PART II

GRANITES IN THE HIMALAYAS AND THEIR COMPARISON WITH HERCYNIAN GRANITES IN EUROPE

1. Introduction

The Himalayas form part of the great arc like orogenic belt extending from Spain to Indonesia. The Himalayan mountain system is a conspicuous landmass characterized by its unique crescent shape, high orography, varied lithology and complex structure. It extends for 2400 km along the arc and 2200 km along the chord. The width varies between 325 and 425 km. The mountain ranges trend NW-SE in the western Himalayas and E-W in the central Himalayas. Orographically, the Himalayas can be divided into four parallel zones from south to north. First – the Sub-Himalayas comprises the low hill ranges of Siwalik. Second – the Lesser Himalayas forms a series of mountain ranges, which do not cross 4000 m altitude; Third – the Higher Himalayas comprises very high mountain ranges with glaciers rising above 4000 msl. Fourth- the Trans Himalayas, comprises high mountain ranges with glaciers to the north of the Higher Himalayan range.

1.1 Tectonostratigraphic Subdivisions of Himalayas

The Himalayan fold belt can be divided into several tectonic zones, separated by means of deep faults or thrusts that lie parallel to the main Himalayan trends (Fig. 23 and Table 8). These tectonic zones have distinct lithostratigraphy, tectonic architecture, history of metamorphism, deformation and magmatic episodes.

In general, the Himalayas have been constructed by various parallel deep faults or thrusts along its entire length. The major E-W trending faults and thrusts are marked by various-cross cut transcurrent faults and lineaments (Fig. 24). Four thrusts are mainly responsible for present architecture of the Himalayas, (i.e. the Himalayan Frontal Fault, (HFT), the Main Boundary Thrust (MBT), the Main Central Thrust (MCT), and the Indus Tsangpo Suture Zone (ITSZ).

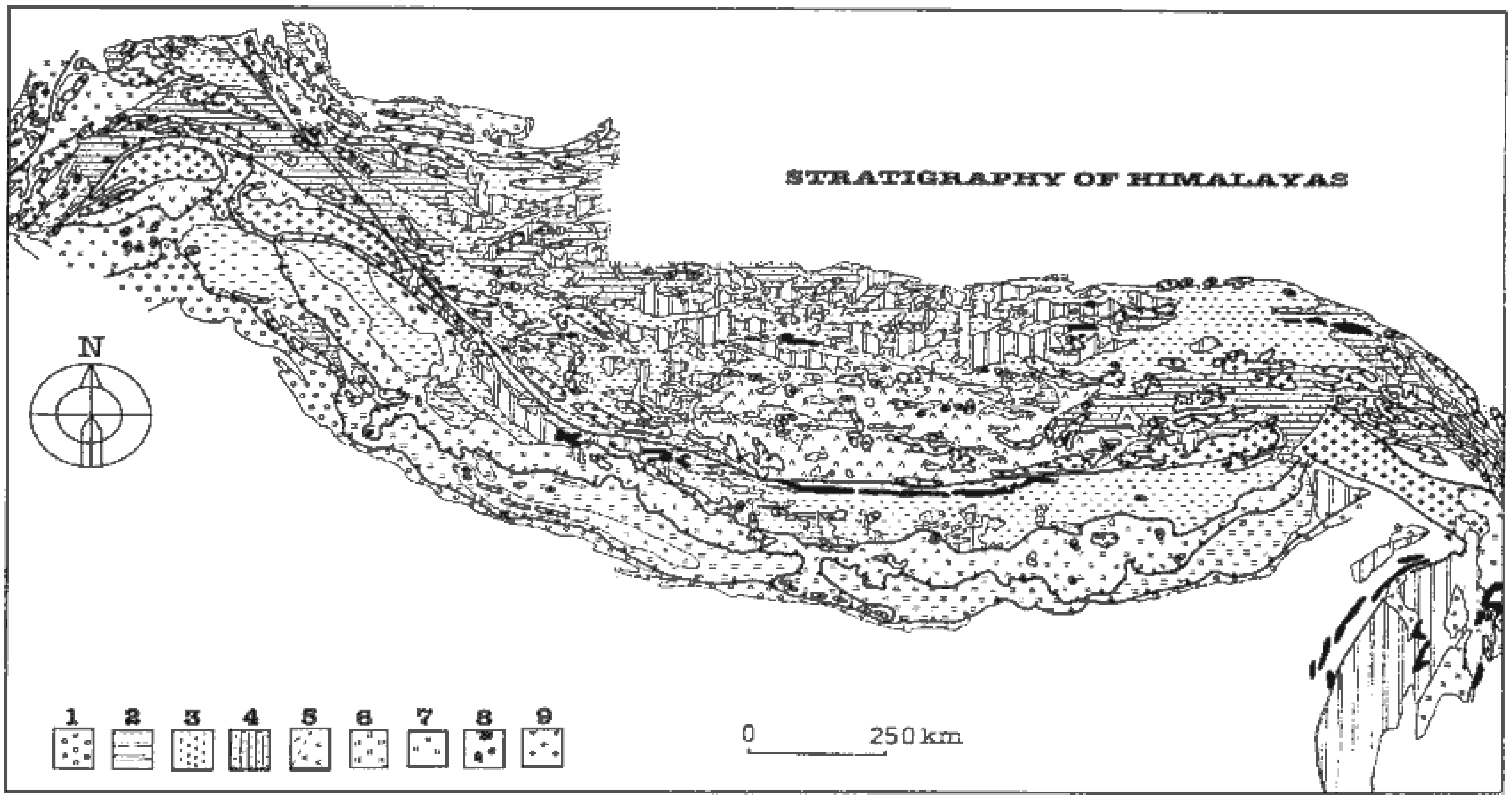


Fig. 23. Simplified geological map of Himalayas [compiled after Sharma (1990), GSI (1990), Valdiya (1980) and many authors]. 1 - Siwaliks and equivalents, 2 – Tertiary Formations, 3 – Mesozoic Formations, 4 – Paleozoic Formations, 5 – Basic and ultrabasic volcanics, 6 – Poorly- or Unmetamorphosed Precambrian Formations, 7 – Precambrian crystalline rocks, 8 – ophiolites, 9 – granitoids.

