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Distribution of boron in the rocks of central Nepal Himalaya

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ABSTRACT

Boron content in the rocks of central Nepal Himalaya depends upon the lithology and the grade of metamorphism. The concentration of boron is abundant (up to 322 ppm) in the metasedimentary rocks of the Lesser Himalaya. There seems to be a rather good correlation between the boron content in the rocks and the grade of metamorphism. The boron content progressively increases from chlorite to garnet isograds, then it systematically decreases in the staurolite±kyanite, kyanite and sillimanite isograds, respectively. This trend may be related to the inverse metamorphism associated with movement along the Main Central Thrust.

The Manaslu leucogranite contains very high amount of boron (950 ppm). The enrichment of boron in this rock may be due to the release of boron from the Lesser Himalayan rocks during the partial melting of the Higher Himalayan Crystallines (Tibetan Slab) as a result of the movement along the MCT. Tourmaline from the Manaslu Granite is also highly rich in boron (8460 ppm).

INTRODUCTION

Boron is a lithophile element concentrated in minerals, mainly in danburite [Ca (B_2SiO_8)], datolite [Ca(OH)$BSiO_4$], tourmaline [(Na,Fe,Al,Li)$Al_6B_3SiO_6O_{27}$], axinite [Ca_2(Mn,Fe)Al_2(BO_3)(Si_4O_{12})(OH)]. The abundance of boron is found mostly in marine sediments, argillaceous schist (100-310 ppm) or argillaceous minerals (illite: 400-600 ppm) (Lardrgren 1945, Reynold 1965, Spears 1965, Etheir and Compbell 1977). During the process of chemical weathering, liberation of boron increases and its amount is concentrated within the argillaceous minerals (Spears 1965). The low-grade metamorphic rocks derived from the argillaceous sediments release some amount of boron during metamorphism. In contrast, higher amount of boron is released during the process of high-grade metamorphism (Harder 1975). During the gradual increase in pressure and temperature and activity of fluids related to the regional metamorphism, boron is released and tourmaline mineral is crystallized (Reynold 1965). The crystallization of tourmaline in magmatic rocks is controlled by several factors such as boron content in the magma, pressure, temperature, fugicity and composition of Al, Fe, Mg, Mn, etc (Bernard et al. 1985).

The Miocene leucogranites of the Himalaya are formed due to partial melting of the pelitic rocks of the hot Higher Himalayn Crystallines (Tibetan slab). A large amount of fluids mainly consisting of B, F, CO_2, H_2O were released from the cold Lesser Himalayan rocks during the thrusting along the MCT and partial melting of the Higher Himalayan Crystallines (France-Lanord and Le Fort 1988).

GEOLOGICAL SETTING

The study area is located in between the longitudes 83°30' to 85°30'E and latitudes 27°5' to 29°00'N (Fig. 1). The area tectonically belongs to the Lesser Himalaya (LH), Higher Himalaya (HH) or Tibetan Slab and Tibetan-Tethys Himalaya (TSH) of central Nepal (Fig. 2). The Miocene Manaslu leucogranite intruding the metasediments of the Tibetan-Tethys Sedimentary Series is also included in this study.

Lesser Himalaya

The unmetamorphosed and greenschist to lower amphibolite facies metamorphic rocks of the Lesser Himalaya is bordered by the Main Boundary Thrust (MBT) in the south and the Main Central Thrust (MCT) in the north. This unit is divided into the Lower Lesser Himalaya and the Upper

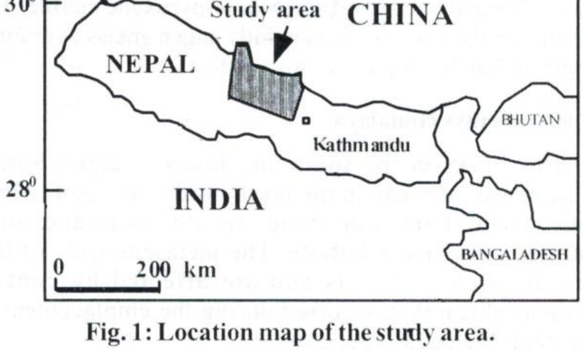

Fig. 1: Location map of the study area.

