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Evidence for the occurrence of Permian Panjal Trap Basalts in the Lesser- and Higher-Himalayas of the Western Syntaxis Area, NE Pakistan

By Kaspar Papritz and Roger Rey[1])

ABSTRACT

The rocks of the Western Syntaxis area can be divided into the tectonic elements of Sub-, Lesser- and Higher-Himalayas. The Subhimalaya contains mainly molasse sediments of the late Paleocene to middle Eocene Murree Formation. The Lesser-Himalaya consists of the Panjal- and the Salkhala Unit, whereas the Higher-Himalaya is built up by a basement- and a cover sequence.

The regional metamorphism increases in grade from lower greenschist facies at the base of the Lesser-Himalaya to upper amphibolite facies in the Higher-Himalaya.

Basic rocks occur throughout the Lesser- and Higher-Himalayas. Field relations, petrography and geochemistry of these rocks are discussed.

In the Salkhala Unit, there are strongly deformed dolerite and amphibolite bodies. In the Panjal Unit, metabasaltic flows, which correlate with the Permian Panjal Trap are found. Deformed dolerite and amphibolite dykes occur in the Higher-Himalayan basement. Well developed amphibolite sheets mark the base of the Higher-Himalayan cover. They probably represent metamorphic lava flows.

Petrographic indices for an intrusive magmatic origin of the basic rocks are documented in the dolerites and amphibolites of the Salkhala Unit, in the metabasalts of the Panjal Unit as well as in the dolerites and amphibolites of the Higher-Himalayan basement.

Amphibolites of the Higher-Himalayan cover have metamorphic mineral assemblages and textures. All pre-existing magmatic fabrics are overprinted.

The tholeiitic to mildly alkalic chemical composition in major- and trace elements of all basic rocks can be compared with Panjal Trap basalts of Suru and Kashmir.

From similarities in stratigraphic position, petrography and geochemistry, we conclude that the basic rocks of the Western Syntaxis area can be correlated with the Permian Panjal Trap basalts and that their volcanic emplacement is associated to the same magmatic event. The basic rocks of the Higher-Himalayan cover and of the Panjal Unit are interpreted as metamorphosed basaltic surface flows, whereas the basic rocks of the Salkhala Unit and the Higher-Himalayan basement represent their subsurface equivalents.

A Permian age of the amphibolites in the Higher-Himalayan cover allows us to bracket the age of the associated metasediments in the cover and the underlying granitic gneisses and metasediments of the basement.

ZUSAMMENFASSUNG

Das Gebiet der westlichen Syntaxis kann in die tektonischen Elemente des Sub-, Lesser- und Higher-Himalayas aufgeteilt werden. Der Subhimalaya besteht hauptsächlich aus den spätpaläozänen bis mitteleozänen Molassesedimenten der Murree Formation. Der Lesser-Himalaya wird in die Panjal- und die Salkhala Unit aufgeteilt, währenddem sich der Higher-Himalaya aus einer Basement- und einer Cover-Abfolge zusammensetzt. Von der Basis des Lesser-Himalayas steigt der regionale Metamorphosegrad von der unteren Grünschieferfazies bis zu höherer Amphibolitfazies im Higher-Himalaya.

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Feldbeobachtungen, Petrographie und Geochemie der basischen Gesteine, die im Lesser- und Higher-Himalaya recht verbreitet sind, werden diskutiert.

In der Salkhala Unit finden sich stark deformierte Dolerit- und Amphibolitkörper. Metamorph überprägte Basaltflows in der Panjal Unit werden mit den permischen Panjal Trap Basalten korreliert. Im Higher-Himalaya Basement sind es deformierte Dolerit- und Amphibolitgänge. Sehr markante, mächtige, über weite Strecken verfolgbare Amphibolitlagen charakterisieren die Basis des Higher-Himalaya Cover. Petrographische Anzeichen für eine intrusiv magmatische Herkunft sind sowohl in den basischen Gesteinen der Salkhala Unit als auch der Panjal Unit und des Higher-Himalaya Basement bekannt. Einzig in den Amphiboliten des Higher-Himalaya Cover wurden alle präexistierenden magmatischen Gefüge metamorph überprägt.

Die Basica wurden auf Haupt- und Spurenelemente analysiert. Alle untersuchten Gesteine zeigen eine tholeiitische bis schwach alkalische Zusammensetzung. Aufgrund des Chemismus können sie mit den Panjal Trap Basalten von Suru und Kashmir verglichen werden.

Aus den Ähnlichkeiten bezüglich der stratigraphischen Position, der Petrographie und der Geochemie schliessen wir, dass die Basica aus dem Gebiet der Westlichen Syntaxis mit den permischen Panjal Trap Basalten korreliert werden können, und dass ihre Intrusion respektive Extrusion zum selben magmatischen Ereignis gehört. Die Basica des Higher-Himalaya Cover und der Panjal Unit entsprechen metamorphen, basaltischen Oberflächenergüssen, währenddem die basischen Gesteine der Salkhala Unit und des Higher-Himalaya Basement ihre hypabyssischen Äquivalente darstellen.

Das permische Alter der Amphibolite des Higher-Himalaya Covers erlaubt uns, das Alter der mit den Basica assoziierten Metasedimente des Covers und der darunterliegenden granitischen Gneisse und Metasedimente des Basements einzugrenzen.

1. Introduction

In the Western Syntaxis area (Fig. 1), which comprises the Hazara Kashmir Syntaxis and its northern continuation, the Himalayas can be divided from south to north into three main tectonic elements (GRECO et al. 1989), in accordance with the division put forward by GANSSER (1964) into Sub-, Lesser- and Higher-Himalaya. Mostly crystalline metamorphic and magmatic rocks build up the Lesser- and Higher-Himalayas. Their extent to the north is limited by the Indus suture, which separates them from the Kohistan sequence.

In the Lesser-Himalaya, the Panjal- and the Salkhala tectonic units can be distinguished. The Higher-Himalaya can be subdivided into a basement-cover sequence (GRECO et al. 1989). The regional metamorphism increases in grade from lower greenschist facies at the base of the Lesser-Himalaya to higher amphibolite facies in the Higher-Himalaya.

Basic rocks form a considerable amount to the Lesser- and Higher-Himalayan rocks in the area. Especially the base of the Higher-Himalayan cover sequence in the Western Syntaxis area is characterized by an easily identifiable tectonostratigraphic "marker bed": Dark garnet-amphibolite sheets interbedded with light coloured marbles can be traced over several tens of kilometers. In their exposure and lithostratigraphic position, the amphibolite sheets can be compared with metamorphosed Permian basalts (Panjal Trap basalts) from Suru (Ladakh) (HONEGGER 1983). This leads to the speculation that the amphibolites in the Western Syntaxis area can be correlated with the Panjal Trap.

It is widely accepted that the Panjal Trap represent continental flood basalts. Unlike them, the Tertiary Columbia River basalts of NW-USA are a thoroughly studied and well understood flood basalt province. It could be shown there, that flood basalts can spread over distances of hundred kilometers away from their center of eruption

(Schmincke 1967). Typical for flood basalts is their lateral uniformity in chemical composition, a fact which can be used for correlations of individual lava flows between different profiles (e.g. Reidel 1983).

The purpose of this work is to characterize the amphibolite sheets of the Higher-Himalayan cover together with basic rocks from the Higher-Himalayan basement and the Lesser-Himalaya, in order to discuss their age and its implications on the regional geology. Their field relations, petrography and geochemistry are discussed and compared with Permian Panjal Trap basalts. Petrographic and geochemical descriptions of Panjal Trap basalts are given by Singh et al. (1976) from Zanskar in Ladakh, Honegger et al. (1982) from the Suru area in Ladakh, NW-India and Bhat & Zainuddin (1978, 1979) from Lidderwat, NE of Srinagar in Kashmir.

2. Geological Setting

In the Western Syntaxis area, the Sub-Himalaya consists mainly of molasse like sediments (Murree formation) of late Paleocene to middle Eocene age (Bossart & Ottiger 1989). These sediments form a wide zone along the southern foothills of the Himalayan mountain range. Their northernmost occurrence lies in the Western Syntaxis area, where they form a domal structure (Bossart et al. 1988), the Hazara Kashmir Syntaxis. The metamorphic grade is very low.

Two different tectonic units can be distinguished in the Lesser-Himalaya (Fig. 2): a tectonically lower Panjal imbricate zone or Panjal Unit, which tectonically can be compared with the Parautochtonous Zone in NW-India (Fuchs 1975 and Thakur & Gupta 1983), and a higher Salkhala Unit (Greco et al. 1989).

The Salkhala Unit is composed of strongly deformed metasediments of a great variety, possibly of Precambrian age (Salkhala formation in the sense of Calkins et al. 1975). They comprise micaschists, marbles, graphitic phyllites, and quartzites and are intruded by a porphyritic granite, subsequently transformed into granitic gneiss, which probably can be correlated with the Cambrian Mansehra granite (Greco et al. 1989). Acid intrusives are found throughout the Salkhala Unit. At the base, near the Panjal thrust occur pegmatitic, weakly deformed dykes, whereas in the upper parts granitic to alkali granitic concordant sheets were intruded into the country rock. Within both, the metasedimentary and the granitic parts, deformed amphibolite and dolerite dykes can be found. The metamorphic grade in the Salkhala Unit reaches upper greenschist facies conditions.

Late Paleozoic to Triassic rocks occur in the Panjal Unit. They are stacked in three imbricate slices. Only one of the three slices contains a complete stratigraphic section: graphitic schists and clastic rocks lie at the base (tilloides of Bossart et al. 1988) and can be compared with the upper Carboniferous Agglomeratic Slates (Bion & Middlemiss 1928) from Kashmir. They are overlain by the Permian to Triassic Panjal Trap volcanics and Triassic carbonates (Bossart et al. 1988). The metamorphism is of lower to middle greenschist facies.

According to Wadia (1934) and Thakur & Gupta (1983) the Kashmir Nappe Zone in NW-India contains a stratigraphic section from the Precambrian Salkhala metasediments to lower Mesozoic rocks, including the Panjal volcanics.