Table 8. Lithotectonic zones across the N-S section in the Himalayas

Western Himalayas	Central Himalayas
—*Main Karakorum Thrust*—	—Indus Tsangpo Sutur zone—
Ladakh- Kohistan magmatic arc zone, Tethys,	
—Main Mantle Thrust—	—? Trans Himadri Fault ?—
Nanga Parbat and Peshawar Plains, , Vaikrita	—*Main Central Thrust*—
	Lesser Himalayas
	—*Main Boundary Thrust*—
	Siwaliks
	—*Himalayan Frontal Fault*—

1.2 Orogenies in the Himalayas

In the Himalayan fold belt, signatures of several orogenic events from Pre-Cambrian to Oligocene are seen. These signatures vary from zone to zone. The foreland of the Himalayan range is comprised of deformed rocks of the Indian margin of Gondawana of Precambrian age (Gansser, 1964, Le Fort, 1975, Singh, 1978, Ahmad and Alam, 1978, Valdiya, 1984). Many authors have discussed the evidence for pre-Himalayan orogenies (e.g. Kumar et al., 1978; Bhargava, 1980; Jain et al., 1980; Saxena, 1980, Baig et al., 1988; Joshi and Rajpoot, 1988). Two pre-Himalayan orogenies are generally agreed viz. the Precambrian and Cambrian. Crystalline rocks of the Lesser Himalaya have been subjected to both of these pre-Himalayan orogenic events (Joshi and Rajpoot, 1988, 1989). The Himalayan orogeny is considered to begin in the Late Cretaceous and it has continued to the present (Raina, et al., 1980; Windley, and 1983, Molnar, 1986).

However, many authors have argued that no significant evidence for a pre-Himalayan orogeny exists (Powell and Conaghan, 1978; Powell et al., 1979; Gansser, 1981; and Windley, 1983).

1.3 Geotectonic evolution of the Himalayas

Many contrasting models have been proposed to explain the peculiarities and for accommodating the unique characters of the Himalayan fold belt. Most of the authors have been limited to a particular section of Himalayas. The most frequently discussed models for the evolution of Himalayas are illustrated in Fig. 25. Three main types of model have been proposed, namely Geosynclinal, Block movement, and Plate tectonic.

Geosynclinal model

The classical geosynclinal concept for the Himalayas was discussed by Ray (1974), Ray and Acharyya (1976), Acharyya and Ray (1982). The sequence of development of the geosyncline is shown in Fig. 25. This model proposes three layered tectonic slabs. The Indian crustal basement laying downward is overlain by a Palaeo-Mesozoic shelf and Palaeogene shelf geosynclinal sediments. In this model, the major Mesozoic eugeosynclinal magmatic and metamorphic events have been interpreted to have taken place in the areas of the nappe system. The nappe system possibly initiated during Early Palaeogene and glided southward