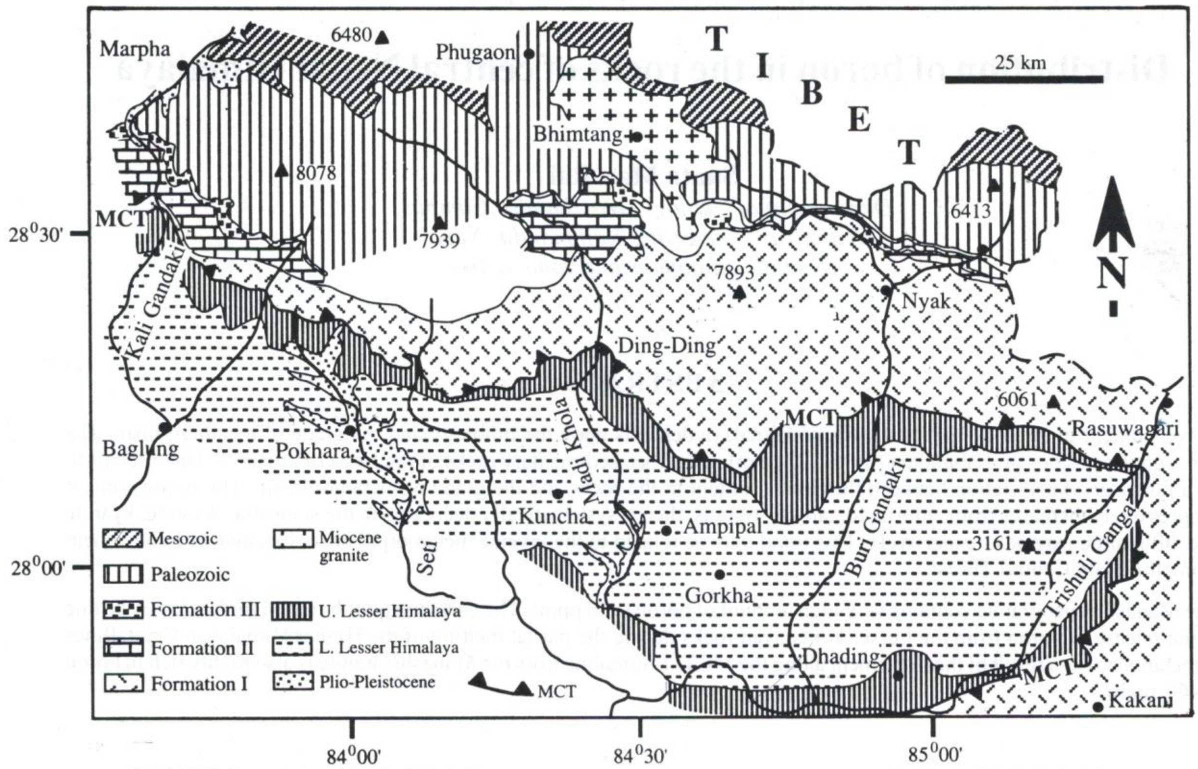

Fig. 2: Geological map of the central Nepal Himalaya (after Colchen et al. 1980, 1986; Rai 2001). Paleozoic-Mesozoic: Tibetan-Tethys Himalaya, Formation I-III: Higher Himalaya and MCT: Main Central Thrust.

Lesser Himalaya (Le Fort 1975): The Lower Lesser Himalaya consists of the homogenous and thick sequence of phyllite, schist, greywacke and metasandstone, while the Upper Lesser Himalaya comprises mainly of slate, phyllite, schist, metasandstone, quartzite, carbonate rocks and Ulleri-type augen gneiss.

