	0.91	0.91	0.39	0.58	0.91	0.86
Fe_2O_3	3.90	4.72	2.47	5.79	5.79	3.62	2.96	2.96	4.78	3.74	5.78	3.90	5.90	2.53	3.07	5.47	5.60
MnO	0.06	0.07	0.04	0.07	0.07	0.06	0.04	0.04	0.07	0.05	0.09	0.09	0.09	0.04	0.05	0.09	0.08
CaO	1.75	1.71	0.91	1.17	1.15	1.74	1.14	1.14	1.66	1.60	1.25	1.29	1.29	0.91	1.59	1.50	2.64
K_2O	3.51	3.77	5.26	2.93	2.92	3.42	4.65	4.65	3.84	3.71	3.73	3.79	3.79	5.36	3.73	2.60	4.03
MgO	1.58	1.82	0.89	1.81	1.82	1.28	1.16	1.16	1.86	1.47	2.15	2.17	2.17	0.92	1.46	1.70	2.59
Na_2O	2.92	2.64	2.76	3.49	3.45	3.51	2.70	2.70	2.51	2.87	2.41	2.43	2.43	2.79	2.85	4.21	2.80
P_2O_5	0.17	0.20	0.19	0.21	0.21	0.20	0.23	0.23	0.20	0.19	0.18	0.20	0.20	0.17	0.18	0.17	0.16
Total	99.89	99.50	99.78	99.68	99.49	99.04	100.54	99.80	99.74	100.29	99.55	100.07	99.70	99.97	99.32	100.13	100.33
Trace elements (ppm)																	
Nb	13	16	18	16	17	13	15	13	16	15	13	17	12	13	17	15	7
Zr	206	240	155	248	247	197	189	183	263	197	213	373	151	204	279	231	263
Y	37	49	42	48	47	38	50	51	48	36	37	49	39	37	48	36	27
Sr	60	68	64	48	56	52	55	47	70	65	61	71	51	57	81	340	44
Rb	223	226	309	271	268	240	261	267	229	224	222	235	318	226	157	213	107
Th	18	24	19	26	21	19	21	24	22	17	18	33	24	18	27	27	13
Pb	20	16	34	11	8	25	24	24	16	22	22	10	32	23	10	25	6
Ga	16	18	18	15	17	17	14	14	19	17	16	18	18	16	17	22	10
Zn	46	45	32	19	19	46	40	41	44	43	46	54	31	44	40	65	15
Cu	4	17	2	4	6	12	4	3	20	6	1	nd	2	5	5	4	8
Ni	18	22	8	32	28	13	14	12	23	14	18	31	10	15	28	32	22
Co	8	14	5	13	12	6	6	7	14	9	9	14	5	12	13	20	12
Cr	37	46	20	62	64	30	27	29	49	35	38	66	21	34	64	72	57
Ce	58	88	60	116	113	66	71	64	76	65	64	121	53	58	103	100	60
V	71	73	37	72	72	55	45	45	90	67	68	94	35	69	88	101	69
La	30	46	25	52	54	18	36	37	36	17	25	58	24	27	43	52	28
Ba	364	517	421	302	294	320	358	374	518	404	365	596	417	387	473	1037	318
Sc	10	11		12	12	9	6	8	11	6	10	10	6	9	13	14	11
Rb/Sr	3.70	3.30	4.83	5.65	4.78	4.58	4.79	5.65	3.26	3.47	3.63	3.28	6.29	3.96	1.93	0.63	2
K/Na	1.20	1.43	1.91	0.84	0.84	0.97	1.72	1.72	1.53	1.30	1.55	1.56	1.56	1.92	1.31	0.62	1.44
mol. A/CNK	1.14	1.17	1.32	1.23	1.22	1.09	1.17	1.17	1.20	1.13	1.41	1.28	1.43	1.34	1.13	1.13	1.20
Si/Al	5.33	5.22	4.52	5.16	5.26	5.16	5.45	5.42	5.22	5.57	4.73	5.36	4.58	4.38	5.57	4.92	4.01

by crystallisation of Kf + Pl + Bt ± Ms assemblage.