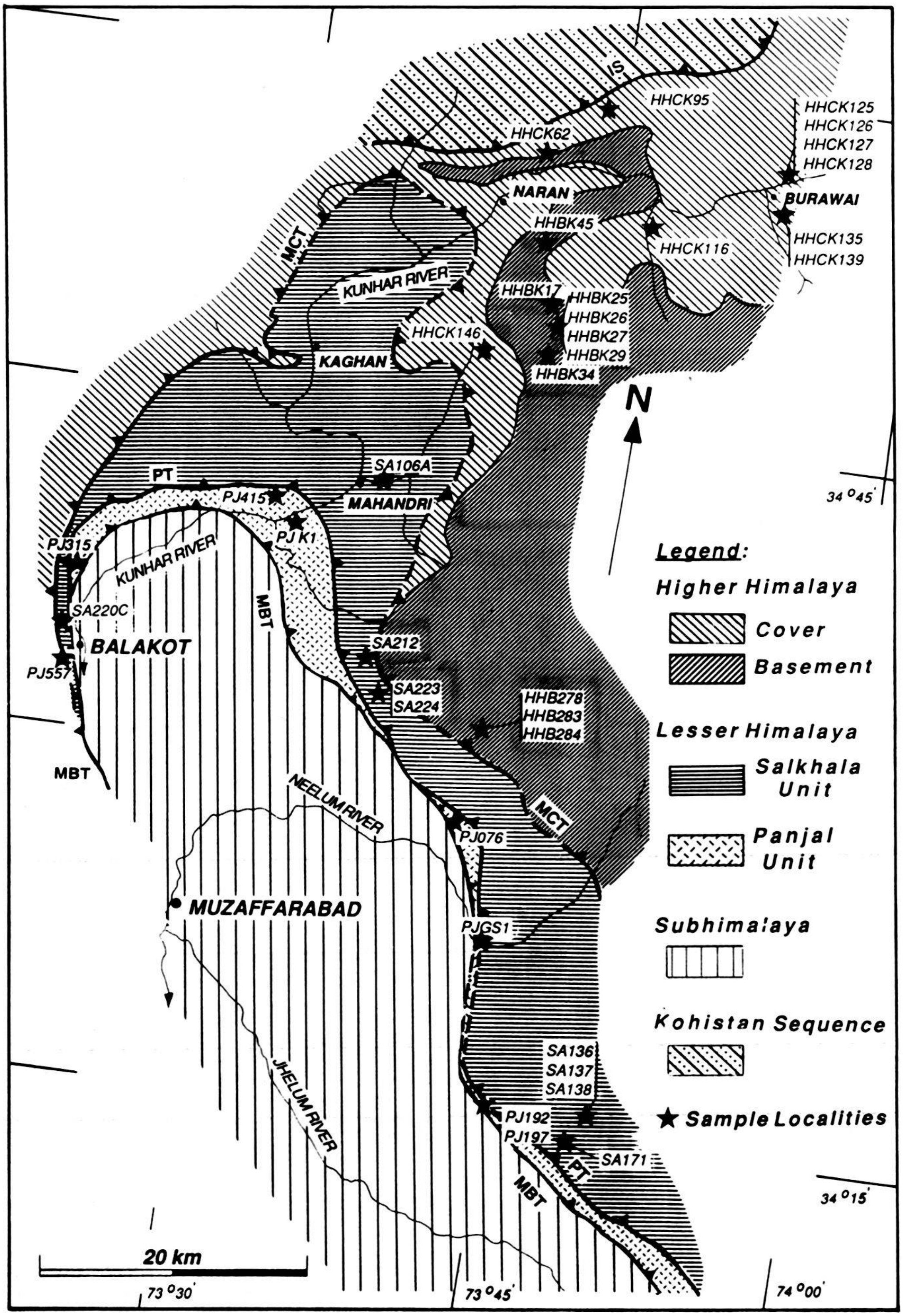

Fig. 1. Tectonic Sketch Map of the Western Syntaxis area of the Himalayas with localities of analyzed samples. It comprises the Hazara Kashmir Syntaxis and the northern continuation of its apex. Compiled from Bossart et al. (1989) & Greco et al. (1989). IS: Indus suture, MBT: Main Boundary thrust, MCT: Main Central thrust, PT: Panjal thrust. Sample prefixes: PJ: sample from Panjal Unit; SA: sample from Salkhala Unit; HHC: sample f rom Higher-Himalayan cover; HHB: sample from Higher-Himalayan basement.

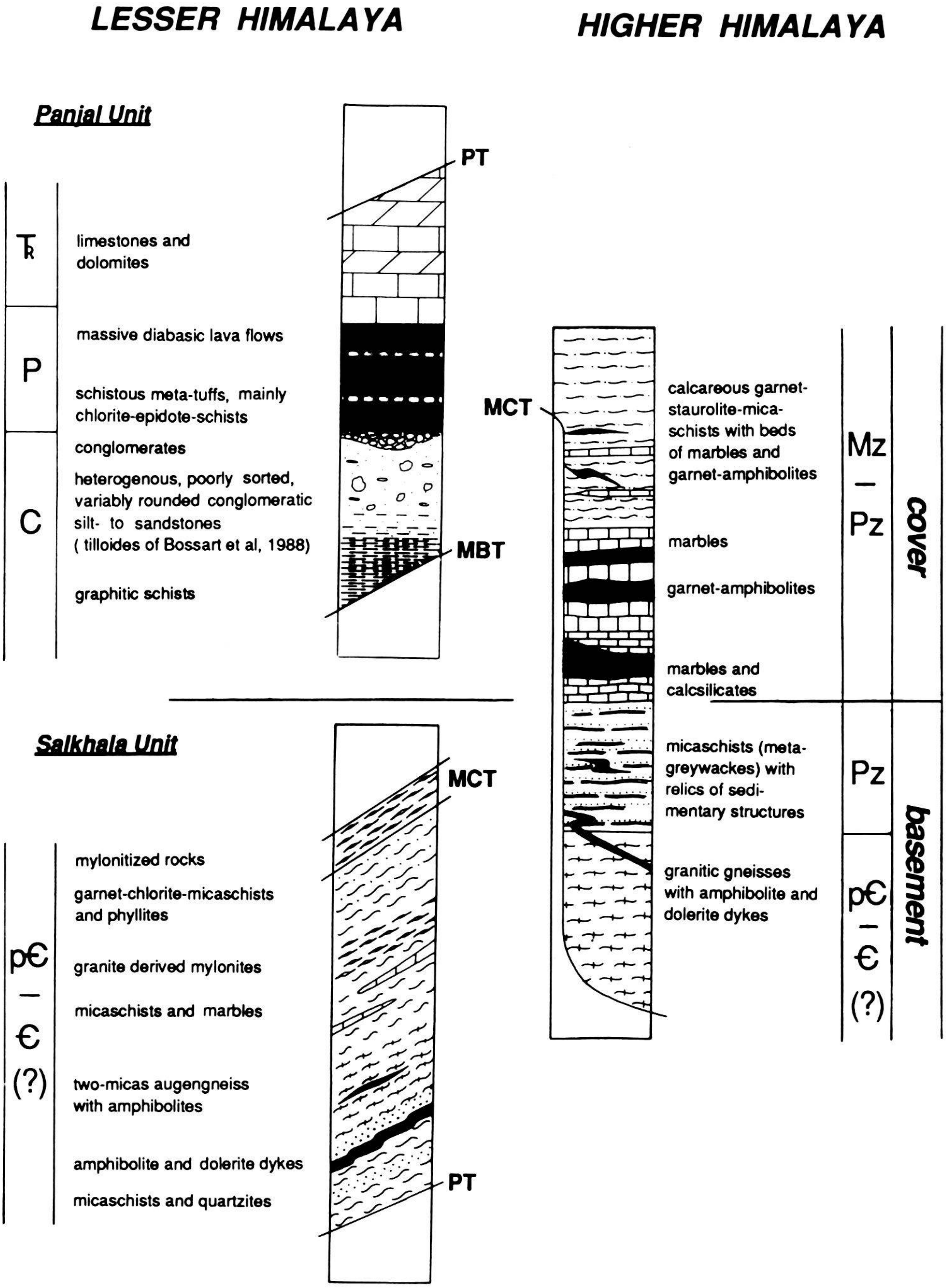

Fig. 2. Schematic stratigraphic profiles (not to scale) of the Lesser-and Higher-Himalayas of the Western Syntaxis area. The profiles are compiled from Bossart et al. (1988), Greco et al. (1989) and own observations. The Salkhala Unit laterally varies strongly in lithologic composition. MBT: Main Boundary thrust, MCT: Main Central thrust, PT: Panjal thrust.

It can be assumed that the higher grade metamorphic Precambrian metasediments and early Paleozoic gneisses of the Salkhala Unit formed a deeper crustal rock sequence, whereas the late Paleozoic to Triassic sediments and volcanics of the Panjal Unit formed a higher part in the stratigraphic section. This stratigraphic configuration must have persisted in the Western Syntaxis area up to the Himalayan orogeny which produced the syndeformational metamorphism throughout the Lesser-Himalaya (GRECO et al. 1989) and carried the upper greenschist metamorphic rocks of the Salkhala Unit over the lower grade Panjal Unit along a major thrust plane (Panjal thrust) BOSSART et al. 1988).

The shear zone which separates the Lesser- from the Higher-Himalaya is characterized by the occurrence of granite derived mylonites. It can be correlated with the Main Central thrust (MCT) (GRECO et al. 1989).

A crystalline nappe with a basement-cover sequence builds up the Higher-Himalaya in the Western Syntaxis area (GRECO et al. 1989). Metamorphic mineral assemblages in both parts indicate higher amphibolite facies.

The basement comprises a laterally rather inhomogeneous rock association with porphyroblastic granitic gneiss intruded into metasedimentary rocks. These are overlain by feldspathic micaschists (metagreywacke rocks) with relics of sedimentary bedding structures. A Cambro-Ordovician intrusion age is attributed to the granitoides (GRECO et al. 1989), the metagreywacke rocks can be compared to the lower- to middle Paleozoic sediments of the Suru and Padam regions of Ladakh (BAUD et al. 1984, GAETANI et al. 1985, GARZANTI et al. 1986 and FRANK et al. 1987). Both metasedimentary rocks and granitoides are cut discordantly by acid and basic dykes. The latter reveal a transitional range of rocks between well preserved dolerites and completely recrystallized and foliated amphibolites. Regional metamorphism overprinted all direct evidence which could document the age, either of the sediments or the granites of the basement (GRECO et al. 1989).

The cover is laterally more uniform. The base is composed of a distinct association of dark garnet amphibolite sheets, interbedded with pale yellow marbles. Above follow calcareous garnet-staurolite micaschists with isolated bands and beds of marbles and garnet amphibolites.

3. The Panjal Trap

The Panjal Trap (LYDEKKER 1878) in the NW Himalayas comprise large, mainly basaltic volcanic extrusions of Permian to Triassic age (WADIA 1957). They belong to the Panjal volcanic series (MIDDLEMISS 1910) together with the underlying agglomeratic slates. The whole volcanic suite reaches a maximum thickness up to 2500 m in the Kashmir valley (WADIA 1957) (Fig. 3).

The agglomeratic slates comprise intermediate to acid pyroclastic rocks (PAREEK 1976), interfingered with tilloides and alluvial deposits. Their thickness and lateral extent is highly variable and in some areas they may be missing completely as it is the case in the Western Syntaxis area (OTTIGER 1986).