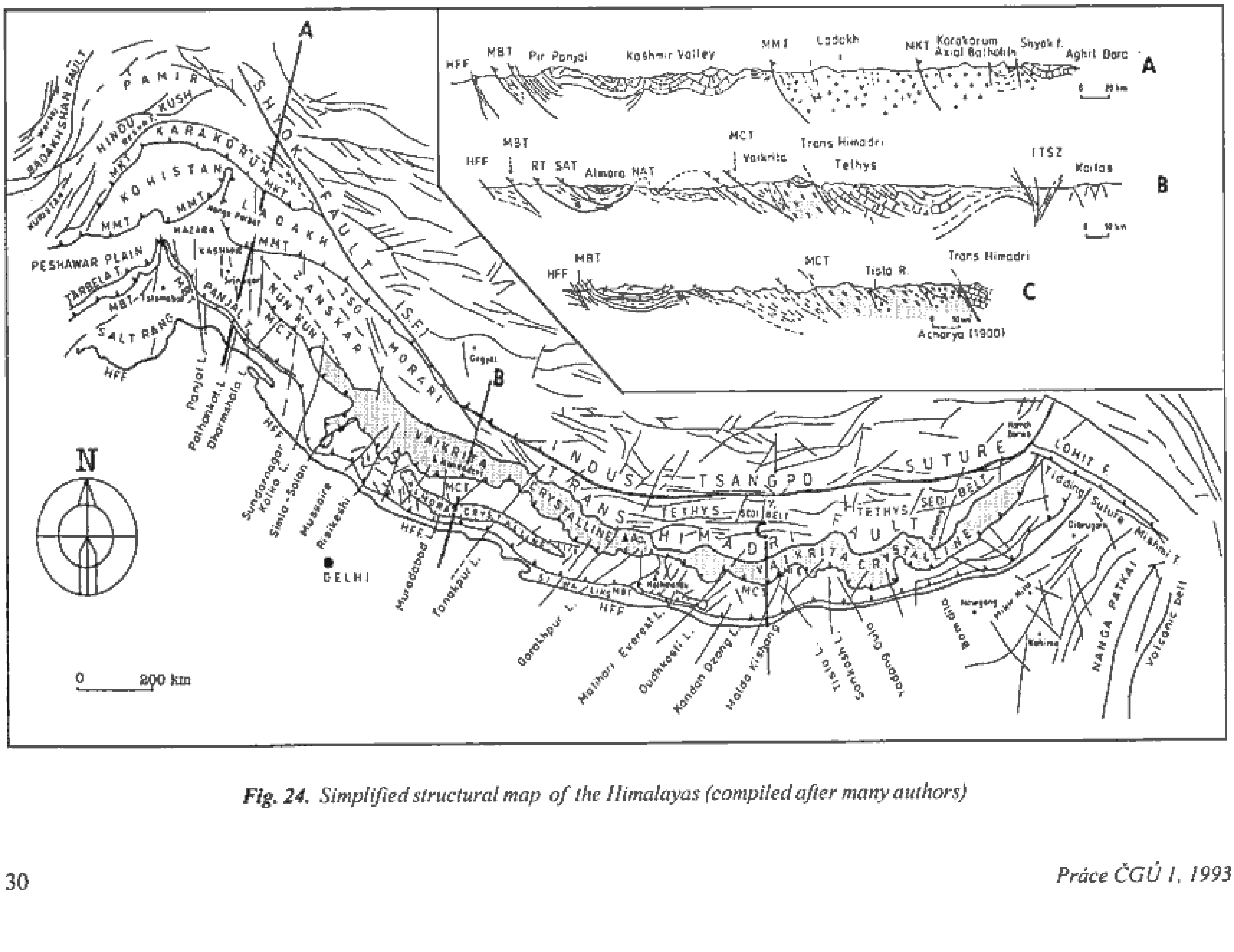


***Fig. 24.** Simplified structural map of the Himalayas (compiled after many authors)*

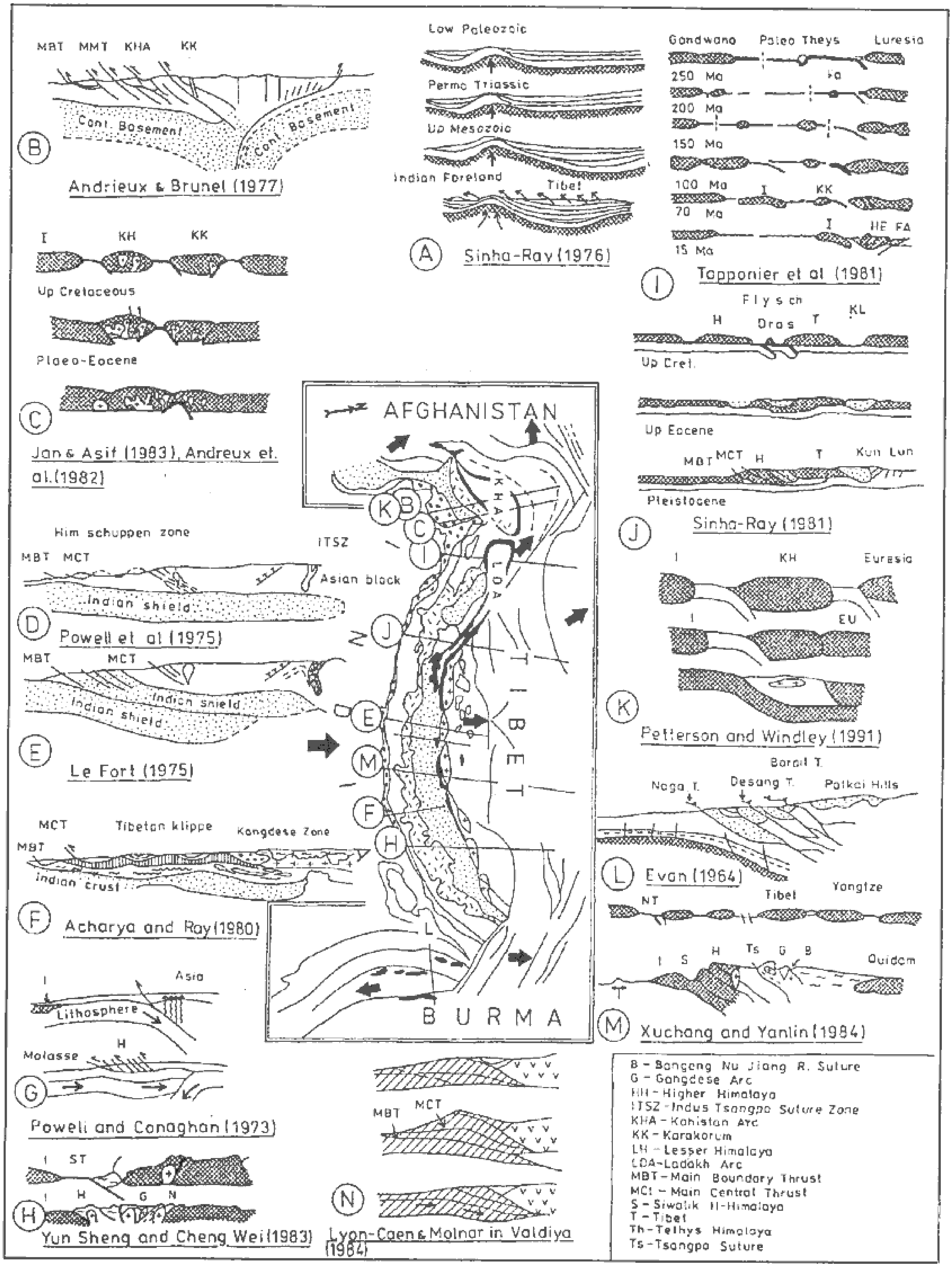


Fig. 25. Various schemes of the tectonic evolution of the Himalayas.

upto Late Neogene and possibly even to recent times in the foothill belt, at least in the Eastern Himalaya. The Indus Tsangpo Suture Zone (ITSZ) marking the inter plate oceanic crust might be continued into the central Burmese ophiolite zone.