Higher Himalaya (Tibetan Slab)

This unit tectonically lies in between the MCT in the south and South Tibetan Detachment System (STDS) in the north. It consists of 10-12 km thick succession of amphibolite to granulite facies metamorphic rocks. From bottom to top, it is divided into three formations: Formation I, Formation II and Formation III (Le Fort 1975). The Formation I consists of mainly pelitic gneiss. The Formation II consists of calcic gneiss, banded gneiss and amphibole-pyroxene marble. The Formation III consists of essentially augen gneiss of granitic origin and minor amount of mica schist.

Tibetan-Tethys Himalaya

The STDS in the south and Indus Tsangpo Suture Zone beyond the map in the north border this unit, which consists of shale, limestone, spilite, metasandstone, marble, schist and quartzite. The metasediments of this unit are rich in fossils and are affected by contact metamorphism that occurred during the emplacement of Miocene Manaslu leucogranite.

Manaslu Leucogranite

This granite outcrops over an area of about 400 km^2. It is elongated in a NW-SE direction with a length of about 30 km and 13 km in width. The mineral assemblages of this granite are quartz, Na-rich plagioclase, K-feldspar, muscovite and biotite. This granite is usually tourmaline rich. This leucogranite was generated in response to thickening of the crust (Le Fort 1975, 1981) after the collision between the Indian and Eurasian plates around 50 Ma. Rb/Sr and U/Pb data suggest that a crystallization age of this granite ranges from 25 to 18 Ma (Daniel et al. 1987), whereas 40Ar/39Ar suggests a shorter time of emplacement and cooling, around 20 Ma (Copeland et al. 1990).

METAMORPHISM

The appearance of chlorite, biotite, garnet, staurolite±kyanite from lower to higher sections of the Lesser Himalaya records the inverted metamorphic evolution during the MCT movement (Le Fort 1975, Hodges et al. 1996). The retrograde metamorphism on the base of the Higher Himalayan Crystallines due to rapid cooling by conduction and the progressive increase of metamorphic grade in the Lesser Himalaya towards MCT correspond to the MCT movement (Pecher 1978, Pecher and Le Fort 1986). The rapid cooling and decrease in pressure due to tectonic denudation along the STDS resulted in the retrograde metamorphism in the upper section of the Higher Himalaya. The grade of the metamorphism decreases from the base to the top of the Tibetan-Tethys Sedimentary Series.

BORON DISTRIBUTION

The boron, which is an indicator of the circulation of fluids, played an important role during the Himalayan orogeny. The amount of boron was measured in the different rocks from different tectonic units by gamma prompt method. 12 samples from the Lesser Himalaya, 16 samples from the Higher Himalayan Crystallines, 11 samples from the Tibetan-Tethys Sedimentary Series and 22 samples from the Manaslu leucogranites were used for the measurement of boron content. The boron content varies from 1 ppm to more than 300 ppm even in the same formation. The higher amount of boron (maximum 322 ppm) is found to be concentrated in the Upper Lesser Himalayan rocks. In Manaslu leucogranite the boron content ranges from 12 ppm (sample U470) to 951 ppm (sample DK 028). The distribution of boron with reference to lithology of different formations from different tectonic units is summarized below (Tables 1 and 2).

The boron content in schist of the Lower Lesser Himalaya varies from 18 ppm (sample L 81) to 127 ppm (sample L 82) (Table 1). The conglomeritic metasandstone (243 ppm) contains higher amount of boron than in the pure metasandstone (18 ppm). In the Upper Lesser Himalaya, the boron content in the carbonaceous schist varies according to degree of metamorphism. The rocks from chlorite isograd contains 53 ppm, garnet isograd (301 ppm) and kyanite isograd (107-171 ppm). The schist of the Upper Lesser Himalaya contains higher amount of boron than the schist of the Lower Lesser Himalaya. This variation in boron content depends on composition of the various types of schists (i.e., calcic, pelitic or carbonaceous). The highest concentration of boron is found in yellow dolomite (322 ppm).