The Panjal Trap basalts consist mainly of massive, aphyric, basaltic flows of a tholeiitic to mildly alkalic chemical affinity (HONEGGER et al. 1982). Associated intermediate and acid differentiation products are reported from various authors, but they form

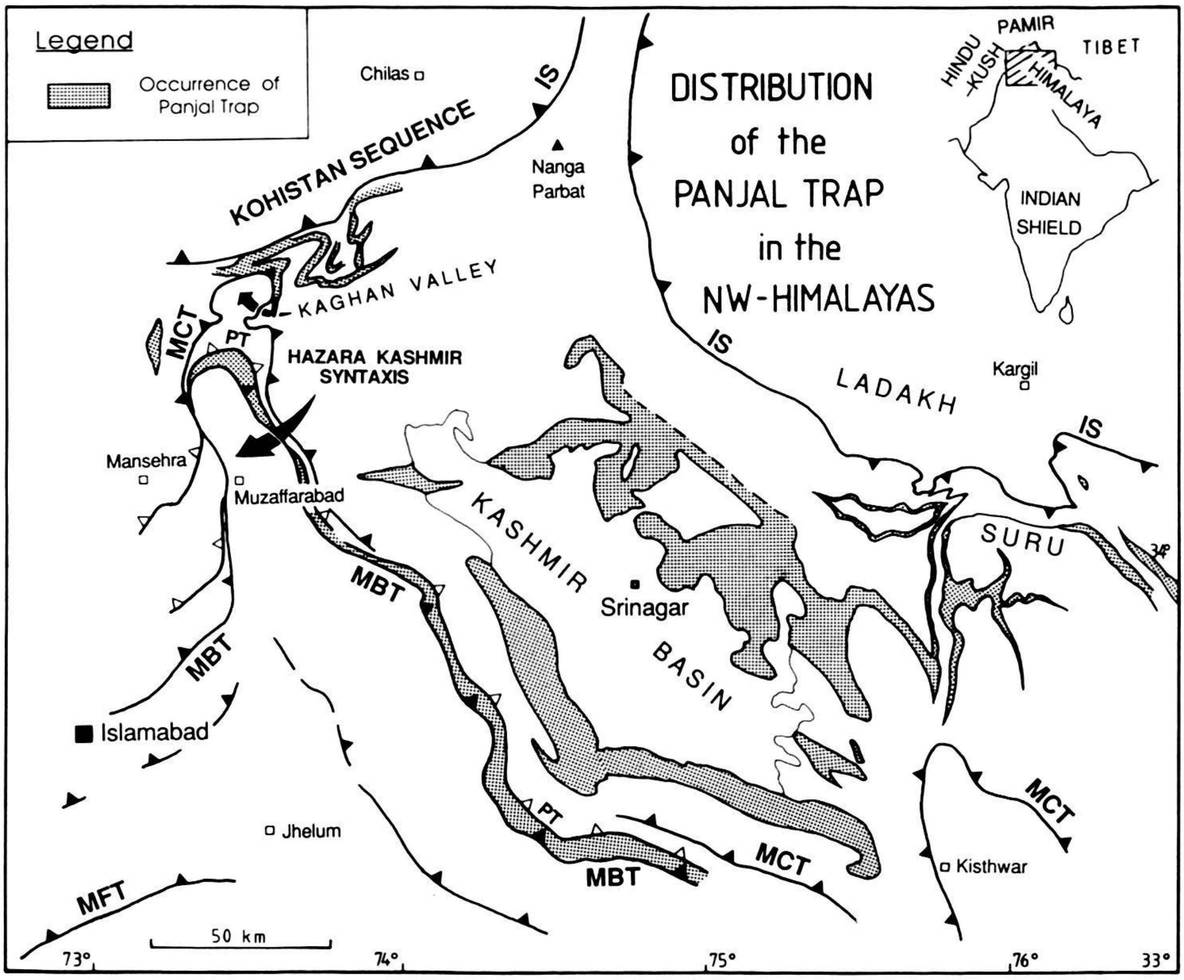

Fig. 3. Distribution of the Panjal Trap in the NW Himalayas modified after GRECO et al. (1989). Stippled Area: Occurrence of Panjal Trap, IS: Indus suture, MBT: Main Boundary thrust, MCT: Main Central thrust, MFT: Salt Range Main Frontal thrust, PT: Panjal thrust.

a minor fraction of the extruded rock volume. (For a review see PAREEK 1976.) East and west from the Kashmir valley, the thickness of the Panjal Trap decreases.

In the Kashmir valley, the Panjal Trap indicate a metamorphic degree of zeolite to upper greenschist facies. Towards northeast the metamorphic grade increases and reaches upper amphibolite facies conditions in the Suru area (HONEGGER et al. 1982). The same metamorphic grade is reached in the Upper Kaghan valley in the Western Syntaxis area (GRECO et al. 1989).

Environmental conditions during the eruption of the Panjal Trap were coastal subaqueous to subaerial as indicated by the under- and overlying sedimentary rocks (NAKAZAWA et al. 1975). The eruption of Panjal Trap has been dated by plant bearing interlayers at the lower and upper contact of the basalt flows. The underlying plant beds in the Vihi area in India are dated as Artinskian (KAPOOR 1977) and the overlying sedimentary rocks as Kungurian to Kazanian (NAKAZAWA et al. 1975). (For time references see HAQ et al. 1987.)

Panjal Trap eruption can be related to a late Paleozoic rifting phase along the northern Indian margin on the following reasons: Extensional tectonic activity in the

Suture zone at the Permian – Triassic break is documented by the marked change from neritic to pelagic sedimentary environment (BASSOULET et al. 1978). Development of a shelf in the Tibetan zone of the Himalayas in Triassic to early Eocene times after the Panjal volcanic event characterizes the evolution of a passive continental margin (BAUD et al. 1984, GAETANI et al. 1985 and GARZANTI et al. 1987).

4. Field Relations and Petrography of Basic Rocks

Basic rocks are found in the Lesser- and Higher-Himalayas of the Western Syntaxis area. Field relations and petrography of the basic rocks of the Western Syntaxis area are discussed. For reasons of clearness, only prograde Alpine regional metamorphism more or less synkinematic to the main deformational phases, which produced the penetrative foliations in the different tectonic units, is considered in the following discussion. Products of metamorphic alterations predating the main Alpine deformation will not be discussed, neither will retrograde metamorphic alteration related to later – phase deformations (for this see GRECO et al. 1989). The magmatic provenance of the protolith of the basic rocks can be established mainly by mineralogical and textural relics, which have not been completely obliterated by syndeformational metamorphic recrystallisation.

4.1 Salkhala Unit

The basic rocks are widespread in the Salkhala Unit. No angular discordances between the rather thin basic rock bodies and the surrounding wall rock were observed, partly because of the bad exposure of the rocks in the Salkhala Unit and because of the strong deformation and isoclinal folds prevalent throughout the Salkhala Unit (GRECO et al. 1989), bringing all observable planar structures (lithologic boundaries, bedding planes of the metasediments and penetrative foliation) into subparallel arrangement.

Foliated amphibolites are the dominant basic rock type in the Salkhala Unit. Their mineral assemblages accord with the regional metamorphic grade. Syndeformational metamorphic alteration is almost complete and leaves hardly any trace of preexisting minerals or textures apart from few augitic clinopyroxene relics in the cores of amphibole porphyroblasts.

In a few cases isolated dolerite bodies within metasedimentary rocks with a nearly unaltered magmatic mineralogy and well preserved igneous intergranular texture have been observed. In unaltered rocks, anhedral augitic clinopyroxene crystals occupy the spaces between randomly orientated, lath-shaped, calcic plagioclase crystals. Partly altered dolerites are characterized by epidotized plagioclases, arranged in a relict intergranular texture, and amphiboles at the rims of clinopyroxene crystals.

4.2 Panjal Unit

The Permian age and the correlation of the basic rocks of the Panjal Unit with Panjal Trap basalts from Kashmir is broadly accepted (BION & MIDDLEMISS 1928; WADIA 1931; CALKINS et al. 1975; GHAZANFAR & CHAUDRHY 1985; BOSSART et al. 1988; GRECO et al. 1989). Two types of basic rocks are found: Massive, light green metaba-

TECTONIC UNIT	ROCK TYPE	FIELD RELATIONS	MINERALOGY primary (magmatic)	MINERALOGY secondary (metamorphic)	TEXTURE	REGIONAL METAMORPHIC GRADE
Lesser Himalaya Panjal Unit	*light green metabasalt partly vesiculous*	*flow banding of massive and schistose varieties*	*pheno-X: plag(ep), cpx matrix: plag(ep),*	*ab,chl,ep,act, czo(bi,stil, wm,cc,ctd)*	*f.-g. intergranular aphyric, partly phyric or glomeroporphyritic*	*lower greenschist facies*
	dark green metatuffite		*FTox*	*chl,ab,czo, ep,bi,wm (stil)*	*foliated - schistose*	
Lesser Himalaya Salkhala Unit	*massive dolerite (transitions)*	*dykes concordant to main foliation in country rock*	*plag,cpx FTox*		*f.-g. to m.-g. intergranular*	*upper greenschist facies*
	amphibolite		*cpx relics*	*am,ab,chl, bi,ep,czo, sph (qtz,FTox,)*	*f.-g. to m.-g. foliated, porphyroblastic*	
Higher Himalaya basement	*massive dolerite (transitions)*	*dykes discordant to main foliation in country rock*	*plag,cpx, FTox(±ol)*	*hbl*	*f.-g. to m.-g. intergranular*	*amphibolite facies*
	massive amphibolite			*hbl,olig,ga, sph,FTox*	*m.-g. to c.-g. foliated, porphyroblastic*	
Higher Himalaya cover	*massive amphibolite*	*boudinaged sheets concordant to foliation and bedding*		*hbl,olig,ga, sph,FTox (cc,ep,zo, bi,±di)*	*m.-g. to c.-g. foliated, porphyroblastic*	

Abreviations:

ab	: albite	czo	: clinozoisite	plag	: calcic plagioclase
act	: actinolite	di	: diopsidic clinopyroxene	plag(ep):	epidotized plagioclase
am	: amphibole				
bi	: biotite	ep	: epidote	sph	: sphene
cc	: calcite	FTox	: Fe-Ti oxide	stil	: stilpnomelane
chl	: chlorite	ga	: garnet	wm	: white mica
cpx	: augitic clinopyroxene	hbl	: green hornblende	zo	: zoisite
		ol	: olivine		
ctd	: chloritoid	olig	: oligoclase		
f.-g.	: fine-grained	m.-g.	: medium-grained	c.-g.	: coarse-grained

Table 1: Description of basic rocks from the Western Syntaxis area.

salts are interbedded at decimeter scale with well foliated, dark green epidote-chlorite-schists. This intercalation can best be ascribed by a flow banding of massive lava flows and schistose tuffites (Bossart 1986). The tuffites are completely recrystallized due to syndeformational metamorphic growth of phyllosilicates, entirely loosing their protolithic mineralogy and texture.

