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Tourmaline chemistry in the Miocene and Paleozoic granites, Central Nepal Himalaya

Santa Man Rai
Department of Geology, Tribhuvan University,
Tri-Chandra Campus, Ghantaghar, Kathmandu, Nepal
(E-mail: santamanrai@yahoo.com)

ABSTRACT

Tourmalines are found in almost all the formations, from the Lesser Himalaya to the Tibetan-Tethys Himalaya. They are equally found in the Miocene and Paleozoic granites in Central Nepal. Aplite-pegmatite dykes and Miocene granite from the Higher Himalaya, Tibetan-Tethys Himalaya also contain the tourmaline.

The chemical composition of tourmalines from the Miocene granite, Paleozoic granite, and aplite-pegmatites is presented in schorlite (Fe)-dravite (Mg)-elbaite (Al) diagram. The tourmalines from the granites are schorlitic (rich in Fe) in composition. No compositional variation between rim and core of the tourmaline in augen gneiss of the Formation III of the Higher Himalaya could correspond to the recrystallization of the tourmaline during the Himalayan metamorphism. The tourmalines from Manaslu and Chhokang granites can be evolved from Mg rich composition in higher temperature towards the Fe rich in lower temperature during the crystallization reflected by the XFe variation. Similarly, the composition of tourmalines is found to evolve from dravite (Mg rich) in the aplite-pegmatite dykes of the Higher Himalaya to schorlite (Fe rich) and elbaite (Al) in the aplite-pegmatite dykes of the Annapurna Formation of the Tibetan-Tethys Himalaya and Manaslu granite.

The aplite-pegmatite dykes intruded into the pelitic rocks contain Mg rich tourmalines while Fe rich tourmalines are found in calcareous host rocks. So, the composition of the tourmalines of aplite-pegmatites can not be controlled by the composition of host rocks, but it is indirectly controlled by the composition of fluid phase of magma.

INTRODUCTION

The rocks of Himalayan range is known for the wide occurrence of tourmaline. It is found in almost all the formations of the central Nepal, from the Lesser Himalaya to the Tibetan-Tethys Himalaya, and granites and the aplite-pegmatitic veins. The fluids have played an important role during the movement along the Main Central Thrust (MCT) and in the evolution of the Miocene leucogranite. The wider distribution of boron (tourmalines) in the central Nepal Himalaya is the indicator of the circulation of the fluids and show distinctively sensitiveness to the physico - chemical constraints of the Himalayan orogeny (Rai 1993, 2003; Rai and Le Fort 1993, 2002). The study of circulation of the fluids in the central Nepal Himalaya has been undertaken by only a few workers applying different methods (Pêcher 1979; Le Fort 1981; France-Lanord 1987; Brouand 1989; Guillot 1993; Rai 1993, 2003; Rai and Le Fort, 1993, 2002).

The study area of central Nepal Himalaya is located between the longitudes 83°30' and 85°30'E and latitudes 27°50' and 29°00'N (Fig. 1a). The main objectives of this study are to know the trend of distribution and chemistry of tourmalines in the granites and aplite-pegmatite dykes in the central Nepal Himalaya.

GEOLOGICAL SETTING

The study area tectonically belongs to the Lesser Himalaya, Higher Himalaya and Tibetan - Tethys Himalaya (Figs. 1a and b).

Lesser Himalaya

The Lesser Himalaya is bounded by the Main Boundary Thrust (MBT) in the south and the Main Central Thrust (MCT) in the north. This unit consists of slate, phyllite, schist, metasandstone, carbonate rocks and Ulleri - type augen gneiss and minor amount of pelitic gneiss in the