It seems that, these authors favoring geosynclinal evolution have paid more attention to the stratigraphy and structures in Himalaya, rather than the position of granite magmatism.

Block movement model

Many authors believe that a complete development of the stratigraphic record from the Proterozoic to recent in the Himalayas can be explained by major episodic block movement with attendant folding and reversal of stratigraphic sequence along deep fractures and faults, which originated at an early stage (Hagen, 1959; Pande, 1967; Eremenko and Datta, 1968; Qureshy, 1969; Saxena, 1973; Hashimoto et al., 1973; and Kaila and Narain, 1976 and Kumar, 1982). The fault planes along which granites and volcanic rocks could have been emplaced were vertical, especially in the Higher Himalayas. Later, when compression became strong, the fault planes inclined so that horizontal movement occured to give rise the nappes in the Lesser Himalayas. This model does not indicate a large scale drifting of the Indian sub-continent and underthrusting of the Tibetan shield. Moreover, a long horizontal translation along low-angle thrusts are not recognized. In its favour, evidence may be provided by occurrence of Upper Gondawana plant fossils in the north of the ITSZ (Sharma et al., 1980, Bally et al., 1980). However, Hus (1978) suggested that the flora north of the Tsangpo River is not Gondawanic but Cathaysian.

Plate tectonic model

The plate tectonic evolution of the Himalayas has been proposed by many authors (Powell and Conaghan, 1978; Crowford, 1974; Sinha Roy, 1976; Thakur, 1983; Valdiya, 1984, Petterson and Windley, 1991 and many others). In this model, authors have focussed mainly on the evolution of the Tethys Himalayas. Most plate tectonic models pressume northwards drifting of the Indian subcontinent (Fig. 25), and its collision with the Eurasian plate in Middle Eocene time (Gansser, 1966, 1977; Dewey and Bird, 1970), followed by underthrusting of the Indian plate under the Tibetan shield since the Miocene (Powell and Conaghan, 1973). Similar opinions regarding plate collision have been proposed by several authors for the different N-S sections across the Himalayas (Fig. 25B,C,K,J).

In the western Himalayas, the history of tectonic evolution differs slightly because of the presence of the Ladakh-Kohistan island arc zone. The welding of island arc (Kohistan-Dras-Shigates) and trench sediments of the Tibetan block within the Indian plate, probably took place in the late Cretaceous to Palaeocene (Shanker et al., 1976; Frank et al., 1977; and Tahirkheli et al., 1979). Likewise thrusting of the Indian plate under the Afgan-Iran continental block was suggested by Andrieux and Burnel (1977), (Fig. 25B,C). The suture zone is represented by the axial zone of flysh and Bela-Muslim Bhag-Zhob ophiolites.

In the central Himalayas, the mechanism for the evolution of Lesser Himalayan crystalline rocks has been explained by nappe movements as shown in Fig. 25. But, several microstructural and metamorphic lines of evidence do not support nappe evolution (Joshi and Rajpoot, 1988, 1989).

In the eastern Himalayas (India-Bhutan-China section) an important model for the tectonic evolution has been proposed by Xuchang and Yanlin (1984) and Yun Shen and Cheng Wei (1983) (Fig. 25H,M). In Burman province (eastern Himalayas), the shelf sediments and basement rocks of the Indian shield are thrusted under the Tertiary sediments of the Patkai-Arakan-Andman belt along a low eastward dipping thrust plane. The tectonic evolution of the eastern Himalayas has been described by two models. According to first- the Shan-Tenasserim margin of the Indo-china plate subducting westward along a steeply dipping Benioff zone and the Patkai-Arakan sediments of Indian plate, moved eastward under the Tertiary sedimentary succession of the Irrawady Basin along the gently eastward-dipping thrust plane. This reversal of the Benioff zone has been explained by the force of buoyancy acting against the sinking of the lithosphere. According to the second model- only eastward subduction along the gently inclined Benioff zone is considered.

1.4 Granitoids in the Himalayas

The granite magmatism in the Himalayas has a long history from the Proterozoic to the Tertiary. Different lithotectonic zones, as previously described have granites of different age, chemistry, petrography, tectonic setting and deformational history. The main granite bodies in the Himalayas are shown in Fig. 26.

Sharma (1983) has distinguished four belts of granitoids in the Himalayas on the basis of age of emplacement and their associated host rocks.

A. Transhimalayan granitoids

This belt of granitoids includes the Ladakh-Kohistan batholith and the Karakorum axial batholith. The Ladakh - Kohistan batholith intruded Upper Cretaceous-Eocene rocks of the Indus suture zone while the Karakorum axial batholith intruded Upper Palaeozoic metamorphites. The granites in the Karakorum axial batholith have been poorly studied. However, two kinds of granite are generally recognised, e.g. biotite granite and leucogranite.