In the massive metabasalts, rare clinopyroxene relics and epidotized plagioclase porphyroclasts form the mineralogical record of the magmatic provenance as well as intergranular and glomeroporphyritic texture. Typical characteristics of the metabasalts of the Panjal Unit are subspherical vesicles, filled with epidote and quartz.

4.3 Higher-Himalayan Basement

Basic dykes with crosscutting relationships to the lithologic boundaries are abundant in the basement part of the Higher-Himalaya. They were affected by the main Alpine synmetamorphic deformational event which produced the penetrative foliation in the Higher-Himalaya. A low angle discordance between the foliation and the dykes is prevalent (Fig. 4). The intrusion of the basic dykes clearly predates the Alpine deformation. Regional metamorphism affected the basic rocks to a variable degree. A transitional range of rocks between well preserved dolerites and completely recrystallized, foliated garnet – amphibolites is found. Dolerites with a magmatic intergranular texture are only found in the granitoid gneisses, a fact which probably can be explained by the absence of a fluid phase during Alpine metamorphism in these rocks (Greco et al. 1989).

Fresh dolerites contain augitic clinopyroxene, Fe-Ti oxides and calcic plagioclase. In slightly altered rocks, fine-grained pseudomorphs of hornblende after clinopyroxene and some small, disseminated garnets are present. With progressive metamorphic alteration the size of amphibole and garnet increases and the metamorphic fabric overprints the relict magmatic texture. Completely altered amphibolites are medium – to coarse – grained and well foliated.

4.4 Higher-Himalayan Cover

The base of the metasedimentary succession of the Higher-Himalayan cover is defined by an association of thick garnet-amphibolite sheets and marbles (Fig. 5). Also higher in the stratigraphic pile, subordinate, isolated amphibolite bodies can be found. The amphibolites are strongly deformed. Rare pillow – like structures and unconformable contacts to overlying sediments (Fig. 7 in Greco et al. 1989) indicate extrusive emplacement of lava for the amphibolites. Their stratigraphic relationships with the amphibolites and dolerites of the basement are not clear.

Petrographic relics of the magmatic protoliths are missing completely in the amphibolites. They are well foliated and their mineralogy is entirely metamorphic.

4.5 Conclusions from Field Relations and Petrography

The formation of the basic rocks predates the Himalayan orogeny. Deformation and simultaneous metamorphic overprint variably affected the basic rocks in all tectonic units.

A magmatic origin can be established from field relations and petrography for dolerites and amphibolites of the Higher-Himalayan basement and metabasalts in the Panjal Unit. Field relations suggest an extrusive nature for the amphibolite sheets in the Higher-Himalayan cover, but petrographic relics are missing completely. An intrusive origin is indicated for the dolerites in the Salkhala Unit. Only some of the amphibolites of the Salkhala Unit lack direct mineralogical evidence for an intrusive origin.

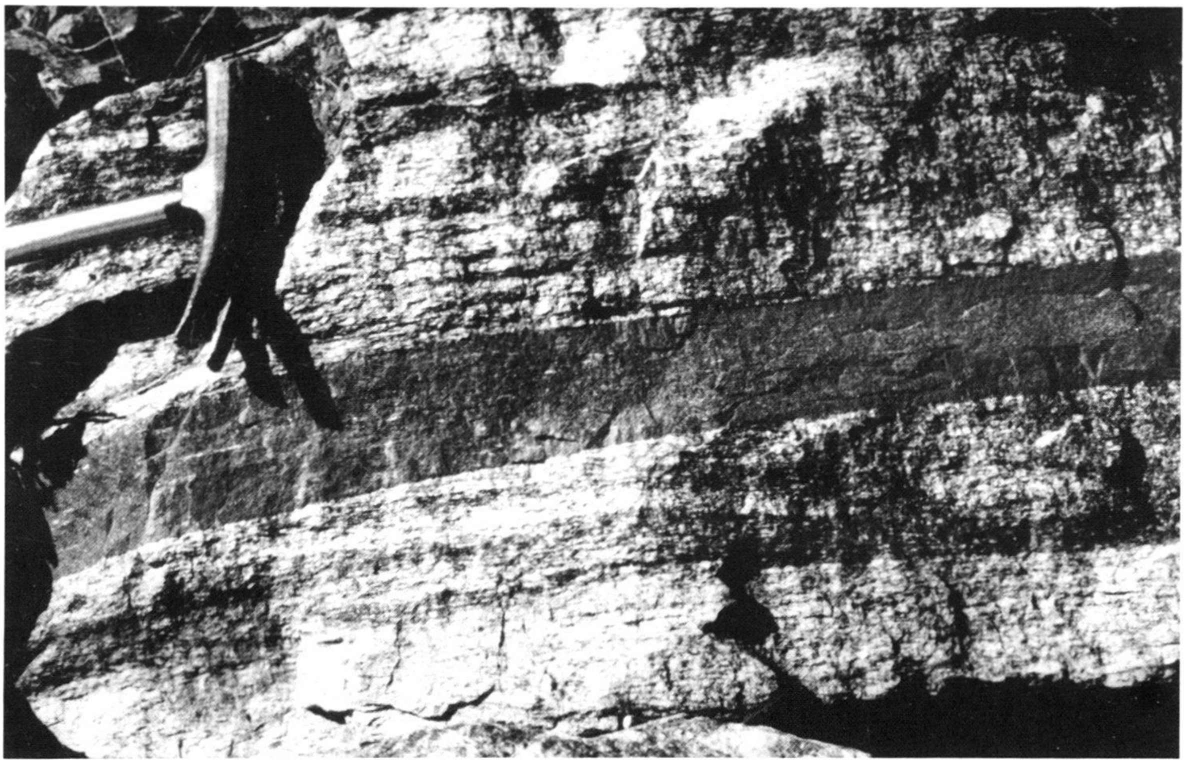

Fig. 4. Discordant amphibolite dyke in granitic augengneiss of the Higher-Himalayan basement.

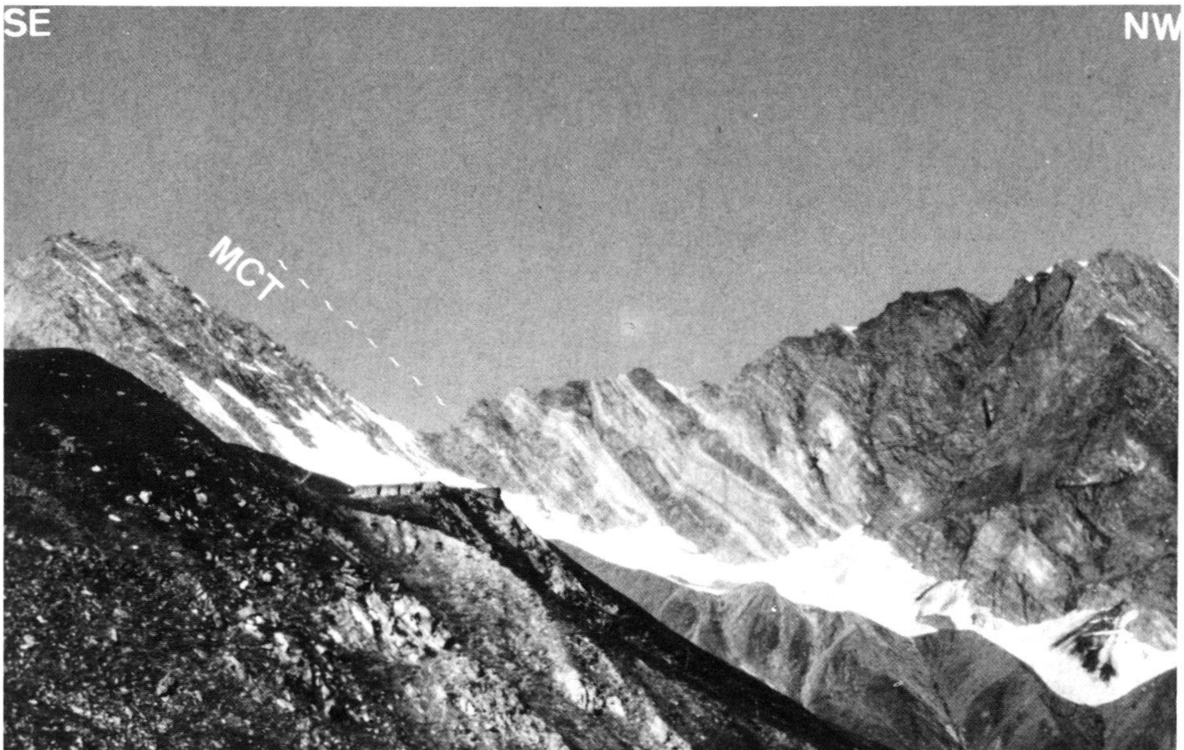

Fig. 5. Boudinaged, dark amphibolites of the Higher-Himalayan cover from a sidevalley west of Naran. They are embedded in yellowish marbles. Above (to the NW) follow calcareous metapelitic rocks of amphibolite facies metamorphic grade. Below (to the SE) lies the mylonite zone (MCT), which cuts the lithologies discordantly at a low angle.

In the possibly Precambrian to early Paleozoic rocks (Greco et al. 1989) of the Higher-Himalayan basement, the amphibolites and dolerites are of intrusive, hypabyssal nature. For the sharp contact relationships of amphibolites and dolerites in the Salkhala Unit, it is suggested that they also were intruded as hypabyssal dykes into the Precambrian to Cambro-Ordovician country rock, although no crosscutting discordances were observed in the strongly deformed rocks. A post-lower Paleozoic age can be deduced from the intrusive character of the basic dykes in the Salkhala Unit and the Higher-Himalayan basement. Metabasalts in the Panjal Unit and amphibolite sheets in the Higher-Himalayan cover represent basaltic surface flows.

5. Sampling and Geochemical Analytical Techniques

The chemical analyses were made on small rock specimens which had been collected for the general description of the regional geology. No systematic profiles of the basic rock bodies were sampled. The samples to be analyzed were chosen from a collection of rock specimens from both limbs of the Hazara Kashmir Syntaxis and its northern continuation of the apex area (Fig. 1) after the following criteria:

— Samples from the center of the basic bodies in order to minimize the effects of chemical reequilibration between the intruding rock body and the surrounding wall rock.
— Homogenous and representative mineralogy of the rock body.
— No signs of weathering or hydrothermal alteration.
— Minimum content of phyllosilicates of metamorphic origin.
— Well identifiable relics of magmatic origin of the rock (relics of primary texture and mineralogy).