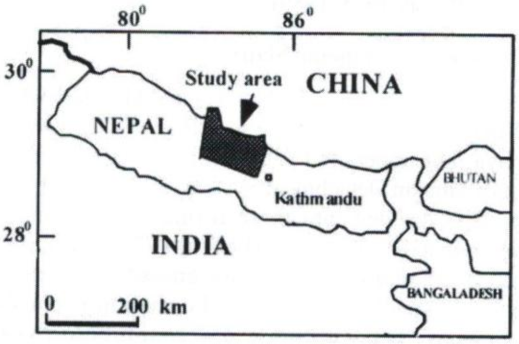

Fig. 1a: Location map of the study area

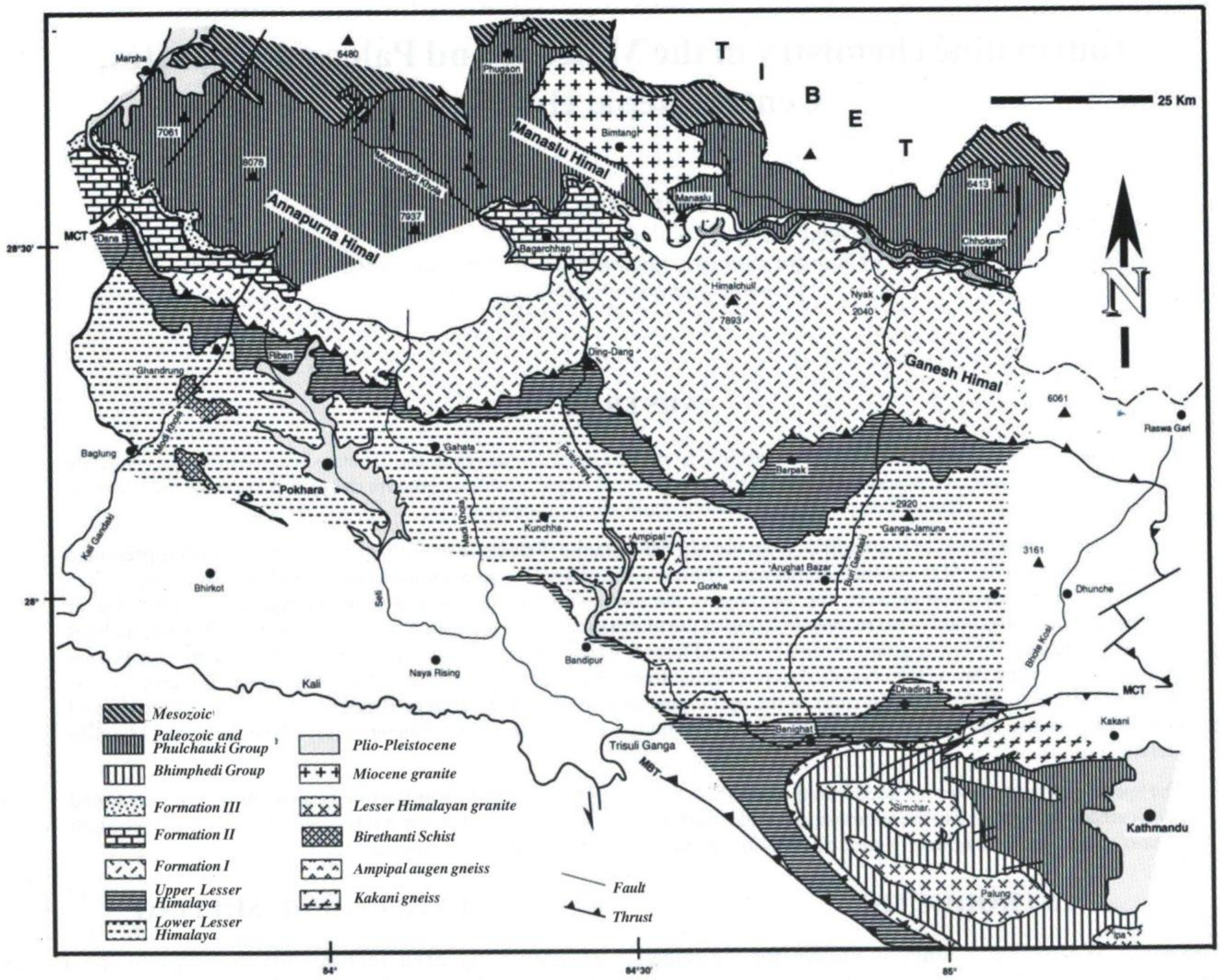

Fig. 1b: Geological map of the central Nepal Himalaya (Colchen et al. 1980, 1986; Stocklin 1980). Plaeozoic-Mesozoic: Tibetan-Tethys Himalaya, Formation I-III : Higher Himalaya, Upper Lesser Himalay-Lower Lesser Himalaya : Lesser Himalaya, MCT : Main Central Thrust.

vicinity of the MCT. The upper stratigraphic unit in the vicinity of the MCT has undergone strong deformation and metamorphism producing garnet, staurolite and kyanite (Le Fort 1975; Pêcher 1978, 1989).

Higher Himalaya (Tibetan Slab)

Tectonically, the Higher Himalaya includes the rocks lying above the MCT and below the fossiliferous Tibetan-Tethys Himalaya. The upper limit of this unit is generally marked by the South Tibetan Detachment System (STDS). 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 micaceous gneiss, indicating the probable sedimentary origin. The Formation II consists of calcic gneiss, banded gneiss and amphibole-pyroxene bearing marble. The Formation III consists of essentially augen gneiss of granitic origin and minor amount of mica schist.

Tibetan-Tethys Himalaya

The metasediments of this unit are originally the epicontinental marine deposits of ante-Llanvirnian to upper Cretaceous age. These metasediments are rich in fossils. The grade of the metamorphism decreases from the base to the top of the section. This unit consists of limestone, marble, phyllite, schist, quartzite and calcareous gneiss.

Granites in different tectonic units

Manaslu leucogranite and arm of Chhokang

Manaslu leucogranite in central Nepal forms a lenticular pluton intruded in the sediments of the Higher Himalaya and Tibetan-Tethys Himalaya (Le Fort 1981, Colchen et al.

1986). This pluton extends along NW-SE direction and continues with an arm of Chhokang towards ESE of 60 km length (Le Fort 1981). The thickness of the Manaslu granite is about 10 km.

The granite consists of medium to fine grained quartz, plagioclase, K-feldspar, two mica and tourmaline. The granite is leucocratic, poor in silica and calcium, rich in aluminium and alkaline (generally sodium).

The age of this pluton was determined by using different methods: 18.1 ± 0.5 Ma by Rb-Sr isochron in total rock (Deniel 1985, Deniel et al 1987), 18.4 – 13.3 Ma by Ar/Ar in muscovite (Copeland et al. 1990), 18.5 ± 0.2 Ma by Ar/Ar in muscovite in contact of the Manaslu granite (Guillot et al. 1994), 19.3 ± 0.3 Ma by Th – Pb in monazite of Bhimtang-Manaslu (Harrison et al. 1998).

Pegmatites and aplites from the Higher HImalaya and Annapurna Formation (Tibetan-Tethys Himalaya)

The aplite-pegmatite dykes are found to be intruded in the sediments of the Higher Himalaya (Figs. 2a and b). Different generations of the intrusions can be found. The aplite-pegmatites consist of coarse to medium grained plagioclase, quartz, K-feldspar, biotite, muscovite and tourmaline. The aplite intruded in Manaslu granite is leucocratic, peraluminous, and poor in quartz.

The pegmatites intruded in the different formations of the Tibetan Slab are generally leucocratic, peraluminous. The pegmatites and aplites found in Annapurna Formation of the Tibetan-Tethys Himalaya are mainly parallel to the bedding /foliaton (Fig. 2c). These are leucocratic and peraluminous.

Formation III augen gneiss

Towards the top of the Tibetan Slab of the Higher Himalaya outcrops a formation of coarse augen gneiss named as Formation III (Le Fort 1975, Colchen et al. 1980, Le Fort et al. 1986). The rock consists of an assemblage of quartz-K feldspar-plagioclase-biotite-muscovite-sillimanite-garnet. The chemical composition is peraluminous and mesocratic to leucocratic, the association is quartz-rich (Le Fort et al. 1986). The Rb/Sr whole rock age of this augen gneiss is 513 ± 30 Ma (Le Fort et al. 1986).

Lesser Himalayan Granite

The Lesser Himalayan granites are located in the frontal part of the Kathmandu nappe (Fig. 1b). These bodies form lenticular shapes and generally are parallel to the Himalayan chain (Hashimoto et al. 1973, Stocklin 1980). The bodies are intrusives in the metasediments of the Kathmandu nappe.

Two types of granite can be recognized in the Lesser Himalayan granites .

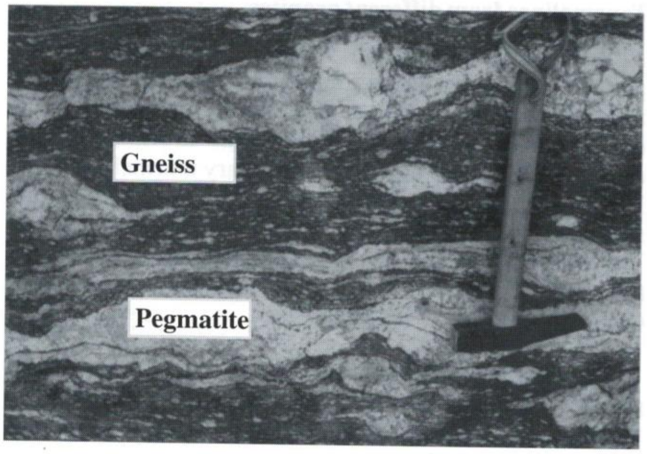

Fig. 2b: Tourmaline bearing boudin pegmatite is well exposed along the foliation plane of the gneiss of the Formation II of the Higher Himalaya.

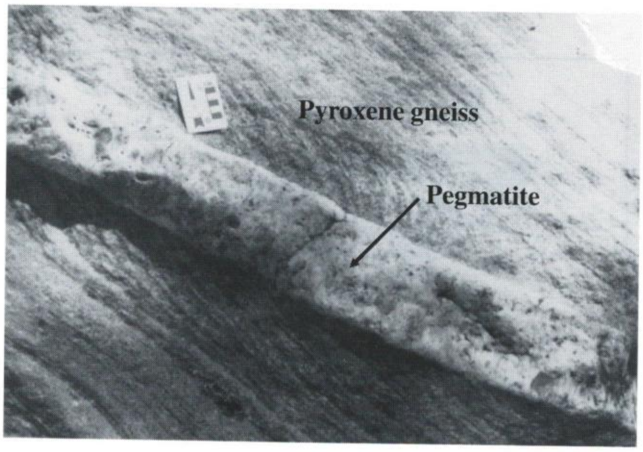

Fig. 2a: Field photographs of the tourmaline bearing aplite-pegmatites. Tourmaline bearing pegmatite obliquely intrudes the pyroxene – gneiss of the Formation II of the Higher Himalaya.