The pelitic gneiss of Formation I of the Higher Himalaya contains very low amount of boron (3-16 ppm) (Table 1). The marble of Formation II has also very low boron content (3-17 ppm). The pure marble contains lower amount of boron than that of the impure marble. The augen gneiss of Formation III has also low boron content (7-17 ppm).

In the Tibetan-Tethys Sedimentary Series, the boron content varies from 7 ppm (pyroxene-marble) to 157 ppm (siliceous marble) (Table 1). Whereas the boron content in the Manaslu leucogranite ranges from 13 ppm to 951 ppm (Table 2).

METAMORPHISM VS. BORON DISTRIBUTION

In the Lesser Himalaya, there seems to be a rather good correlation between the boron content and the grade of metamorphism (Fig. 3). The boron content seems to progressively increase from chlorite isograd (17.57 ppm) to garnet isograd (322 ppm) (Table 1), then it decreases in the kyanite ± staurolite isograd (83 ppm) of the Upper Lesser Himalaya and it continues to decrease in the kyanite isograd (8.3 ppm) and sillimanite isograd (3.18 ppm) in the Formation I of the Tibetan Slab (Fig. 3). This distribution of boron could be related to the inverse metamorphism, related to Main Central Thrust movement. During the low-medium grade metamorphism (chlorite to garnet isogrds) the boron is accumulated by the replacement of aluminum and the aluminum could inversely replace the boron during the high grade metamorphism (kyanite and sillimanite isograds) resulting the low boron content. This distribution shows that the boron bearing minerals, e.g. tourmaline will be destabilized from the certain degree of metamorphism (620-650 °C) with increasing temperature and the liberation of boron occurrs mixing with the fluids of rocks (Sisson et al. 1988). In the Tibetan slab, the boron might have liberated and moved with other fluids to the higher structural section resulting in the lower amount of boron.

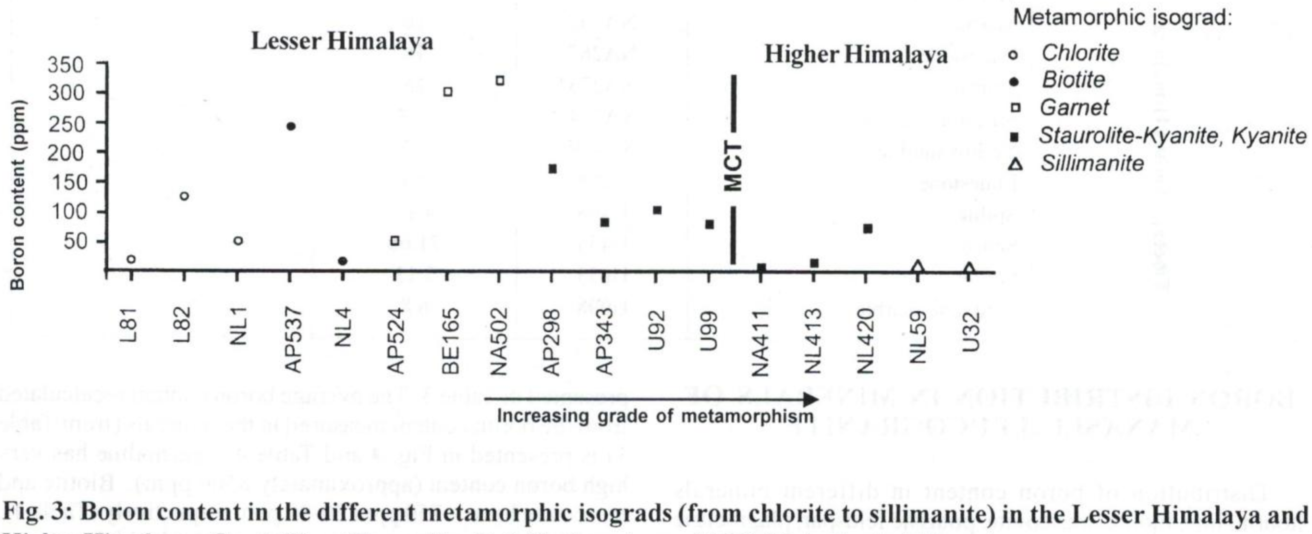

Fig. 3: Boron content in the different metamorphic isograds (from chlorite to sillimanite) in the Lesser Himalaya and Higher Himalayan Crystallines (Formation I). L81: Sample no., MCT: Main Central Thrust.