B. Tethys-Himalayan granitoids

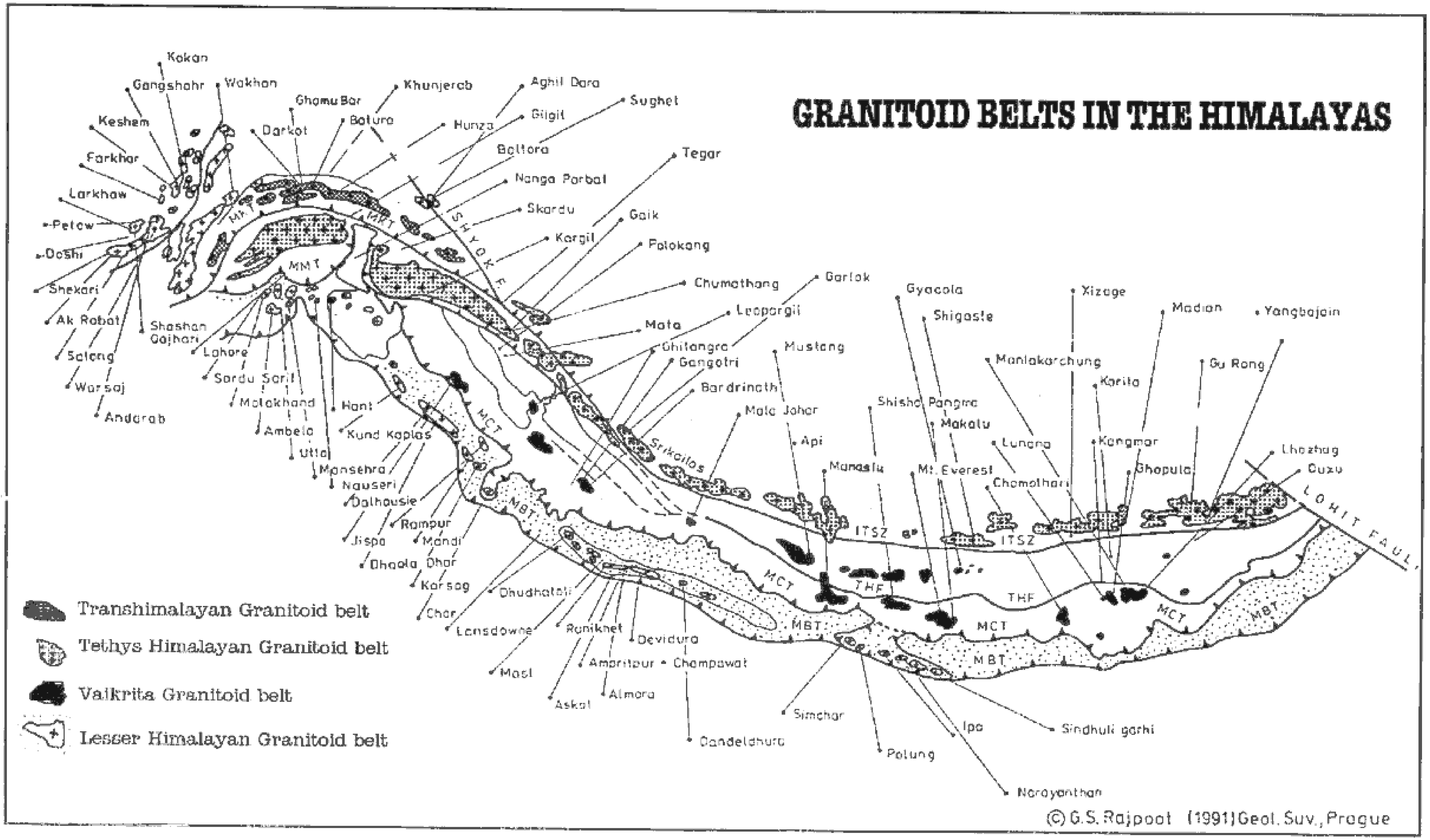
These granitoids are also called the "Lhagoi Kangri granitoids" by many authors. The granitoids are intruded into Jurrasic metamorphites, but in the eastern part they have been dated as 485± 6 Ma (Wang et al. 1980).

C. Vaikrita granitoids

The granitoids in this belt are intruded into the thick pile of katazonal metamorphites that underlie the Tethyan sediments. This belt of granitoids, includes both biotite granites and leucogranites. The biotite granites are generally considered as Cambrian and the leucogranites have been dated as Tertiary.

D. Lesser Himalayan granitoids

These granitoids are mainly of two types, namely deformed, biotite rich granodiorite of Precambrian age and undeformed tourmaline-bearing monzogranite of Cambrian age. The Lesser Himalayan granitoids frequently occur in the crystalline rocks along the entire length of the Himalayas.