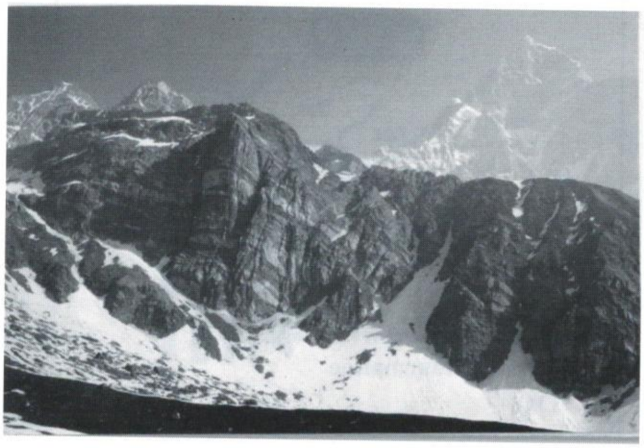

Fig. 2c: Tourmaline bearing aplite-pegmatites are well exposed along the bedding/foliation plane in the sediments of the Annapurna Formation of the Tibetan-Tethys Himalaya

a. The porphyritic granite consists of quartz, K-feldspar, plagioclase, biotite, muscovite, tourmaline ± cordierite. This granite is adamellite, peraluminous, rich in quartz and colored minerals, poor in alkalines and strontium.

b. The leucocratic granite consists of fine grained quartz, K-feldspar, plagioclase, muscovite, biotite, tourmaline, cordierite and rarely garnet, apatite and zircon. The granite is subleucocratic to mesocratic, peraluminous, rich in quartz and poor in alkalies.

The age of this granite is Cambro-Ordovician: 486 ± 21 Ma (Beckinsale in Mitchell 1981), 466 ± 40 Ma (Le Fort et al. 1983), 470 ± 5.6 Ma (Einfalt et al. 1993).

PETROGRAPHY OF TOURMALINE

Tourmalines from different granites

The tourmalines from the Manaslu leucogranite are fine grained –to medium grained, subautomorphs to automorphs, zoned with fractures. These fractures are perpendicular to the alignment of crystals. Late stage tourmalines are developed along the boundary of primary tourmalines (Fig. 3a). Similarly, the tourmalines from Chhokang granite are subautomorphs to automorphs, well zoned and fractured. The recrystallization of quartz can be observed in the fracture (Fig. 3b). The origin of tourmaline from Manaslu and Chhokang granites is magmatic.

Tourmalines from the Lesser Himalayan granite are fine grained –to medium grained, poikilitic in texture containing the inclusion of quartz. These tourmalines are also magmatic in origin.

The tourmalines from augen gneiss of Formation III of the Higher Himalaya (Tibetan Slab) are fine grained –to medium grained, xenomorphs to autumorphs, non- zoned. The fractures found in tourmalines are perpendicular to the alignment of mineral. These tourmalines are probably recrystallized during the Himalayan orogen from the primary tourmalines in Cambro-Ordovician granite.

Tourmalines from aplite-pegmatites

The tourmalines from pegmatites of the Higher Himalaya are fine grained to medium grained, xenomorphs to subautomorphs, non- zoned with less fracture. The quartz, muscovite and zircon are inclusion minerals (Fig. 3c). Similarly, the tourmalines from the aplite-pegmatites of the Annapurna Formation of the Tibetan -Tethys Himalaya are fine grained to medium grained, sub-automorphs, less zoned with inclusion of quartz and plagioclase (Fig. 3d). The fractures are well developed. These tourmalines are probably late magmatic in origin. The tourmalines from the aplite-pegmatites of the Manaslu granite are automorphs to subautomorphs, zoned with late stage tourmaline (Fig. 3e).

TOURMALINE CHEMISTRY

The microprobe analyses of tourmalines collected from different granites and aplite-pegmatites were carried out in the Institut Polytechnique de Grenoble and CRPG-CNRS, Nancy, France, using CAMEBAX SX-50 microprobe. The accelerating voltage was 15 kV for a sample current of 15.1 nA and counting time of 5 s. Standards were natural silicates and oxides. Representative chemical analyses are presented in Table 1 and 2. The results obtained from the microprobe analyses are recalculated in the three major end members of tourmaline: schorlite (%), dravite (%) and elbaite (%). The amount of Li could not be obtained from the microprobe, so the proportion of the elbaite is indirectly calculated on the basis of amount of dravite and schorlite. The structural formula of the tourmaline is based on the 24.5 oxygen. For the present study, the general structural formula used is Na (Mg, Fe, Mn, Li, Al)$_3$ Al$_6$ (Si$_6$ O$_{18}$) (BO$_3$)$_3$ (OH, F)$_4$. For each end member, the structural formulae used are: schorlite : Na

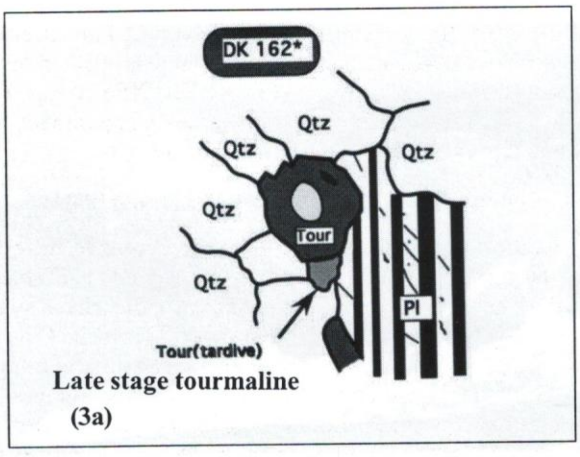

Fig. 3a: Morphology of the tourmlines. (a) Tourmaline from the Manalu granite is subautomorph to automorph, zoned with development of late stage tourmaline. Pl: Plagoclase, Qtz: Quartz, Tour: Tourmaline

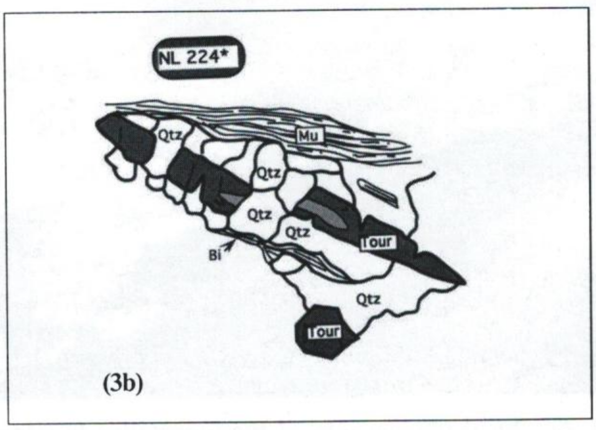

Fig. 3b: Tourmaline from the Chhokang granite is automorph, well fractured with zonation. Bi: Biotite, Mu: Muscovite, Qtz: Quartz, Tour: Tourmaline.