Major and trace elements were analyzed by X-ray fluorescence (XRF) on a Philips sequential spectrometer PW 1450 at the EMPA, Dübendorf (Switzerland). USGS rock samples were used for calibration. For details of analytical techniques and computer corrections see Nisbet et al. (1979).

The accuracies of trace element measurements range around ±2–3% at 1000 ppm, ±5–10% at 100 ppm and ±10–20% at 10 ppm.

6. Geochemistry of Basic Rocks

For the discussion of the geochemical analyses, we group the data after the tectonic units:

— PJ (Tab. 2a): massive, light green metabasalts from the Panjal Unit.
— SA (Tab. 2b): amphibolites and dolerites from the Salkhala Unit.
— HHC (Tab. 2c): amphibolites from the Higher-Himalayan cover.
— HHB (Tab. 2d): amphibolites and dolerites from the Higher Himalayan basement.

Geochemical analyses were made mainly for basalt type discrimination and comparison with Panjal Trap basalts from Kashmir and Suru. Effects of secondary alteration as well as magma differentation are only discussed here as far as they could influence basalt type discrimination.

	DATA SUBGROUP PJ_{alk}			DATA SUBGROUP PJ_{thol}				
ELEMENTS (wt %)	PJ557	PJ076	PJ192	PJ315	PJK1	PJGS1	PJ197	PJ415
SiO_2	46.00	45.84	47.38	50.22	47.06	50.71	49.50	50.73
TiO_2	3.03	2.42	2.26	1.16	1.63	1.32	1.47	1.21
Al_2O_3	18.41	16.68	16.45	14.36	16.34	17.28	16.65	13.63
Fe_2O_3 tot	11.85	14.75	15.68	11.14	14.07	10.54	9.93	12.94
MnO	0.04	0.25	0.11	0.21	0.14	0.09	0.11	0.12
MgO	7.53	6.81	4.32	7.26	7.09	6.52	5.51	5.04
CaO	4.67	3.99	6.47	7.41	10.06	6.43	7.63	9.32
Na_2O	5.07	4.23	5.33	4.00	1.21	4.84	3.74	4.57
K_2O	0.03	0.78	0.14	0.09	0.82	0.37	1.80	0.06
P_2O_5	0.45	0.27	0.23	0.11	0.16	0.14	0.18	0.12
SUM	97.09	96.02	98.58	95.96	98.58	98.24	96.52	97.74
ELEMENTS (ppm)								
F	973	<250	<250	311	701	<250	<250	<250
Ba	<10	279	68	37	244	82	319	26
Rb	<8	10	<8	<8	<8	<8	54	<8
Sr	168	50	86	61	184	255	181	50
Nb	27	15	5	<4	<4	<4	<4	<4
La	39	25	<20	<20	<20	<20	<20	<20
Ce	63	59	66	27	32	22	21	27
Nd	29	30	31	<25	<25	<25	<25	<25
Y	20	37	32	13	21	15	17	14
Zr	197	250	206	92	122	103	119	75
V	231	287	293	257	274	239	203	267
Cr	206	49	29	493	338	281	152	600
Ni	83	47	69	18	98	84	76	140
Co	40	75	83	48	72	30	32	50
Cu	<3	<3	<3	196	28	77	83	456
Zn	108	226	119	85	110	77	75	59
Sc	43	24	27	40	33	29	26	38
S	<50	<50	<50	<50	<50	<50	<50	<50
Y/Nb	0.74	2.47	6.40	>3.25	>5.25	>3.75	>4.25	>3.50
Na2O/CaO	1.09	1.06	0.82	0.54	0.12	0.75	0.49	0.49
subgroup in fig.6	P1	P1	P1	P2	P2	P2	P2	P2

Table 2a: Geochemical analyses of metabasalts from the Panjal Unit (PJ data group) of the Western Syntaxis area. Data subgroups are discussed in the text. Sample localities are shown in Fig. 1.

	DATA SUBGROUP SA_{alk}					DATA SUBGROUP SA_{thol}			
ELEMENTS (wt %)	SA223	SA224	SA106A	SA212	SA220C	SA171	SA136*	SA137*	SA138*
SiO_2	45.77	46.29	44.56	49.66	49.35	46.09	49.25	47.99	48.66
TiO_2	3.06	2.49	4.23	2.93	3.19	1.38	1.41	1.74	1.79
Al_2O_3	13.93	13.81	14.29	13.83	12.31	13.96	15.05	13.65	13.82
Fe_2O_3 tot	15.66	14.75	15.08	13.79	16.85	12.25	12.67	13.56	13.62
MnO	0.23	0.24	0.23	0.18	0.22	0.18	0.19	0.19	0.20
MgO	6.22	6.18	5.26	5.17	5.17	7.27	7.01	6.89	6.67
CaO	10.31	9.97	9.24	7.37	9.14	13.15	12.23	11.00	10.70
Na_2O	2.79	2.89	2.84	4.32	2.23	1.87	2.41	2.26	2.28
K_2O	0.58	0.41	1.58	1.16	0.47	0.28	0.39	0.73	0.48
P_2O_5	0.36	0.32	0.85	0.34	0.37	0.13	0.15	0.18	0.19
SUM	98.91	97.35	98.16	98.75	99.30	96.56	100.76	98.19	98.41
ELEMENTS (ppm)									
F	1348	896	1549	1208	607	1102	787	624	629
Ba	92	87	1227	284	57	93	57	115	113
Rb	31	17	54	40	13	<8	12	31	10
Sr	408	348	752	167	264	304	171	180	181
Nb	19	13	13	26	18	<4	<4	<4	<4
La	20	<20	111	53	32	<20	<20	<20	<20
Ce	59	57	84	80	59	26	<15	21	17
Nd	28	<25	50	33	39	<25	<25	<25	<25
Y	24	21	15	25	36	11	26	22	21
Zr	146	135	129	192	233	70	85	104	105
V	328	272	383	357	360	310	349	395	315
Cr	75	66	47	34	72	136	126	135	119
Ni	53	73	33	37	59	103	81	79	82
Co	93	86	83	70	87	80	72	71	52
Cu	36	115	<3	<3	317	141	171	171	178
Zn	120	137	100	82	142	81	87	95	92
Sc	30	28	28	27	38	46	49	44	39
S	739	3523	<50	<50	3160	<50	79	<50	338
Y/Nb	1.26	1.62	1.15	0.96	2.00	>2.75	>6.50	>5.50	>5.25
Na2O/CaO	0.27	0.29	0.30	0.59	0.24	0.14	0.20	0.21	0.21
subgroup in fig.6	S1	S1	S1	S2	S1	S2	S2	S2	S2

Table 2b: Geochemical analyses of amphibolites and dolerites from the Salkhala Unit of the Western Syntaxis area. Data subgroups are discussed in the text. Sample localities are shown in Fig. 1. Samples with an asterisk are dolerites.

	DATA SUBGROUP HHC_{alk}					DATA SUBGROUP HHC_{thol}				
ELEMENTS (wt %)	HHCK139	HHCK125	HHCK146	HHCK116	HHCK62	HHCK95	HHCK128	HHCK127	HHCK126	HHCK135
SiO_2	47.68	45.78	47.20	46.86	48.89	48.23	47.43	47.76	47.20	48.07
TiO_2	3.85	4.36	4.03	4.43	3.28	1.55	2.42	2.94	2.61	2.76
Al_2O_3	13.13	12.09	11.88	11.44	13.56	14.81	14.56	13.68	14.15	16.57
Fe_2O_3 tot	14.60	17.57	16.93	17.84	15.10	12.25	12.65	14.36	13.28	11.65
MnO	0.20	0.21	0.20	0.20	0.19	0.16	0.18	0.19	0.19	0.16
MgO	5.78	5.23	5.12	4.96	4.64	7.22	6.62	6.56	6.36	4.15
CaO	10.43	9.98	9.72	8.58	6.74	8.84	11.49	9.86	9.95	9.84
Na_2O	2.78	2.68	2.23	3.03	5.31	3.33	2.24	2.72	2.89	3.77
K_2O	0.66	0.47	0.32	0.14	0.19	0.65	0.42	0.41	0.26	0.78
P_2O_5	0.27	0.34	0.43	0.42	0.47	0.18	0.23	0.28	0.25	0.25
SUM	99.38	98.71	98.06	97.90	98.37	97.22	98.24	98.76	97.14	98.00
ELEMENTS (ppm)										
F	1126	888	826	754	311	560	914	728	463	671
Ba	271	65	60	<10	<10	123	95	68	<10	234
Rb	23	<8	<8	<8	<8	<8	<8	<8	<8	22
Sr	333	258	208	170	75	219	397	480	457	860
Nb	13	24	17	19	23	<4	6	11	8	8
La	47	70	68	75	39	<20	<20	<20	<20	<20
Ce	53	81	68	78	78	25	36	44	35	31
Nd	<25	33	36	43	39	<25	<25	<25	<25	<25
Y	25	33	38	44	39	18	19	24	22	19
Zr	163	229	257	279	293	104	139	164	146	141
V	405	485	471	409	408	333	375	333	286	353
Cr	80	87	69	55	<6	121	118	116	107	67
Ni	66	58	51	57	24	62	87	87	83	46
Co	96	85	79	73	43	56	83	73	59	54
Cu	138	424	355	352	113	172	155	165	177	150
Zn	123	165	153	172	104	94	99	111	107	99
Sc	47	43	39	42	31	47	38	41	38	31
S	<50	<50	167	<50	1791	<50	<50	<50	<50	<50
Y/Nb	1.92	1.38	2.24	2.32	1.70	>4.50	3.17	2.18	2.75	2.38
Na2O/CaO	0.27	0.27	0.22	0.35	0.79	0.38	0.19	0.28	0.29	0.38
subgroup in fig.6	C2	C2	C2	C2	C1	C1	C2	C2	C2	C1

Table 2c: Geochemical analyses of amphibolites from the Higher-Himalayan cover of the Western Syntaxis area. Data subgroups are discussed in the text. Sample localities are shown in Fig. 1.