GRANITOID BELTS IN THE HIMALAYAS
Kokan
Gangshahr
Wakhan
Keshem
Farkhar
Larkhaw
Petow
Doshi
Shekari
Ak Robat
Salang
Warsaj
Andarab
Shashan Gojhari
Lahore
Sardu Sarif
Malakhand
Ambela
Utla
Mansehra
Nauseri
Dalhousie
Jispa
Dhaola Dhar
Karsag
Char
Lansdowne
Masi
Askot
Almora
Amritpur
Champawat
Ranikhet
Devidura
Dudhatoli
Dandeldhura
Simchar
Palung
Ipa
Narayanthan
Sindhuli garhi
Ghamu Bar
Darkot
Batura
Khunjerab
Hunza
Aghil Dara
Gilgit
Sughet
Baltora
Nanga Parbat
Skardu
Kargil
Tegar
Gaik
Palokang
Chumathang
Garlok
Leopargil
Mata
Ghitangra
Gangotri
Bardrinath
Mustang
Mata Johar
Api
Manaslu
Shisha Pangma
Makalu
Mt. Everest
Gyacola
Shigaste
Manlakarchung
Xizage
Karita
Kangmar
Lunang
Chomathari
Ghapula
Madian
Gu Rong
Yangbajain
Lhozhag
Cuxu
Hant
Kund Kaplas
Rampur
Mandi
Srikailas
MKT
MMT
MBT
MCT
THF
ITSZ
SHYOK F.
LOHIT FAULT
Transhimalayan Granitoid belt
Tethys Himalayan Granitoid belt
Vaikrita Granitoid belt
Lesser Himalayan Granitoid belt
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2. Leucogranites in the Himalayas and their comparison with Hercynian younger granites

Leucogranites in the Himalayas have been extensively analyzed for whole rock composition, mineral composition, and various isotopes, by authors from various countries (India, France, U.K., Canada, U.S.A, Japan etc.) in attempts to understand the characteristics of leucogranites formed in a collisional zone. In the Himalayas, two lithotectonic zones frequently include the leucogranites i.e. "Vaikrita Thrust Sheet" and "Hindukush - Karakorum range" (Fig. 23&24). In this chapter, the composition of leucogranites of the Hindukush-Karakorum belt and the Vaikrita thrust sheet are compared with the leucogranites of Hercynian Europe. The term "leucogranites of Hercynian Europe" is here used to define the Group 4 granites in the Cornubian and Krušné hory-Smrčiny batholiths (as described in Part I).

2.1. Hindukush - Karakorum granitoids

The Hindukush-Karakorum unit lies to the north of Ladakh-Kohistan magmatic arc unit in western Himalayas (Fig. 27). It comprises Palaeozoic to Cretaceous sedimentary rocks, metasedimentary rocks, mafic and ultramafic rocks. This zone has been studied by many authors (Casnedi, 1979; Tahirkheli, 1979; Bard et al., 1980; Crawford and Windley, 1990; Brookfield, 1980, 1989; Gansser, 1977, 1980 etc.). The Hindukush-Karakorum unit is generally agreed to be thrusted over the Ladakh-Kohistan unit along the Main Karakorum Thrust (Fig. 27), most probably around 50 Ma ago. The leucogranites were emplaced after the end of the last phase of deformation. The granitoids are intruded into Devonian (?) to Permian metasedimentary rocks (up to amphibolite facies) and form a curved linear batholith about 20 km wide, extending from the north of Nuristan to the Shyok fault (Karakorum axial batholith). In general, the granites are porphyritic and have a pinkish colour. The well studied granites are located in the area of Ghamu Bar, the Darkot pass, Batura, the Hunza valley and Baltoro (Fig. 26). In this account, the geochemical data of the above said granite bodies of the Karakorum axial batholith are considered (the data sheet can be obtained from the authors). A systematic study of the Karakorum axial batholith has not been done, perhaps due to politically disputed terrain and difficult approach.

Typology of the Karakorum granite

Nomenclature of Karakorum granitoids is summarised in Table. 9. According to Rajpoot (1992) the granitoids are mainly "Peraluminous, mesocratic, moderately differentiated Monzogranites" with some "peraluminous, leucocratic, highly differentiated syeno - monzogranites" (Fig. 29). The later type of granite (leucogranite) is usually found as dykes.

It seems that many granites studied in the Karakorum axial batholith are not leucogranites in terms of chemistry, but in the literature they are generally confused with leucogranites.

Tectonic discrimination of the granites

The processing of geochemical data in the commonly used tectonic discrimination schemes reveal that the Karakorum granitoids are "volcanic arc granites", after Pearce et al., 1984), "late orogenic" after Batchlor and Bowden, 1985), and "post - orogenic", after Maniar and Piccolli, 1989 and after Rajpoot 1992).