In the alkali versus ferromagnesian and alumina versus ferromagnesian plots (Fig. 7), the gneisses showed very similar trends to that of peraluminous S-type granites after Patino Douce (1999). Primordial mantle normalised trace elements patters (normalizing values are after McDonough et al. 1992) show that the gneisses are depleted in Ba, Nb, Sr and Ti (Fig. 8a) which matches well with the Paleozoic S-type granites (Fig. 8b) of the Tso-Murari Complex, Ladakh, India (Islam et al. 2006), and the Lachlan Fold Belt of Australia (Wyborn et al. 1992). Besides, the U-Pb zircon chronology of the augen gneisses has magmatic age of nearly 470 Ma, and U-Pb monazite chronology from pegmatites is 21.5 ± 0.5 Ma (Johnson et al. 2001). It is inferred that the magmatic age of nearly 470 Ma was the time time of emplacement of the protolith of augen gneisses (porphyritic granite) and age of ~21 Ma of pegmatites is the time of deformation and metamorphism of the granites into the augen gneisses. The augen gneisses have concordant relationships with the country rocks and are also not much thick. Hence, the protolith of the augen gneisses were most probably injected into the rocks of the Kulikhani Formation as a sill. Considering their exposed position and relationship with associated

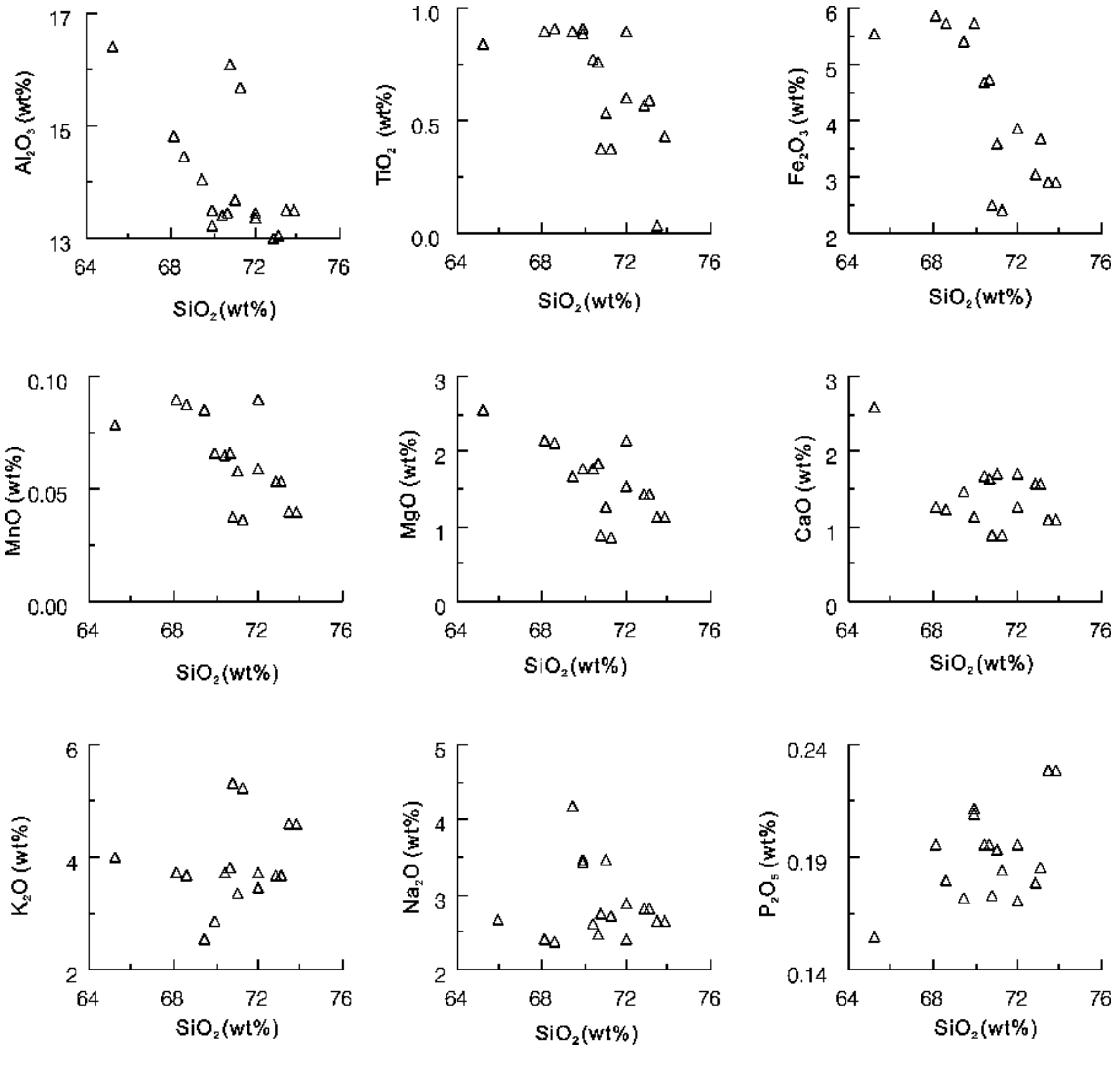

Fig. 4 Harker's variation diagram of the augen gneisses from the Mahesh Khola section