	DATA SUBGROUP HHB$_{alk}$			DATA SUBGROUP HHB$_{thol}$						
ELEMENTS (wt %)	HHBK45*	HHBK17*	HHB278*	HHBK26	HHBK25*	HHBK27*	HHBK29	HHB284*	HHBK34	HHB283*
SiO_2	49.91	50.00	52.47	47.04	47.25	47.95	47.72	48.67	48.16	48.70
TiO_2	1.95	2.25	3.25	1.17	1.16	1.38	1.64	1.75	1.81	1.86
Al_2O_3	14.03	14.24	13.00	16.47	16.51	14.07	15.97	12.77	14.57	13.91
Fe_2O_3 tot	13.51	14.51	16.76	11.40	11.25	12.77	13.08	14.21	13.18	14.39
MnO	0.20	0.21	0.23	0.17	0.16	0.19	0.19	0.24	0.19	0.24
MgO	5.61	5.03	3.01	9.31	9.00	7.53	7.09	6.77	6.34	5.77
CaO	9.86	9.89	7.11	11.02	11.03	12.12	9.67	10.94	11.04	10.65
Na_2O	2.60	2.78	2.27	1.71	2.19	2.24	2.07	2.23	2.53	2.35
K_2O	1.14	1.25	1.71	0.25	0.26	0.34	0.73	0.57	0.42	0.63
P_2O_5	0.29	0.31	0.25	0.12	0.12	0.15	0.18	0.18	0.23	0.23
SUM	99.10	100.47	100.06	98.66	98.93	98.74	98.34	98.33	98.47	98.73
ELEMENTS (ppm)										
F	810	913	<250	657	777	439	553	597	642	543
Ba	264	289	364	55	54	76	209	150	97	171
Rb	29	38	68	<8	<8	<8	15	18	<8	19
Sr	217	227	166	162	161	148	192	150	200	166
Nb	13	18	13	<4	<4	<4	<4	<4	<4	<4
La	<20	32	62	<20	<20	<20	<20	<20	<20	<20
Ce	63	64	59	<15	<15	16	37	<15	27	31
Nd	<25	26	28	<25	<25	<25	<25	<25	<25	<25
Y	30	36	41	15	16	20	24	29	24	35
Zr	186	203	216	48	46	74	115	110	118	133
V	358	421	406	244	252	365	285	377	378	347
Cr	65	37	11	317	309	214	100	56	133	35
Ni	58	45	<3	127	117	98	82	60	65	50
Co	61	69	31	61	59	56	69	56	65	60
Cu	170	253	0	26	44	181	54	211	198	299
Zn	111	111	126	76	74	80	105	118	95	114
Sc	38	38	40	39	39	42	39	47	45	40
S	364	<50	186	304	1309	1950	1290	<50	<50	<50
Y/Nb	2.31	2.00	3.15	>3.75	>4.00	>5.00	>6.00	>7.25	>6.00	>8.75
Na2O/CaO	0.26	0.28	0.32	0.16	0.20	0.18	0.21	0.20	0.23	0.22
subgroup in fig.6	B1	B1	B1	B2	B2	B2	B2	B2	B2	B2

Table 2d: Geochemical analyses of amphibolites and dolerites from the Higher-Himalayan basement of the Western Syntaxis area. Data subgroups are discussed in the text. Sample localities are shown in Fig. 1. Samples with an asterisk are dolerites.

6.1 Major Element Characteristics

The (Na_2O+K_2O) vs. SiO_2 variation diagram (Fig. 6) illustrates a considerable variability in composition for all datagroups. PJ-, SA- and HHC-samples lie in both the alkalic and subalkalic compositional fields, the HHB-samples plot in the subalkalic field only. Datapoints in Fig. 6 can be classified in two groups for each tectonic unit (Groups P1 and P2 for PJ-samples, S1 and S2 for SA-samples, C1 and C2 for HHC-samples and B1 and B2 for HHB-samples, see also Fig. 6 and Tabs. 2a-d).

Na and to a lesser extent also Si are likely to vary due to secondary alteration process like postmagmatic metasomatism and spilitisation (Best 1982). The influence of spilitisation can be illustrated by the Na_2O/CaO ratio (see Tabs. 2a-d). This ratio is high (> 0.66 according to Bearth & Stern 1971) for spilitic rocks. The rock samples of the P1 datagroup (Fig. 6) from the Panjal Unit and one sample from the Higher-Himalayan cover (HHCK62) have a Na_2O/CaO ratio of more than 0.66. Amphibolite and dolerite samples from the SA and the HHC datagroups have a more variable ratio

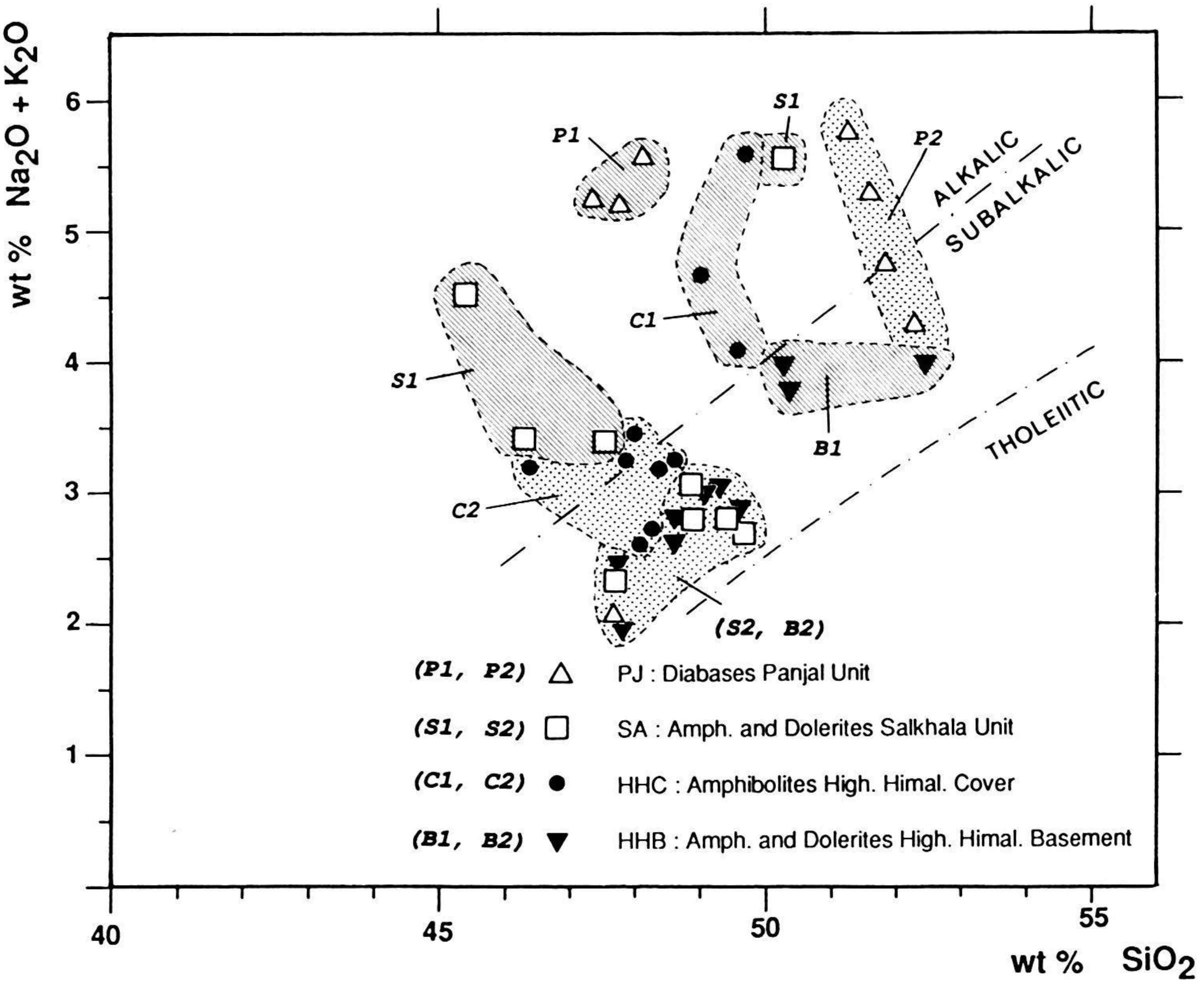

Fig. 6. (Na_2O+K_2O) vs. SiO_2 variation diagram. Alkalic-subalkalic boundary after MacDonald & Katsura (1964), tholeiitic boundary after Kuno (1968). Analyses are plotted anhydrous and calcite free. Data grouped after tectonic units from the Western Syntaxis area: PJ: Panjal Unit; SA: Salkhala Unit; HHC: Higher-Himalayan cover; HHB: Higher-Himalayan basement.

than the dolerites and amphibolites of the HHB datagroups, but they all lie well below 0.66.

The classification of the analyzed basic rocks into alkalic, subalkalic and tholeiitic rocks only by the ($Na_2O + K_2O$) vs. SiO_2 variation diagram is problematic and has to be compared with the distribution of other elements which are less likely subject to secondary alteration.

The P_2O_5 vs. TiO_2 variation diagram (Fig. 7) is more reliable for discrimination of primary, magmatic geochemical character of basic rocks, because P and Ti are immobile during secondary alteration of the rocks (CANN 1970). Alkalic basalts generally have a higher content in Ti and P than tholeiites (HAWKINS 1980). In Fig. 7 the datapoints of each tectonic unit can be classified in two subgroups, one with a tholeiitic character (low Ti and P content) (subgroups PJ_{thol}, SA_{thol}, HHC_{thol} and HHB_{thol}), the other with a slightly alkalic character (subgroups PJ_{alk}, SA_{alk}, HHC_{alk} and HHB_{alk}). In Tabs. 2a-d the analyses are grouped after these subgroups.

This classification in Fig. 7 into tholeiitic and slightly alkalic samples matches with the classification in Fig. 6 for metabasalts of the Panjal Unit (PJ) and for dolerites of the Higher-Himalayan basement (HHB). For rocks of the Salkhala Unit (SA) and the Higher-Himalayan cover (HHC) the two classifications differ. (See also Tabs. 2a-d.)