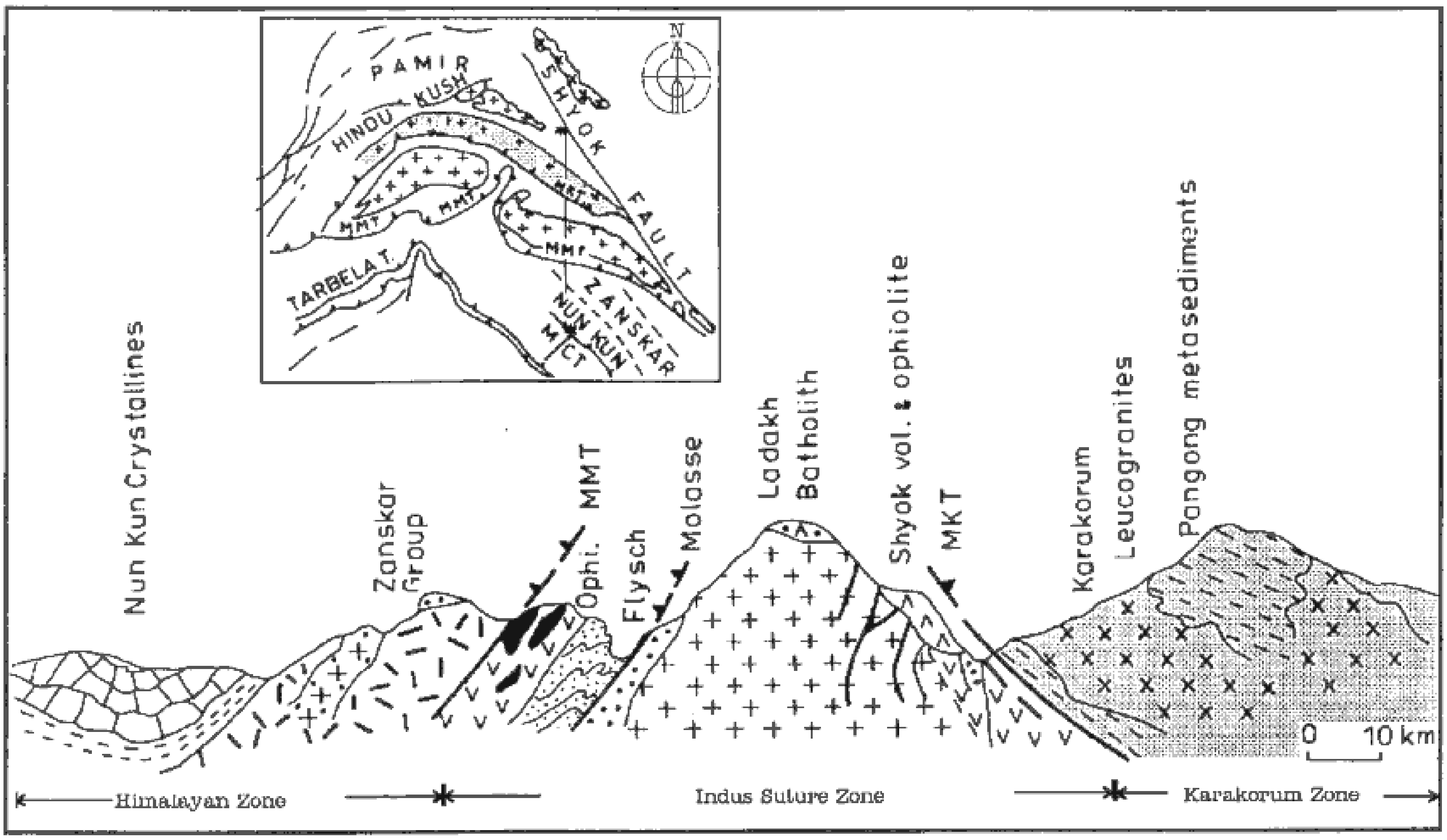

Fig. 27 N-S cross section of Karakorum axial batholith.

Table 9. Classifications of leucogranites in Hercynian Europe (G3 and G4) and Himalayas (Karakorum axial batholith and Vaikrita thrust sheet)

	Hercynian	Vaikrita	Karakorum
Nomenclature			
Hatchinson (1979)	Granite	Granite	Granite
Cox et al. (1979)	Granite	Granite	Granite
Middlemost (1985)	Granite	Granite	Granite
Le Matre (1989)	Mg	Mg	Mg
Debon and Le Fort (1983)	Granite	Adamellite	Adamellite
Jensen (1976)	C.A.Gra.	C.A. Granite	C.A.Granite
Winchester and Flyod (1977)	Granite	Granite	Granite
Harpum (1963)	Granite	Adamellite	Adamellite
Rajpoot (1992)	Syenogranite	Syenogranite	Mg
Petrographic Types			
Peccerillo and Taylor (176)	High K	High K	High K
Debon and Le Fort (1983)	Leucog.	Leucog.	Leucog.
La Roche (1980)	Leucog.	Leucog.	Leucog.
Irvine and Baragar (1971)	Sub-alkaline	Sub-alkaline	Sub-alkaline
Chappell and White (1974)	S-Type	S-Type	I-Type
Whalen et al..(1987)	FS	FS	FS
Bouseily and Sokkary (1975)	SD	SD	SD
Olade (1980)	Sn bearing	Sn bearing	Sn barren
Tectonic discrimination			
Pearce et al..(1984)	VAG/SCG	VA	VA
Bathlor and Bowden (1985)	SCG	SCG	SCG
Maniar and Piccoli (1989)	POG	POG	POG
Rajpoot (1992)	POG	POG	POG
Rajpoot (1992)	SD	SD	PD

Abbreviations in Table 9 correspond with the abbrevations of Table 5.

2.2 Leucogranites in Vaikrita thrust sheet

The Vaikrita (~ means deformed and metamorphosed in "Sanskrit") Group forms the northernmost part of the Indian plate and is made up of a thick sequence of crystalline rocks and migmatites, which include garnet-kyanite-staurolite gneiss as well as augen gneisses. These rocks directly underlie the Tethyan rocks (Fig. 28). The Vaikrita crystalline rocks are intruded by granitoids, which occur at the altitude of 6,000 to 8,000 m in the Himalayas. The Vaikrita crystallines rocks have also been called in the literature the "Higher Himalayan Crystalline rocks".

The crystalline rocks are delimited to the south at Main Central Thrust (MCT) but the northern margin is not yet fully understood. Some authors believe that these rocks grade imperceptibly northward into the sedimentary formations of the Tethys zone as seen in Zanskar, Spiti and west Nepal, but others believe that the "Trans Himadri Fault" (THF) separates the Vaikrita crystalline rock from Tethys in the north. The THF has been considered as an old and normal fault in the margins of continental basin in the frontal part of the northward advancing Indian plate.