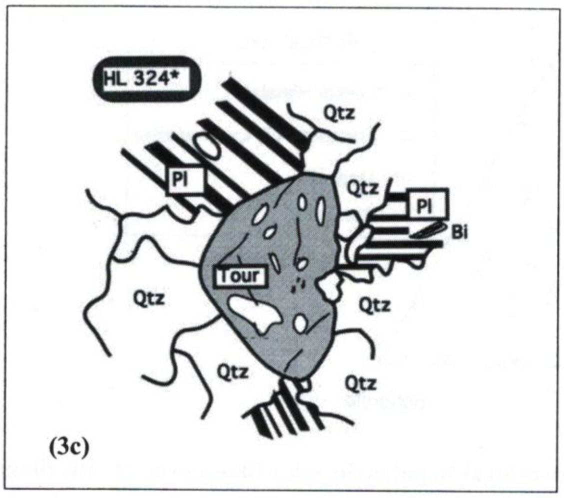

Fig. 3c: Tourmaline from the pegmatite intruded in the pelitic gneiss of the Formation I of the Higher Himalaya is xenomorph, well fractured with the inclusion of the quartz, muscovite and zircon. Bi: Biotite, Pl: Plagioclase, Qtz: Quartz, Tour: Tourmaline.

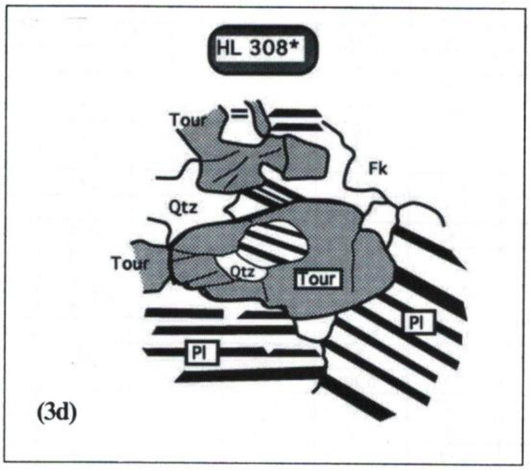

Fig. 3d: Tourmaline from the pegmatite intruded in the sediments of Annapurna Formation is subautomorph, fracture with the inclusion of quartz and plagioclase. Fk: Potassium feldspar, Qtz: Quartz, Tour: Tourmaline.

$(Fe, Mn)_3 Al_6 B_3 Si_6 O_{27} (OH, F)_4$; dravite : $Na (Mg)_3 Al_6 B_3 Si_6 O_{27} (OH, F)_4$ and elbaite : $Na (Al, Li)_3 Al_6 B_3 Si_6 O_{27} (OH, F)_4$.

The average chemical analyses of individual end members obtained from the tourmalines in different granites and aplite-pegmatites are presented in Figs. 4 and 6 and Tables 3, 4 and 5. The chemistry of tourmalines found in different granites and aplite-pegmatites is described below.

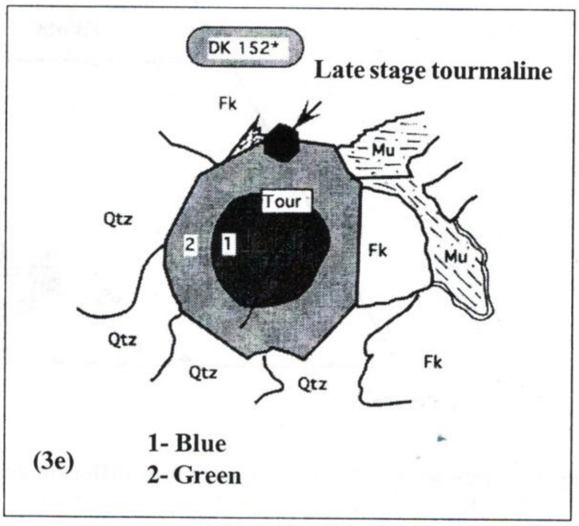

Fig. 3e: Tourmaline from the aplite intruded in the Manaslu granite is automorph to subautomorph, well zoned with development of late stage tourmaline and zircon. Fk: Potassium feldspar, Mu: Muscovite, Qtz: Quartz, Tour: Tourmaline.

Manaslu Granite

59 analyses of tourmalines from 10 granite samples (sample no. D 63, DK 162, DK 220, DK 250, DK 280, DK 295, DK 317, U 464, XG 07, XG 116) (Tables 1 and 3) were analysed and studied. The average composition of tourmaline from Manaslu granite shows 58% schorlite, 26% dravite and 16% elbaite (Fig. 4). The XFe varies from 0.61 to 0.91. The average XFe is 0.69. The composition of tourmaline is generally schorlite (Fig. 4).

Chhokang Granite

Five granite samples (sample no. NL 224, U 697, U 743, U 884, U 944) from Chhokang granite were studied and the chemistry of tourmalines were analysed (Table 3). Thirteen samples of tourmaline were analysed. The average composition of tourmaline from this granite is 60% schorlite, 26% dravite and 14% elbaite (Fig. 4). The XFe ranges from 0.64 to 077. The average value of XFe is 0.70. The composition falls generally in the domain of schorlite (Fig. 4).

Augen gneiss of Formation III (Higher Himalaya)

Twenty -two analyses of tourmaline from two different granite samples (HL 033, NL 471) were carried out (Tables 1 and 3). The average composition of tourmalines from augen gneiss is 46% schorlite, 41% dravite and 13% elbaite (Fig. 4). The composition does not show any systematic evolution between the rim and core of the crystals. This homogenity in composition could correspond to recrystallization of tourmaline during the metamorphism. These tourmalines are less schorlitic as compared to the tourmalines from the Manaslu, Chhokang and Lesser Himalayan Granite (Fig. 4).

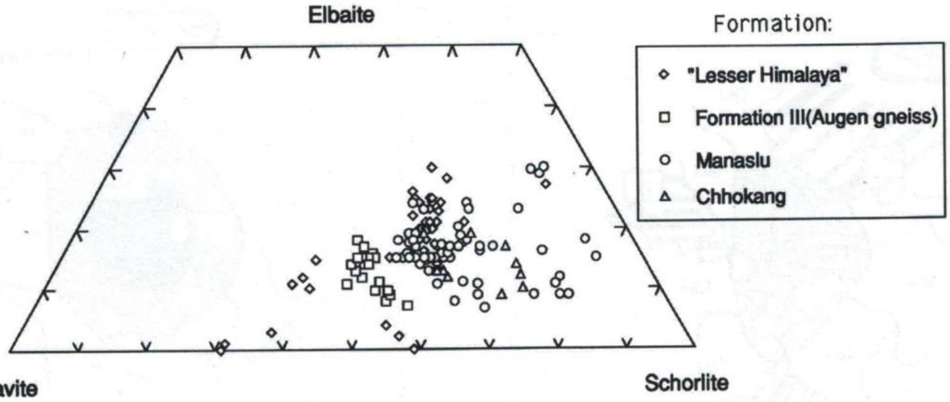

Fig. 4: Compositions of tourmalines in four different granites from central Nepal in the schorlite-dravite-elbaite diagram.