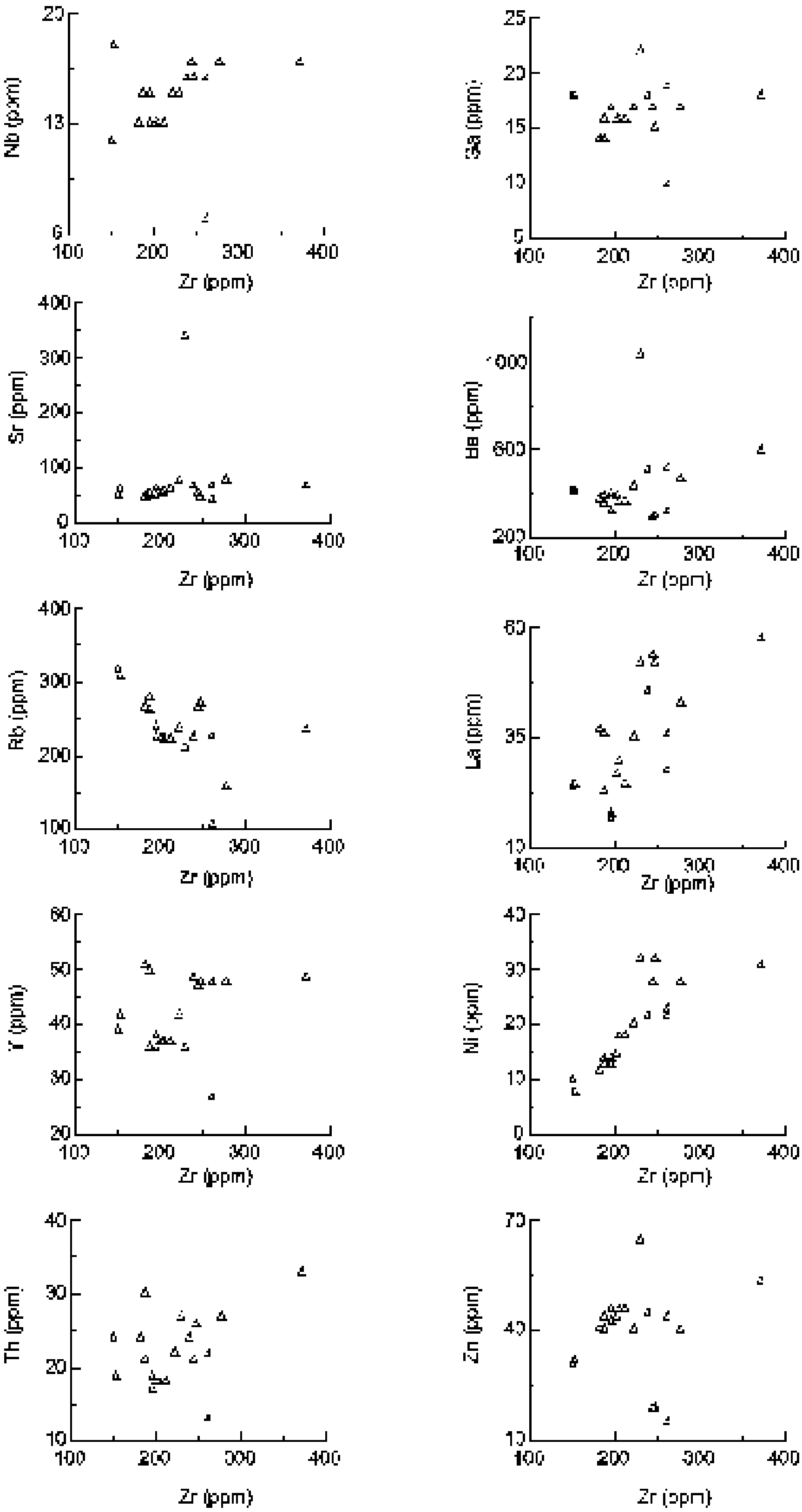

Fig. 5 Zircon versus selected trace elements of the augen gneisses from the Mahesh Khola section

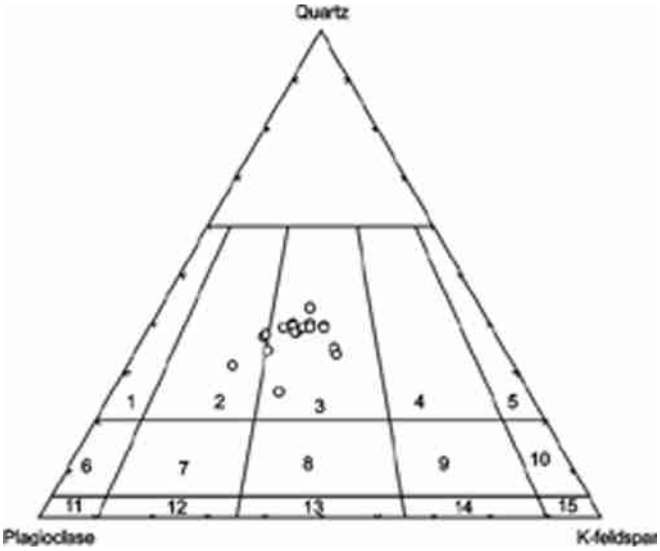

Fig. 6 The augen gneisses from the Mahesh Khola section plotted on the granitoid classification diagram of Streckeisen (1976). Th compositional fields are: 1-Tonalite, 2-Granodiorite, 3-Monzogranite, 4-Syenogranite, 5-Alkali Feldspar Granite, 6-Quartz Diorite, 7-Quartz Monzodiorite, 8-Quartz Monzonite, 9-Quartz Syenite, 10-Quartz Alkali Feldspar Granite, 11-Gabbro, Diorite and Anorthosite, 12-Monzodiorite, 13-Monzonite, 14-Syenite, and 15-Alkali Feldspar Syenite