Table 1: Boron content (in ppm) in different rocks belonging to different tectonic units of central Nepal Himalaya

Tectonic unit		Lithology	Sample No.	Boron (ppm)	Metamorphic isograd
Lesser Himalaya	Lower Lesser Himalaya	Greywacke	L81	17.57	Chlorite
		Schist	L82	127	Chlorite
		Carbonaceous schist	NL1	52.81	Chlorite
		Conglomeritic greywacke	AP537	242.86	Biotite
		Schist	NL4	18.25	Biotite
		Schist	AP524	51.51	Garnet
	Upper Lesser Himalaya	Carbonaceous schist	BE165	301	Garnet
		Yellow dolomite	NA502	322	Garnet
		Carbonaceous schist	AP298	170.8	Kyanite
		Schist	AP343	84.57	Staurolite + Kyanite
		Carbonaceous schist	U92	107	Kyanite
		2Mica-Garnet-Stouralite schist	U99	83	Staurolite-Kyanite
Higher Himalaya (Tibetan Slab)	Formation I	2Mica-Kyanite gneiss	NA411	8.3	Kyanite
		Kyanite-gneiss	NL413	15.1	Kyanite
		Kyanite – banded gneiss	NL420	77	Kyanite
		Sillimanite-gneiss	NL59	4.6	Sillimanite
		Sillimanite – gneiss	U32	3.18	Sillimanite
	Formation II	Marble	D5	12	
		Marble	D87	11	
		Pyroxene-marble	NA132	17	
		Pure marble	NA141	3.9	
		Phlogopite marble	NA142	6.4	
		Muscovite-Pyroxene-marble	NA143	7.3	
		Pure marble	NA146	3	
		Graphitic marble	NA148	14	
	Formation III	Augen gneiss	D77	17	
		Augen gneiss	NL478	11.9	
		Augen gneiss	U925	6.9	
Tibetan -Tethys Himalaya		Spilite	N4	1.3	
		Marble	NA162	16	
		Limestone	NA267	16	
		Marble	NA273	15	
		Siliceous marble	NA274	157	
		Yellow marble	NL449	17	
		Limestone	U258	56	
		Spilite	U408	4.13	
		Schist	U453	71.66	
		Spilite	U653	3.13	
		Pyroxene-marble	U998	6.8	

BORON DISTRIBUTION IN MINERALS OF MANASLU LEUCOGRANITE

Distribution of boron content in different minerals (tourmaline, biotite, muscovite, potassic feldspar, plagioclase and quartz) from ten samples of the Manaslu leucogranite is presented in Table 3. The average boron content recalculated from the boron content measured in the minerals (from Table 3) is presented in Fig. 4 and Table 4. Tourmaline has very high boron content (approximately 8500 ppm). Biotite and muscovite have < 750 ppm 70-80 ppm respectively (Table 4). As biotite contains tourmaline inclusions, the high value of

Table 2: Boron content (ppm) from the Manaslu leucogranite

Granite	Sample No.	ppm
Higher Himalayan Granite (Manaslu leucogranite)	D16	60
	D22	120
	DK157	34
	DK195	103.1
	DK28	951
	DK43	100
	DK45	43
	DK53	16.6
	DK54	32.5
	DK59	20.9
	T17	160
	U172	820
	U277	30
	U330	820
	U464	390
	U476	13
	U476A	15.3
	U476B	15.2
	U697	663.7
	U743	248
	X12	131
	X77	300

boron is expected. Muscovite generally contains low amount of boron (Harder 1975, Reynold 1965). Potash feldspar, plagioclase and quartz have also very low concentration of boron (< 10 ppm) (Table 4).