Table 1: Representative chemical composition of the tourmalines in four different granites from the central Nepal. The microprobe analyses were carried out in the Institute Polytechnique de Grenoble and CRPG - CNRS, Nancy, France, using CAMEBAX SX -50 microprobe. G : Granite

Granite	Rock	Sample No.	SiO2	Al2O3	FeO total	MnO	MgO	CaO	Na2O	K2O	TiO2	Total
Lesser Himalaya	G	74153	35.88	34.16	9.70	0.23	3.25	0.19	1.92	0.02	0.27	85.62
	G	KP 190	35.50	34.01	13.14	0.11	0.90	0.13	1.12	0.00	0.26	85.17
	G	KP 246	35.16	33.00	10.42	0.00	3.12	0.20	1.82	0.01	0.66	84.39
	G	SR 68	35.91	30.69	7.58	0.00	6.99	0.47	2.02	0.04	0.05	83.75
Manaslu	G	D 63	37.57	31.90	12.10	0.07	2.81	0.22	2.07	0.07	0.51	87.32
	G	D 162	34.42	33.92	12.05	0.38	0.99	0.00	1.88	0.00	0.23	83.87
	G	DK 220	35.34	32.74	12.31	0.21	2.65	0.24	1.91	0.01	0.61	86.02
	G	DK 250	35.99	33.20	11.42	0.03	2.77	0.22	2.16	0.02	0.81	86.62
	G	DK 280	35.25	33.06	9.91	0.00	3.70	0.28	1.94	0.06	0.71	84.91
	G	DK 295	35.89	32.87	10.72	0.16	3.82	0.28	2.11	0.07	0.94	86.86
	G	DK 317	35.49	34.73	10.24	0.00	3.59	0.21	1.94	0.02	0.33	86.55
	G	U 464	34.93	32.68	10.30	0.04	4.03	0.20	2.32	0.06	0.76	85.32
	G	XG 07	35.31	31.58	13.51	0.58	0.71	0.15	2.12	0.06	0.58	84.6
	G	XG 116	35.25	32.21	14.45	0.21	0.76	0.07	1.94	0.04	0.19	85.12
Chokkang	G	NL 224	35.03	31.94	13.02	0.10	3.43	0.44	2.13	0.10	0.89	87.08
	G	U 697	34.96	31.39	13.18	0.01	2.09	0.29	2.10	0.06	0.75	84.83
	G	U 743	35.61	32.36	11.53	0.06	3.47	0.32	2.19	0.07	0.54	86.15
	G	U 884	35.33	32.41	11.97	0.50	2.05	0.02	2.30	0.02	0.61	85.21
	G	U 944	37.23	33.26	12.96	0.08	3.38	0.08	2.20	0.09	0.94	90.22
Formation III (Higher Himalaya)	Ortho-gneiss	HL033	35.76	32.99	9.52	0.00	5.13	0.66	2.21	0.07	0.58	86.92
		NL471	34.55	31.09	10.16	0.06	4.61	0.6	2.43	0.07	0.82	84.39

Lesser Himalayan Granite

Forty three crystals of tourmaline were analysed from four Lesser Himalayan granite (sample no. 74153, SR 68, KP 190, KP 246). All these results were used to study the chemistry of tourmalines (Tables 1 and 3). The composition of tourmaline shows 48% schorlite, 33% dravite and 19% elbaite (Fig. 4). The average XFe is 0.60.

Mostly, the tourmalines from different granites do not show their systematic variation in chemistry between core and rim. Tourmalines from four samples (74153, DK 295, DK 317 and U743) show an increase of Fe content from core to rim. This evolution could correspond to the origin of tourmalines by fractional crystallization (Neiva 1974). In tourmalines of sample numbers (74153 and DK 317), the Mg content increases poorly with the Fe, but Al decreases from core to rim. In Lesser Himalayan granite, some tourmalines show locally very low content of Al in the rim of crystals. Most crystals show relatively rich in Al in its rim. This variation in composition can be confirmed with the variation in color studied in thin section.

The tourmalines from these different granites fall in schorlite (Fe rich) field (Henry and Guidotti 1985, Fig. 4).

According to the experimental study by Benard et al. (1985), the tourmaline can be crystallized by silicate liquid at high temperature. According to them, the composition of tourmaline can be evolved in the magma from Mg rich in

Table 2: Representative chemical composition of the tourmalines in aplite-pegmatite dykes from the central Nepal. The microprobe analyses were carried out in the Institute Polytechnique de Grenoble and CRPG - CNRS, Nancy, France, using CAMEBAX SX-50 microprobe. FIa, FIIa, FIIb, FIIc, FIIIa, FIIIb: Higher Himalaya

Formation	Rock	Host Rock	Sample No.	SiO2	Al2O3	FeO total	MnO	MgO	CaO	Na2O	K2O	TiO2	Total
Tibetan Slab (FIa)	P	Pel-gneiss	HL 324	35.93	33.48	5.14	0.03	7.52	0.53	2.27	0.04	0.73	85.67
Tibetan Slab (FIIa)	P		MB 307	34.22	31.75	11.00	0.09	4.05	0.42	2.14	0.06	0.03	83.76
	P		MB 356	35.82	30.29	8.87	0.10	7.09	2.11	1.73	0.02	0.44	86.47
Tibetan Slab (FIIb)	P	Mig-gneiss	MB 368	35.87	29.64	10.58	0.07	6.82	1.67	0.06	0.11	0.71	85.53
	P		MB 371	35.56	32.85	9.29	0.09	5.48	0.38	2.42	0.05	0.28	86.4
Tibetan Slab (FIIc)	P	Banded gneiss	HL 79	34.20	27.34	10.67	0.07	6.67	1.42	2.92	0.08	0.72	84.09
	P		Hl 165	35.67	29.71	8.34	0.01	7.24	2.15	1.53	0.06	0.59	85.3
	P		HL 251	36.20	29.27	8.35	0.22	6.76	1.24	2.09	0.03	1.02	85.18
	P	Calc-gneiss	MB 418	34.86	32.33	11.67	0.16	3.21	0.73	2.19	0.06	1.41	86.62
Tibetan Slab (FIIIa)	P	Pel-gneiss	HL 115	36.91	33.29	5.23	0.03	6.99	0.22	2.32	0.00	0.59	85.58
Tibetan Slab (FIIIb)	P	Augen gneiss	HL 281	33.88	29.84	11.96	0.05	3.93	0.71	2.11	0.10	0.97	83.55
	P		N 9.14	33.60	34.32	15.08	0.04	1.29	0.48	2.29	0.23	0.68	88.01
Annarpurna	P	Marble	HL 308	33.70	32.34	12.45	0.09	2.34	0.47	2.15	0.04	1.09	84.67
	P	Banded gneiss	HL 310	34.12	30.18	13.39	0.01	2.87	0.42	2.33	0.13	1.14	84.59
	P		Hl 312	35.45	27.45	13.74	0.11	4.03	0.65	2.44	0.04	1.22	85.13
	P		D 69	35.36	34.25	12.12	0.08	2.29	0.24	2.08	0.03	0.47	86.92
	P		N 81	34.23	32.39	10.20	0.00	3.82	0.29	0.05	0.03	0.70	81.71
	A	Mu-limestone	HL 358	34.31	32.56	14.57	0.17	0.73	0.16	2.17	0.04	0.58	85.29
	P	Limestone	NL 448	34.56	32.07	16.27	0.09	0.72	0.25	1.97	0.04	0.56	86.53
	P	Mu-limestone	HL 258	34.25	31.79	13.86	0.11	1.58	0.29	1.96	0.07	0.86	84.77
	A	Px-gneiss	NL 267	35.70	34.15	15.56	0.25	0.58	0.08	2.63	0 35	0.40	89.7
Manaslu	A	Granite	DK 152	35.82	35.09	11.23	0.19	2.41	0.00	1.75	0.00	0.10	86.59
	A		DK 185	34.19	33.19	11.43	0.41	2.81	0.25	2.05	0.03	0.46	84.82