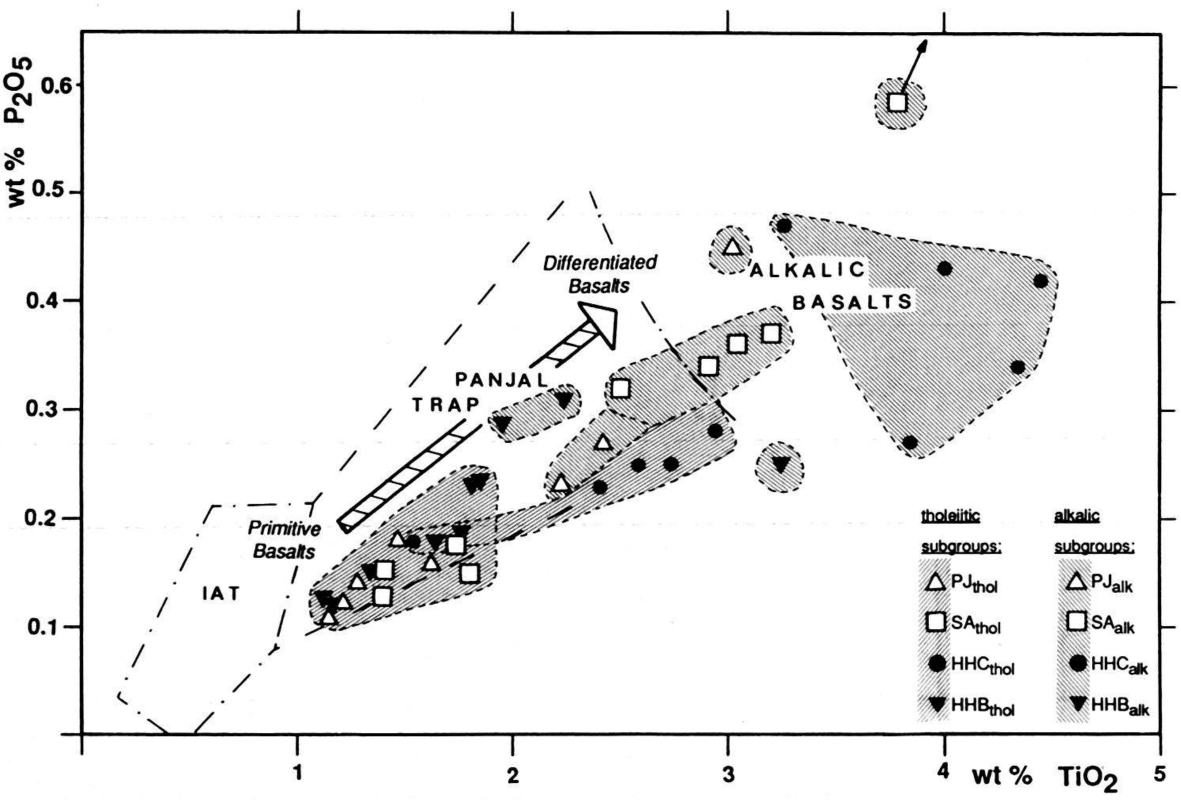

Fig. 7. P_2O_5 vs. TiO_2 variation diagram. Island Arc Tholeiite (IAT) discrimination field and alkalic basalt field from HAWKINS (1980); Panjal Trap distribution field from HONEGGER et al. (1982). Data grouped after tectonic units from the Western Syntaxis area: PJ: Panjal Unit; SA: Salkhala Unit; HHC: Higher-Himalayan cover; HHB: Higher-Himalayan basement.

6.2 Trace Element Characteristics

Not only Ti and P but also Y, Nb and Zr are commonly regarded to be intensive to metasomatic alteration processes (CANN 1970).

In the Ti/100-Zr-3xY discrimination diagram (Fig. 8), the bulk of PJ-, SA- and HHC-samples clearly lie in the same compositional field which was designed by PEARCE & CANN (1973) for within plate basalts. Only the HHB-samples seem to show a slightly higher relative content in Y. Panjal Trap basalts from Suru lie in the same discrimination field as do the samples from the Western Syntaxis area.

The alkalic-tholeiitic character of basic rocks can be illustrated by the Y/Nb ratio (PEARCE & CANN 1973). Alkalic basalts usually have a Y/Nb ratio, which is less than 1 whereas for tholeiitic basalts, the ratio typically is higher than 1. The Y/Nb of the analyzed samples range from tholeiitic (subgroups PJ_{thol}, SA_{thol}, HHC_{thol} and HHB_{thol}) to transitionally alkalic (subgroups PJ_{alk}, SA_{alk}, HHC_{alk} and HHB_{alk}) (Tabs. 2a-d). 17 of the samples from the Western Syntaxis area have a Nb content of less than 4 ppm, which is the lower detection limit for this element. This low Nb content indicates rather a tholeiitic composition. High content in Nb and the light rare earth elements (LREE) La, Ce and Nd is indicative for alkalic basic rocks (WEDEPOHL 1985).

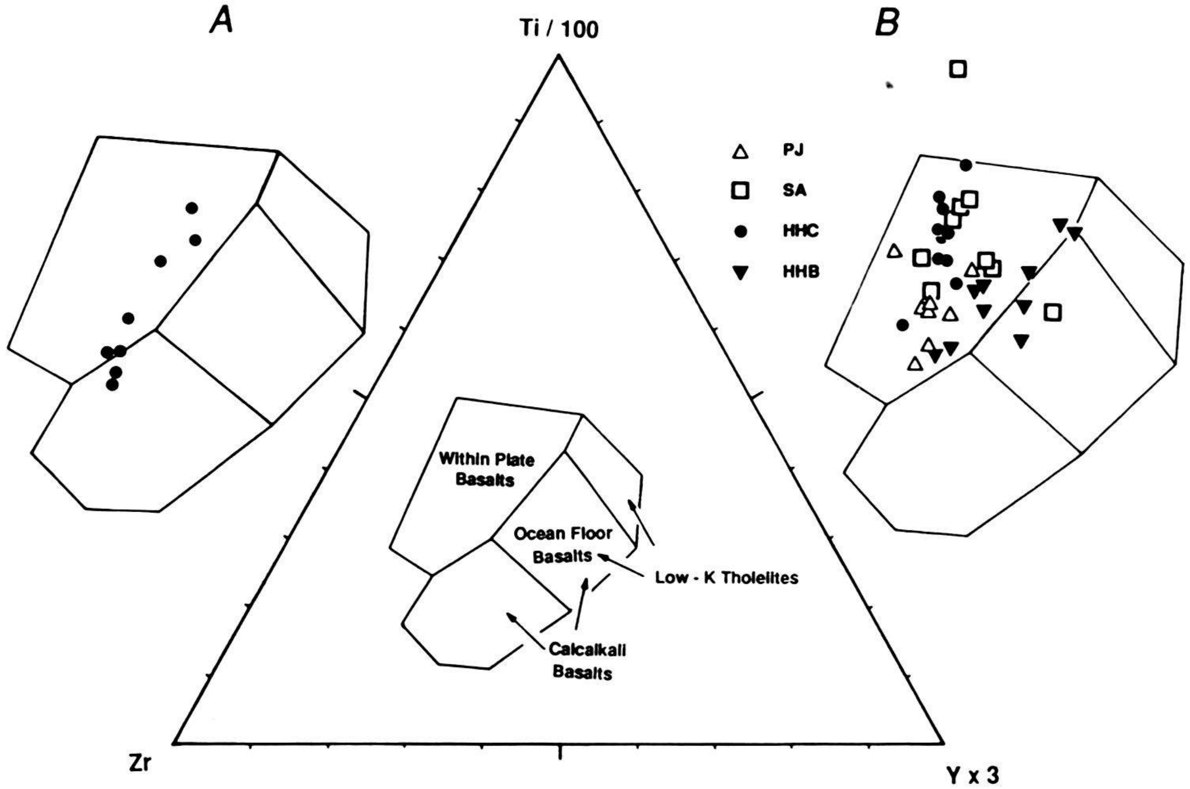

Fig. 8. Ti/100-Zr-3xY variation diagram with discrimination fields for basalts from different tectonic settings after PEARCE & CANN (1973).
A: Panjal Trap basalts from Suru (HONEGGER et al. 1982). B: Samples from the Western Syntaxis area (PJ, SA, HHB and HHC data groups).

In the normalized trace element spidergram (Fig. 9), the mean values of the various data groups (PJ, SA, HHC, HHB) show a similar trend of enrichment/depletion relative to an average tholeiitic MORB. The relative amount of enrichment between the different mean values is not consistent for all elements, but the overall trend is the similar for the PJ, SA and HHB datagroups. This overall trend is best outlined by the HHB datagroup (see Fig. 9). These samples are enriched in Rb, Ba and K by a factor of 3 to 10.5. Nb, Sr, P, Zr and Ti are slightly enriched by a factor of 1 to 2.5. Y and Ni enrichment is close to 1 and Cr is depleted for all datagroups apart from the PJ datagroup which lies close to 1 for this element. The HHC datagroup is less enriched in Rb, Ba and K than the other datagroups (only by a factor of 2 to 4) and has a slightly higher content in Nb, Sr, P, Zr and Y. Apart from the Ti content in the HHC datagroup all data lie well in the range of Panjal Trap basalts from Lidderwat and Suru (Bhat & Zainuddin 1979) and Honegger et al. 1982).

The pattern of enrichment of all data groups is similar to the enrichment pattern for tholeiitic to transitionally alkalic within plate basalts of Pearce (1982).

6.3 Discussion of Data

A slightly alkalic affinty of basic rocks is mainly outlined by enrichment of Rb, Ba, K and Sr as well as of Nb, P, Zr and Ti.

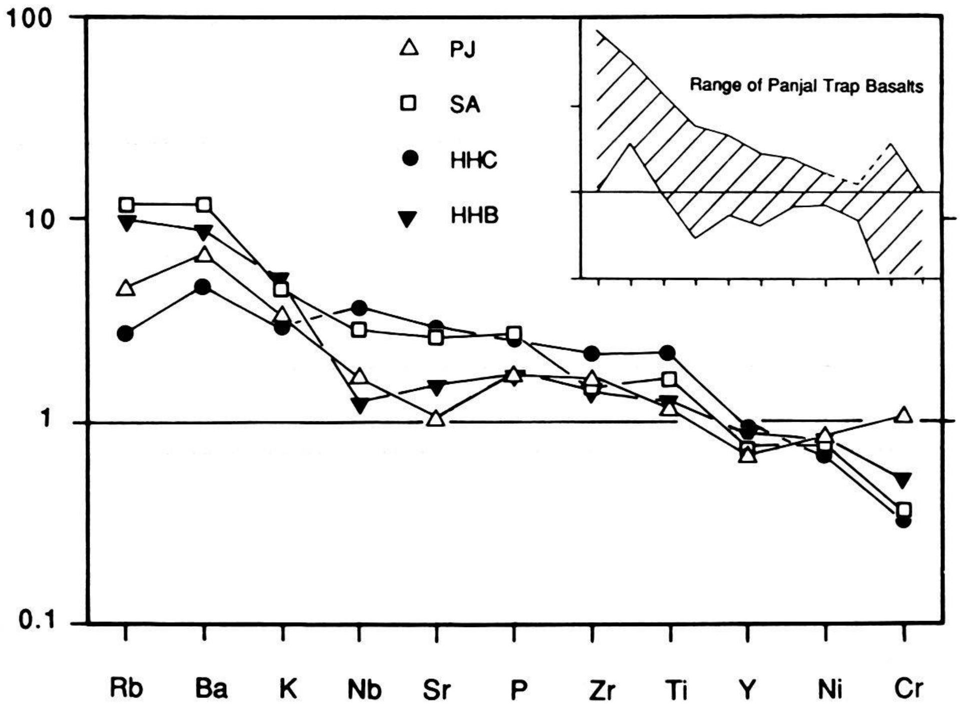

Fig. 9. Tholeiitic Mid Ocean Ridge Basalt (MORB) normalized trace element patterns of mean values of data groups. Standard values of tholeiitic MORB from Pearce (1982). Data groups: PJ: samples from Panjal Unit; SA: samples from Salkhala Unit; HHC: samples from Higher-Himalayan cover; HHB: samples from Higher-Himalayan basement. Range of Panjal Trap from Bhat & Zainuddin (1979) and Honegger et al. (1982).