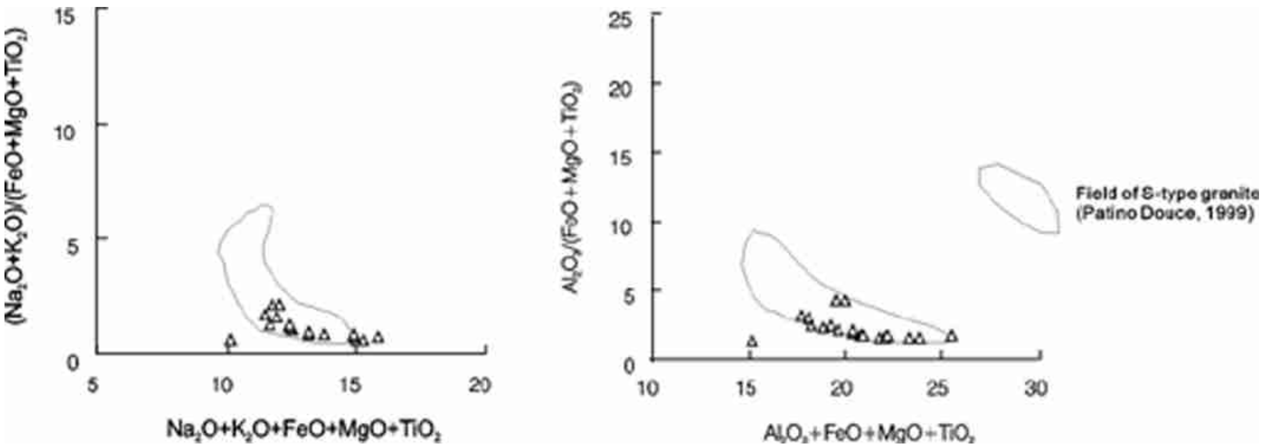

Fig. 7 Plots of alkalis versus ferromagnesian and alumina versus ferromagnesian compenents of the augen gneisses from the Mahesh Khola section

rocks, the protoliths of the augen gneisses are interpreted to be the Paleozoic porphyritic granites which were sheared and metamorphosed during Tertiary. As these rocks show peraluminous S-type nature, the protoliths must be the products of melting of crustal rocks. Quartzo-feldspathic material sturated with alumina can be potential source for the protoliths.

CONCLUSIONS

The protoliths of the augen gneisses must be originated from melting of crustal rocks, as the augen gneiss show peraluminous S-type nature. The primordial mantle normalised trace element pattern of studied augen gneisses is very similar with the

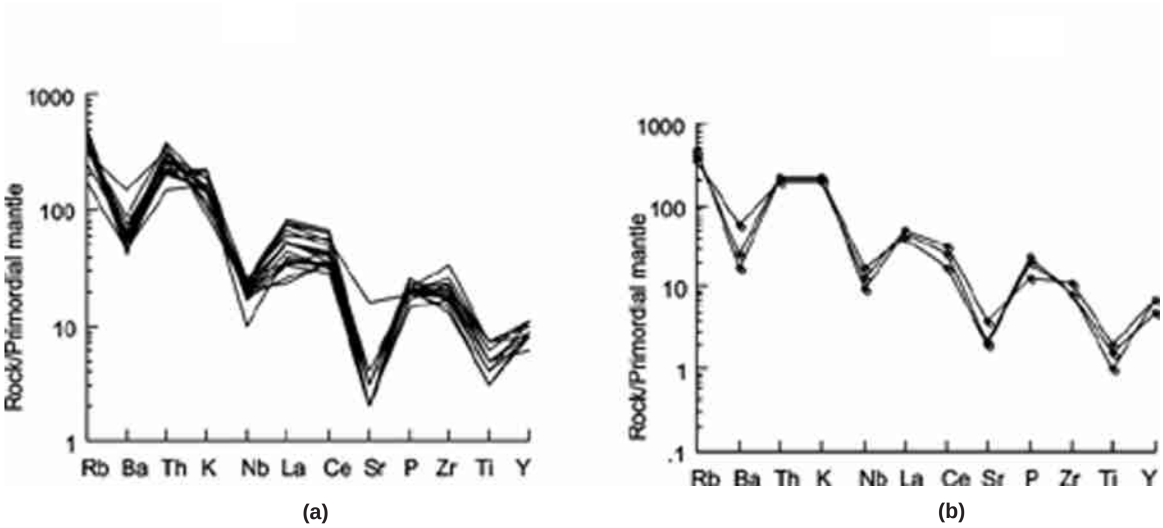

Fig. 8 Multi-element spider diagrams (a) Augen gneisses from the Mahesh Khola section (normalising values are after McDOnough et al. 1992) and (b) Paleozoic S-type granites from the Tso-Morari Crystalline Complex, Ladakh, India (data after Islam et al. 2006)

pattern of the Paleozoic granites from Tso-Morari Complex, Ladakh, India, and Lachlan Fold Belt of Australia. Hence the augen gneisses are interpreted to be deformed porphyritic granitic intrusive (sill) which intruded in the rocks of the Kathmandu Complex during Caledonian Orogeny.

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