A: Aplite, Mig: Migmatite, Mu: Muscovite, P: Pegmatite, Pel: Pelitic, Px: Pyroxene

high temperature towards the Fe rich in low temperature. Such type of evolution can be observed in the tourmalines of Manaslu and Chhokang granites. The XFe variation studied in tourmalines from study area can reflect the crystallization of tourmalines in different temperatures.

The tourmalines from Manaslu and Chhokang granites are more schorlitic (rich in Fe) than the tourmalines of the Lesser Himalayan granite and the ortho-gneiss of the Higher Himalaya (Fig. 4). The composition of tourmalines from the Lesser Himalayan granite is heterogeneous. This heterogeneity could be the result of the partial recrystallization of tourmaline during the metamorphism. At contrast, the composition of the tourmalines from augen gneiss of Formation III (Higher Himalaya) are rather homogeneous (Fig. 4). This homogeneity could correspond to complete recrystallization during the Himalayan orogeny. The composition of tourmalines from the granites of Manaslu and Chhokang is found to be dispersed, probably due to hetrogenic source materials of granitic magma. Sometimes, the XFe of the tourmalines shows an inverse correlation with Ba and Sr content of host rocks (Fig. 5). This could indicate a relation between the composition variation of tourmalines and differentiated magma. This observation can be equally observed in the tourmalines of the Lesser Himalayan granite.

The presence of magmatic tourmaline is a good evidence for the origin of granites by partial melting of pelitic rocks because they generally contain sufficient boron by the substitution of Al in pelite (upto 200 ppm of boron) (Stubican and Roy 1962). The Manuslu and Chhokang granites are the products of partial melting of the pelitic gneiss of the Higher Himalaya due to circulation of fluid issued from the sediments of the Lesser Himalaya (Le Fort 1981). The granitic magma contains important quantity of fluid including boron. Boron is a major element to develop tourmaline. The Fe-Mg containing tourmaline granite is typical peraluminous in nature, which contains andalusite, biotite, muscovite, garnet and cordierite. The tourmalines from granites are of magmatic origin (Pichavant 1981, Charoy 1982). The primary tourmaline in granite is the evidence of boron saturated magma. (Chorlton and Martin 1978). The Manaslu leucogranite contains very high amount of boron (950 ppm) (Rai 2003). Tourmaline from the Manaslu granite is also highly rich in boron (Rai 2003). The enrichment of boron in granite may be due to the release of boron from the Lesser Himalayan rocks during the partial melting of the rocks of the Higher Himalaya as a result of the movement along the MCT.

Aplites from Manaslu granite

The average composition of tourmalines from aplite veins (samples DK 152, DK 185) intruding into Manaslu granite is 57% schorlite, 22% dravite and 21% elbaite (Fig. 6 and Table 4). The average XFe is 0.72. There is no systematic variation in chemistry between the core and rim of tourmaline crystals. The composition is generally homogeneous. These tourmalines fall in the field of schorlite (Henry and Guidotti 1985, Fig. 6).

Aplite-pegmatites from Higher Himalaya (Tibetan Slab)

The aplite-pegmatites are classified on the basis of formations (FI, FII and FIII of the Tibetan Slab). The average composition of tourmalines is presented in Table 4.

Table 3: Average composition of tourmalines in different granites from the central Nepal.

Granite	Sample no.	No. of analyse	Elbaite (%)	Dravite (%)	Schorlite (%)	XFe
Manaslu	D 63, DK162, DK220, DK250, DK280, DK 295, DK317, U464, XG7, XG116	59	16	26	58	0.69
Chhokang	NL224, U697, U743, U884, U944	13	14	26	60	0.70
Formation III (Higher Himalaya)	HL033, NL471 74153, SR68,	22	13	41	46	0.53
Lesser Himalayan granite	KP190, KP 246	43	19	33	48	0.60

Formation I : Only one sample (HL 324) from pegmatite intruded in pelitic gneiss was analazed to study the chemistry of tourmaline. The average composition is 67% dravite, 21% schorlite and 12% elbaite (Fig. 6 and Table 4). The average value of XFe is 0.24. The Mg content slightly increases from the core to rim of the tourmalinecrystal.

Formation II: Two samples (MB 307, MB 356) from pegmatites intruding into two mica-garnet pelitic gneiss were analyzed. The average composition of tourmalines is 50% schorlite, 43% dravite and 7% elbaite (Fig. 6 and Table 4). The tourmaline in sample MB 307 has crystallized in the fracture of garnet. It shows an increase of Mg content from core to rim in the crystal. The Fe content in sample MB307 is higher than the Fe content in sample MB 356. The Al content in sample MB 356 is nil but Mg content is higher than in sample MB 307. This Mg rich tourmaline sample MB 307 could be related to the existence of amphibole near the pegmatite. There is no significant variation in composition of tourmaline sample MB 356.

The average composition of tourmalines from pegmatites intruded in the migmatized gneiss (samples MB 368, MB 371) is 49% schorlite, 39% dravite and 12% elbaite (Fig. 6 and Table 4). The average XFe is 0.56. The poikilitic tourmalines from sample MB 368 show slight decrease of Mg content from core to rim and the Al content is nil. The tourmalines from sample (MB 371) show two phases of evolution of tourmalines. The primary tourmaline is automorph and poor in Mg content and rich in Al than that of late phase tourmaline. The Mg content increases from the core to rim in the primary tourmaline. In contrast, the secondary or late phase tourmaline shows the decrease of Mg content from core to rim. The late phase tourmaline reflects the liquid composition of tourmaline (Brouard 1989). The tourmalines from pegmatites (HL 79, HL 165, HL 251, MB 418) intrude the calcareous rocks. The average composition for these tourmalines is 51% schorlite, 44% dravite, 5% elbaite and the XFe is 0.54 (Fig. 6 and Table 4). There is no systematic variation in chemistry between core and rim. Al content is totally absent in the tourmalines of samples HL 79, HL 165 and HL 251. These tourmalines are rich in Mg content than that of Fe content. This Mg rich nature could be related to the occurrence of calcareous host rocks.