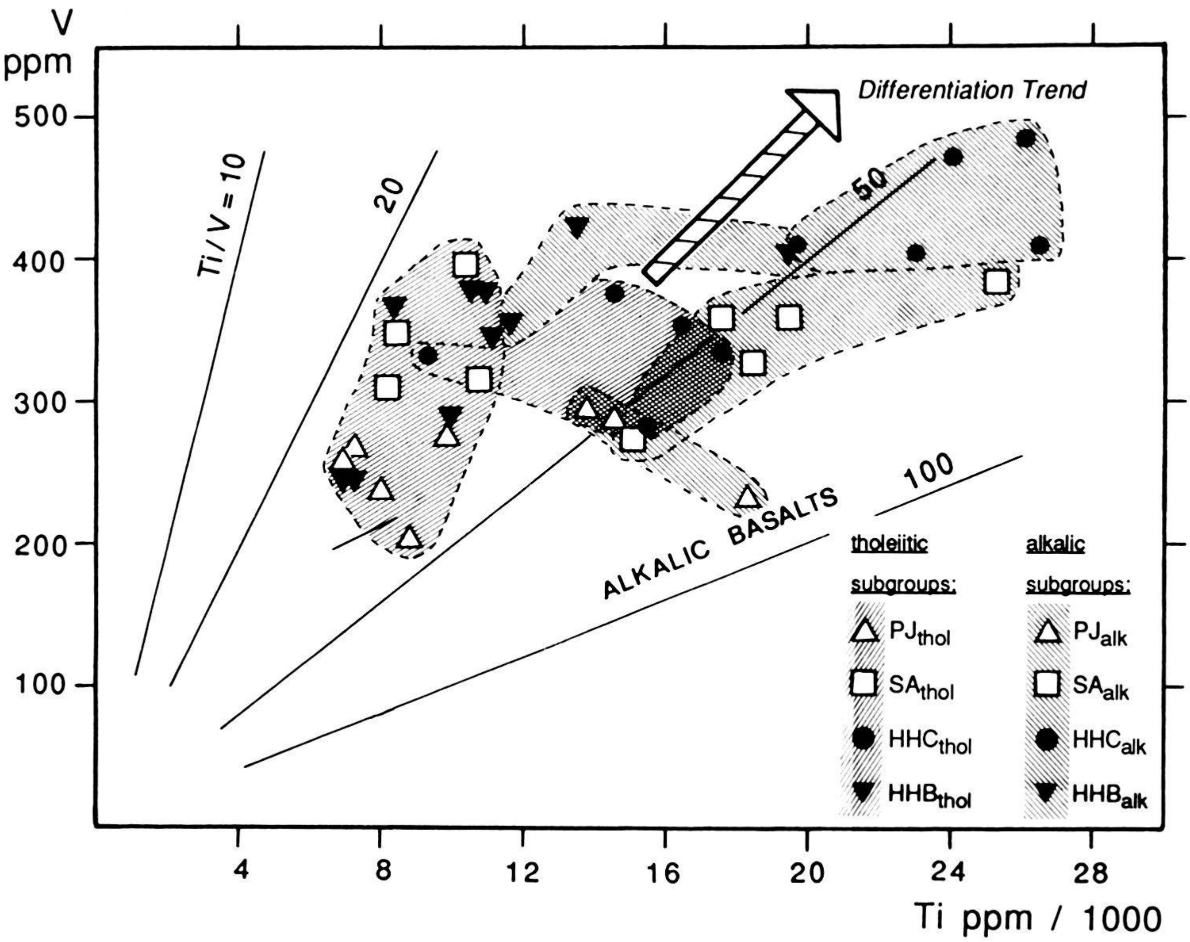

Fig. 10. V vs. (Ti/1000) variation diagram after Shervais (1982). Continental flood basalts range in Ti/V ratio between 20 and 50, alkalic basalts between 50 and 100.

Differentiation due to fractional crystallisation of olivine and plagioclase leads to a successive enrichment of the incompatible elements Nb, P, Zr, V and Ti (Pearce 1982). An alkalic character defined by higher content in Nb, P, Zr and Ti therefore can be explained as an effect of differentiation. With increasing differentiation, the datapoints in the P_2O_5 vs. TiO_2 variation diagram (Fig. 7) progressively move towards higher P and Ti contents and therefore towards the compositional field of alkalic basalts. In the V vs. Ti/1000 variation diagram (Fig. 10), the differentiation trend for olivine and plagioclase fractionation parallels lines of constant Ti/V ratios. Datapoints in Fig. 10 with high content of Ti and V belong to datasubgroups with a slightly alkalic composition (subgroups PJ_{alk}, SA_{alk}, HHC_{alk} and HHB_{alk}). The higher Ti/V ratio of some of these samples rather indicates a primary magmatic alkalic character (Shervais 1982) than a higher state of differentiation. However the high content in incompatible elements Nb, P, Zr and Ti in the samples of the alkalic subgroups goes together with low content in the compatible elements Mg, Cr and Ni (see Tabs. 2a-d), a fact which documents the effect also of differentiation. The lower content in the compatible elements Rb, Ba, K, Ni and Cr (Wedepohl 1985) and the enrichement of incompatible elements in the samples of the HHC datagroup indicates a higher state of differentiation at least for the amphibolites of the Higher-Himalayan cover.

6.4 Conclusions from Geochemistry

The basic rocks from the Western Syntaxis area all have an overall similar chemical composition. Variable content in incompatible elements allows to group the analyses from all tectonic units in tholeiitic and slightly alkalic subgroups. Major elements (mainly Si, Na and Ca) have been subject to metasomatic alteration. The similar distribution patterns of trace elements in basic rocks from all tectonic units allows us to rule out major secondary alterations which would cause strong local variations.

The amphibolites of the Salkhala Unit and the amphibolites of the Higher-Himalayan cover are chemically similar to the dolerites. Therefore their common provenance becomes evident.

The trace element enrichment patterns relative to a tholeiitic MORB of PJ, SA, HHB and HHC data groups are similar to an enrichment pattern which is typical for tholeiitic to slightly alkalic within plate basalts. Trace element distributions indicate an overall similarity in chemical composition between all basic rocks of the Western Syntaxis area and Permian Panjal Trap basalts.

Samples from the Higher-Himalayan cover have a higher content in the elements Nb, Sr, P, Zr and Ti. This can be explained either by a primarily more alkalic character or by a higher degree of differentiation. The first possibility seems to be less likely, because trace elements distributions in alkalic basalts would cause a much higher positive peak of enrichment for Nb relative to P, Zr and Ti as well as a stronger enrichment of Rb, Ba, K and Sr than is the case in Fig. 9.

7. Summary and Conclusions

– In the Western Syntaxis area basic rocks occur in different tectonic units and their emplacement predates regional metamorphism, which increases in grade from south to north.

– In the Panjal Unit metabasalts occur. In the Salkhala Unit few observed dolerites still reveal their magmatic origin, whereas the majority of the basic rocks are completely recrystallized to amphibolites and have only few mineralogical relics of magmatic origin. In the Higher-Himalayan basement, dolerite dykes are found, which are progressively transformed into garnet-amphibolites. Field relations of the amphibolites from the Higher-Himalayan cover indicate their magmatic origin but petrographic relics are missing.

– The basic rocks of the Western Syntaxis area all have a similar geochemistry. They are suggested to be of the same provenance and can be geochemically correlated with the Permian Panjal Trap basalts from Kashmir and Suru. They have a tholeiitic to mildly alkalic basaltic composition. The amphibolites from the Higher-Himalayan cover are more differentiated than the metabasalts from the Panjal Unit and the dolerites and amphibolites from the Salkhala Unit Higher-Himalayan basement.

– The metabasalts of the Panjal Unit and the amphibolites of the Higher-Himalayan cover are metamorphosed basalt flows, extruded at the surface in Permian times. Hypabyssal dolerite – and amphibolite dykes are restricted to the Salkhala Unit and the Higher-Himalayan basement. They have a post-lower Paleozoic age. Their relationships with the surface flows of the Panjal Unit and the Higher-Himalayan cover are not fully clear. However the dykes can be found only below the thick amphibolite sheets at the base of the Higher-Himalayan cover.

– Stutz (1988) describes early Paleozoic basic dykes related to the Cambro-Ordovician magmatic episode in SE-Ladakh. An early Paleozoic age for the basic dykes in the Western Syntaxis area cannot completely be ruled out from their field relations, however petrographic and geochemical analogies to Permian Panjal Trap basalts rather indicate a Permian age.

– The correlation of the amphibolites of the Higher-Himalayan cover with the Panjal Trap allows us to date the overlying metasediments in the cover as latest Paleozoic to Mesozoic. A pre-Permian age of the underlying metagreywacke rocks of the basement confirms the suggested analogies of these rocks to lower to middle Paleozoic sedimentary rocks at the base of the Tibetan series in NW-India.

– The basic rocks believed to be of Permian age underwent only Alpine metamorphism together with the late Paleozoic to Mesozoic metasediments in the Higher-Himalayan cover. This is not the case for the metasedimentary rocks and granitic gneiss in the Higher-Himalayan basement and the Salkhala Unit, for which relict pre-Alpine metamorphic records (Pognante & Lombardo 1989) cannot competely be ruled out. No positive evidence for relics of distinctly pre-Alpine metamorphism in the Western Syntaxis area has been reported up to now (Greco 1989).

– The eruption of basalts with a "within plate basalt geochemistry" in some cases is associated with rifting activities. The Panjal Trap eruption could be related with a rifting phase preparing the opening of the Mesozoic Himalayan Tethys but the question whether or not the Panjal Trap basalts formed in a rifting environment in Permian times cannot be answered on the basis of geochemistry only. Structural evidence of Permian extension tectonics in the NW Himalaya is lacking so far. In Zanskar, it was shown that the eruption of the Panjal Trap during Permian was followed by the evolution of a passive continental margin between Triassic and early Eocene times (Baud et al. 1984; Gaetani et al. 1985; Frank et al. 1987; Garzanti et al. 1987 and Nicora et al. 1987).

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