The Manaslu leucogranite is believed to have formed due to the partial melting of the pelitic rocks of the hot Higher Himalayan Crystallines (France-Lanord and Le Fort 1988). The boron has probably played an important role during the anatexis process (Le Fort 1987). The boron content of the Manaslu granite is very high as compared to Clarke value (30 ppm) for granite (Harder 1975).

Table 3: Boron content (ppm) from different minerals of the Manaslu leucogranite

Sample No.	Mineral	ppm
D22	Muscovite	59.7
D65	Muscovite	48.6
DK28	Potassic feldspar	12.9
DK28	Muscovite	142.7
DK28	Plagioclase	6.6
DK28	Plagioclase+Quartz	10.6
DK28	Tourmaline	8229.4
U315	Potassic feldspar	3.4
U315	Muscovite	72.2
U315	Quartz	2.3
U476	Biotite	21.4
U476	Potassic feldspar	10.7
U476	Muscovite	76.4
U476	Plagioclase	10.1
U697	Biotite	456.3
U697	Muscovite	91.7
U697	Tourmaline	8488.2
U743	Biotite	94.1
U743	Muscovite	85.1
U743	Tourmaline	8662.6
X10	Muscovite	59.1
X12	Biotite	2781.4
X77	Biotite	359.2
X77	Potassic feldspar	11.1
X77	Muscovite	75.2
X77	Plagioclase + Quartz	9.6
X77	Quartz	9

CONCLUSIONS

Boron distribution in formations of different tectonic units of the central Nepal Himalaya is variable. It is found to depend upon the lithology and the grade of metamorphism. The variation in lithology can control the distribution of boron, but their distribution manner is unsystematic. The concentration of boron is higher in the rocks of the Lesser Himalaya. In the Lesser Himalaya, there seems to be a rather

Table 4: Average boron content (ppm) of different minerals recalculated from Table 3

Mineral	(ppm)
Quartz	5.65
Potassic feldspar	8.35
Plagioclase	9.5
Plagioclase+Quartz	10.1
Muscovite	78.97
Biotite	742.48
Tourmaline	8460.07

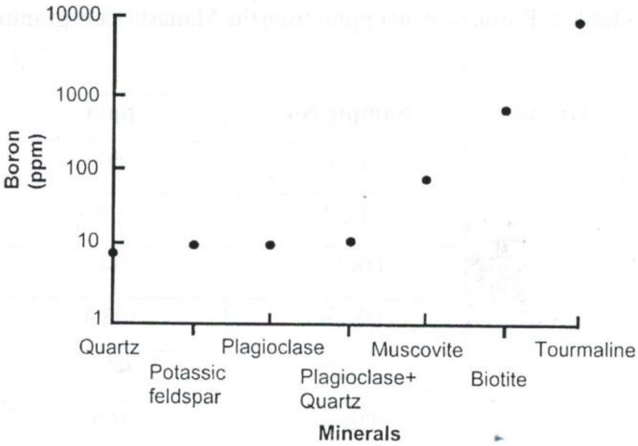

Fig. 4: Average Boron content of different minerals in Manaslu Granite (from Table 3)

good correlation between the boron content and the grade of metamorphism. The boron content systematically increases from chlorite to garnet isograds, then it starts decreasing in the staurolite± kyanite isograd of the Upper Lesser Himalaya and continues to decrease in the kyanite and sillimanite isograds in the Formation I of the Higher Himalayan Crystallines. This distribution of boron could be related to the inverse metamorphism, related to the Main Central Thrust movement.

The enrichment of boron in Manaslu leucogranite might have occurred due to the release of boron from the Lesser Himalayan rocks during the partial melting of the Higher Himalayan Crystallines (Tibetan Slab) as a result of the movement along the MCT.

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