Formation III: The average composition of tourmalines from pegmatites (HL 115 and NL 495) intruding into two mica – garnet pelitic gneiss and two mica garnet banded gneiss is 56% dravite, 28% schorlite and 16%, elbaite and 0.33 XFe (Fig. 6 and Table 4). No systematic chemical variation is observed between core and rim. The host rocks could control the presence of Mg content in tourmalines. In other cases, high Al content could result from the substitution of Fe by Al. The tourmalines from pegmatites HL 281, N9.14 intruding in augen gneiss has the average composition 49% schorlite, 40% dravite, 11% elbaite and 0.55 XFe (Fig. 6 and Table 4).

In general, the tourmalines found in the aplite-pegmatites intruded in all formations of Tibetan Slab fall in the domain of metapelites and metapsammites (Henry and Guidotti 1985, Fig. 6).

Aplite-pegmatites from Annapurma Formation of Tibetan-Tethys Himalaya

The average composition of tourmalines from aplites (samples DK 028, HL 258, NL 267) is 70% schorlite, 20% elbaite, 10% dravite and 0.89 XFe (Fig. 6 and Table 4). The Mg content increases from core to rim, but Fe and Al contents do not show any variation in composition. In sample DK028, the tourmaline contains low Fe content and high Mg content as compared to samples HL 258 and NL 267.

The average composition of tourmalines from pegmatites (samples B6, D69, N69, N81, HL 308, HL 310, HL 312, HL 358, NL 448) is 66% schorlite, 19% dravite, 15% elbaite and 0.78 XFe (Fig. 6 and Table 4). Most of the tourmalines are rich in Fe (60-77% of schorlite). Some tourmalines (samples B6, D69, N69) show systematic evolution between core and rim, with

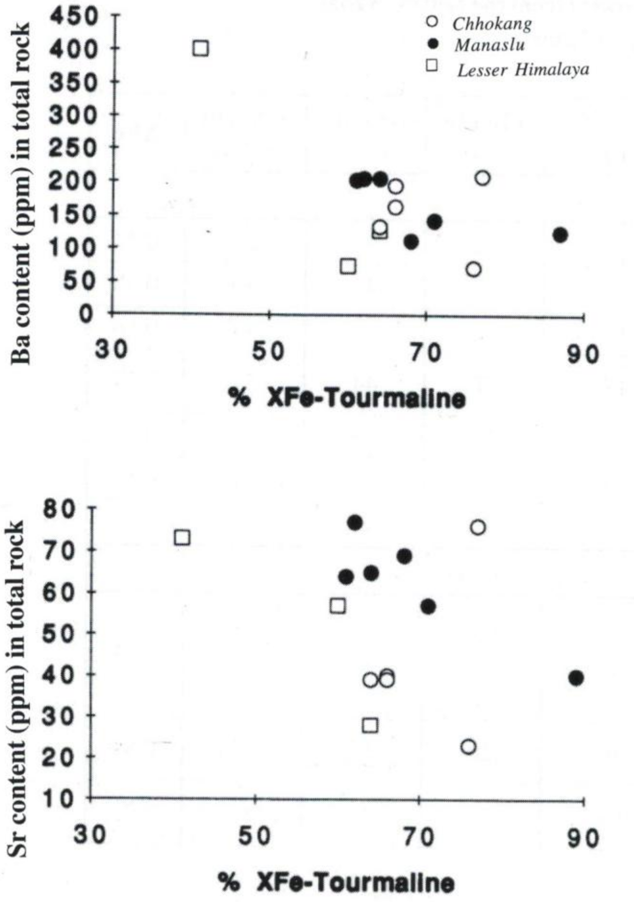

Fig. 5: Correlation between the XFe (%) in tourmaline and the Ba and Sr contents of the host rocks (granites).

an increase or decrease of Mg content. The tourmalines for samples N69 and NL 448 show low content of Mg (dravite, less than 7%). Certain tourmalines (sample HL 310, HL 312) show low content of Al (elbaite, less than 8%) but others show high content of Al (elbaite, 14-36%).

In general, the tourmalines from aplites show higher content of Fe and Al than the tourmalines of the pegmatites. The tourmalines from aplite-pegmatites fall in the domain of granites (poor in Li) and associated aplite-pegmatites (Fig. 6).

RELATION BETWEEN APLITE-PEGMATITES AND THEIR HOST ROCKS

The average composition of tourmalines of aplite-pegmatites with respect to their host rocks is presented in Fig. 7 and Table 5.

The tourmalines from aplite-pegmatites intruded in pelitic gneiss of Formation I (Tibetan Slab) show less schorlite composition (21%, Fig. 7) and more dravitic composition (67%) (Table 5). The high content of Fe (schorlite 76%) is observed in the aplite-pegmatites intruded in the calcic rocks (limestone) of the Annapurna Formation. These tourmalines are equally very poor in Mg (dravite 8%). The tourmalines from aplite-pegmatites intruded into pelitic gneiss are grouped in the domain of dravite (Mg) while the tourmalines from aplite-pegmatites intruded in calcareous rocks are rich in Fe (schorlite). Between the pelitic gneiss and calcareous rocks, the tourmalines of pegmatites intruded in granite and augen gneiss are grouped in between them. This variation in composition suggests that the presence of tourmaline in the host rocks could not influence the composition of aplite-pegmatites and particularly in the composition of tourmalines.

Most authors consider that schorlite is a typical tourmaline of aplite-pegmatites. The tourmalines from the study area show that the tourmalines from aplite-pegmatites do not correspond to their composition with respect to the composition of host rocks. The tourmalines from aplite-pegmatites intruded in calcareous rocks are schrol types. This result is in contrast with the result of Ginzburg (1951) and Melent'ev et al. (1971). So, the composition of the tourmalines of aplite-pegmatites dykes from study area can not be controlled by the composition of country rocks, but it is indirectly controlled by the composition of fluid phase of magma.

CONCLUSION

The composition of tourmalines from the Miocene and Paleozoic granites shown in schorlite (Fe)-dravite (Mg)-elbaite (Al) diagram of Henry and Guidotti (1985) is found to be rich in Fe (schorlitic). The tourmalines from Manaslu and Chhokang granites might have evolved from Mg rich rocks at higher temperature towards the Fe rich in lower temperature during the crystallization as reflected by the XFe variation. The tourmalines of the aplite-pegmatite dykes from the Higher Himalaya are rich in Mg (dravite) as compared to the tourmalines from the Tibetan-Tethys Himalaya and Manaslu granite. So, the composition of tourmalines is found to be evolved from dravite (Mg rich) in the aplite-pegmatite dykes of the Higher Himalaya (lower section) to schorlite (Fe rich) and elbaite (Al) in the aplitepegmatite dykes of the Annapurna Formation of the Tibetan-Tethys Himalaya and Manaslu granite (upper section). The Mg rich tourmalines are probably crystallized at higher temperature in the lower section (aplite-pegmatite dykes of the Higher Himalaya).

The aplite-pegmatite dykes intruding into the pelitic rocks contain Mg rich tourmalines while Fe rich tourmalines are found in calcareous host rocks. So, the composition of the tourmalines of aplite-pegmatite dykes are not controlled by the composition of host rocks, but it is indirectly controlled by the composition of fluid phase of magma.

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Table 4: Average composition of tourmalines in aplite-pegmatites from the central Nepal. A: Aplite, P: pegmatite, FIa, FIIa, FIIb, FIIc, FIIIa, FIIIb: Higher Himalaya.

Tectonic units	Rock	Sample no.	No. of analyze	Elbaite (%)	Dravite (%)	Schorlite (%)	XFe
Tibetan Slab (Higher Himalaya)							
FIa	P	HL324	4	12	67	21	0.24
FIIa	P	MB307, MB356	7	7	43	50	0.55
FIIb	P	MB368, MB371	17	12	39	49	0.56
FIIc	P	HL79, HL165, HL251, MB418	17	5	44	51	0.54
FIIIa	P	HL115, NL495	10	16	56	28	0.33
FIIIb	P	HL281, N9.14	14	11	40	49	0.55
Tibetan-Tethys Himalaya							
Annapurna Formation	P	B6, D69, N69, N81, HL308, HL310, HL312, HL358, NL448	114	15	19	66	0.78
	A	DK028, HL258, NL267	9	20	10	70	0.89
Manaslu granite	A	DK152, DK185	13	21	22	57	0.72

Table 5: Average composition of tourmalines in aplite-pegmatites intruded in different host rocks from the central Nepal. 2M: Two mica, Gr: Garnet, Mu: Muscovite, Px: Pyroxene, Qtz: Quartz.

Sample no.	Host rocks	No. of analyse	Elbaite (%)	Dravite (%)	Schorlite (%)	XFe
HL324	Pelitic gneiss	4	12	67	21	0.24
HL115, MB307, MB356	2M-Gr pelitic gneiss	17	12	51	37	0.42
NL495	2M-Gr banded gneiss	7	12	50	38	0.43
MB368, MB371	Migmatic gneiss	17	11	39	50	0.56
HL79	Qtz-banded gneiss	8	0	50	50	0.50
DK152, DK185	Granite	13	21	22	57	0.72
HL281, N9.14	Augen gneiss	7	10	31	59	0.67
MB418	Calcareous gneiss	5	18	22	60	0.73
B6, D69, N69, N81, HL165, HL251, HL310, HL312	Calcareous banded gneiss	64	12	27	61	0.70
DK028	Px-marble	2	22	17	61	0.78
HL308	Marble	25	15	20	65	0.76
HL258, HL358	Mu-limestone	9	21	10	69	0.87
NL267	Px-gneiss	3	21	5	74	0.93
NL448	Limestone	24	16	8	76	0.91

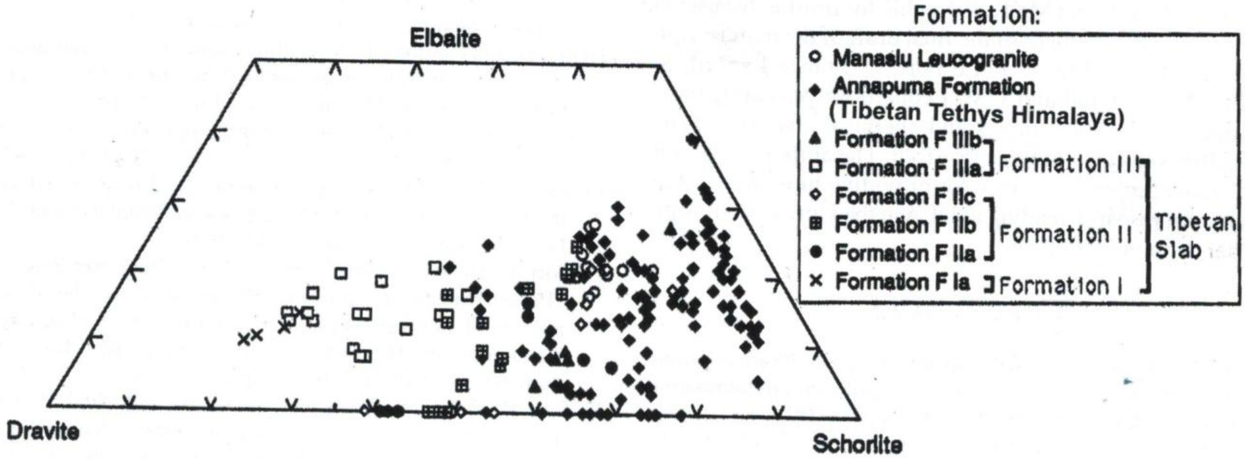

Fig. 6: Composition of tourmalines from aplite-pegmatite dykes from central Nepal in the Elbaite-dravite-schorlite diagram

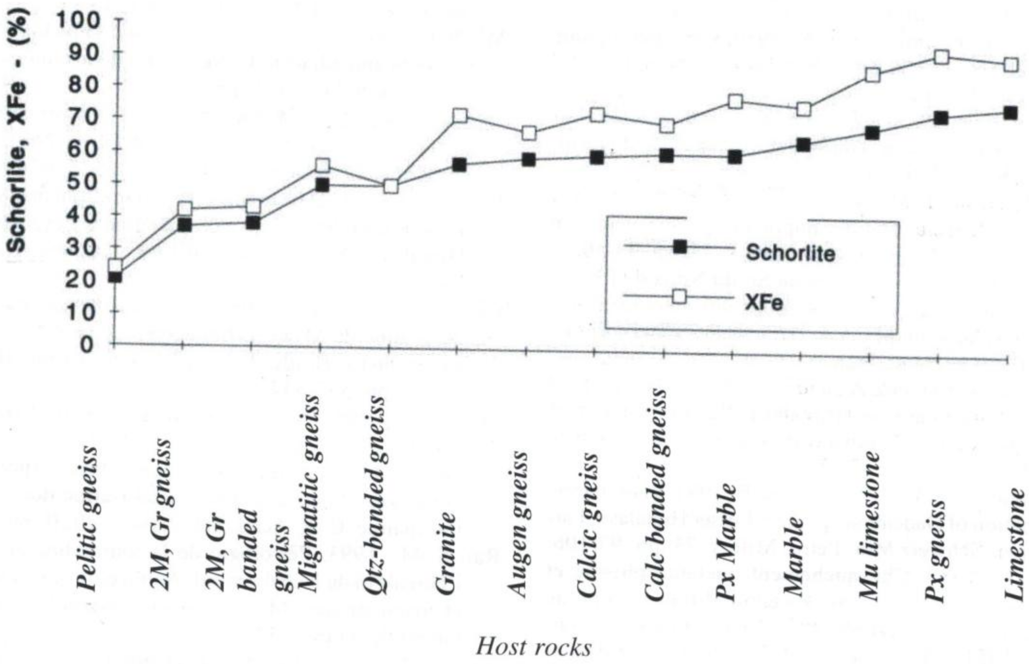

Fig. 7: Relation between XFe (%) and schorlite contents of the tourmalines with their host rocks from aplite-pegmatie dykes in central Nepal.

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