The Vaikrita Group of katazonal metamorphites have been profusely intruded by tourmaline-bearing leucogranite plutons of varying dimensions. Generally, they are dated between 10 and 30 Ma. As individual plutons, they are heterogeneous in shape but as a whole they follow a linear trend (Fig. 26). Most of the granites in this belt are intruded along the margin of the Vaikrita rocks and the overlying Tethyan sediments and are extensively developed in the central part of the Himalayan arc. The well-studied granite bodies are those of Manaslu, Makalu, Badrinath, and Gangotri. Many intrusions of biotite granites (L.Palaeozoic) also occur in the Vaikrita crystalline rocks. In the literature, such granites have sometimes been confused with the late intruded leucogranites.

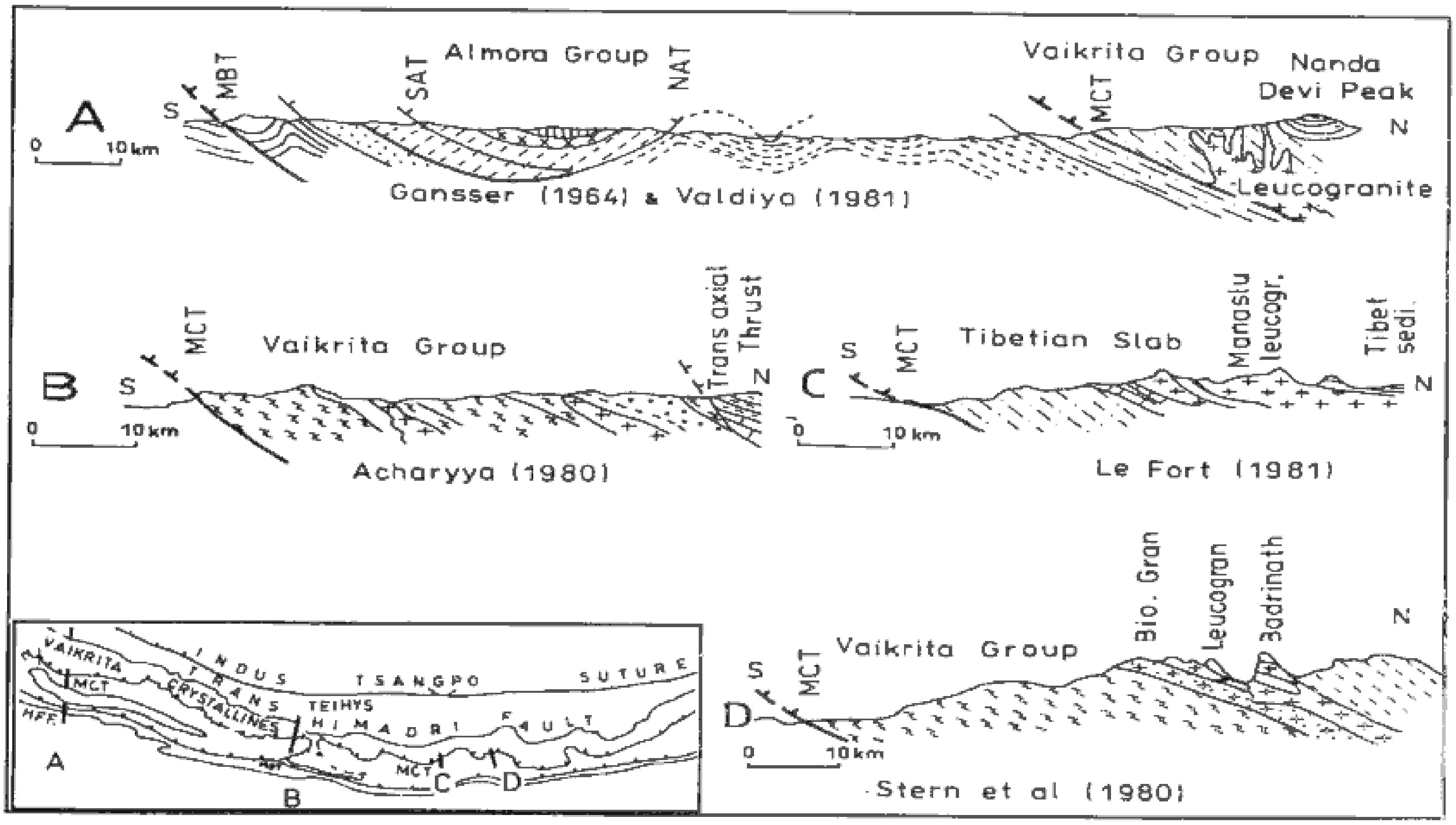

***Fig. 29** N-S cross section of Vaikrita thrust sheet.*

Typology of the Vaikrita granites

According to the commonly used classifications the Vaikrita leucogranites have similar petrographical characteristics as the leucogranites of the Karakorum axial batholith (Table 9). However, the Vaikrita leucogranites are mainly of S-type, highly differentiated, syeno-monzogranites and plot close to the tin-bearing granites of Hercynian Europe (Fig. 29).

Tectonic discrimination of the granites

The Vaikrita leucogranites are syn-collisional granites after Pearce et al., 1984), Late-orogenic after Batchlor and Bowden, 1985), and post-orogenic after Maniar and Piccolli (1989), and also after Rajpoot and Klomínský (1992)

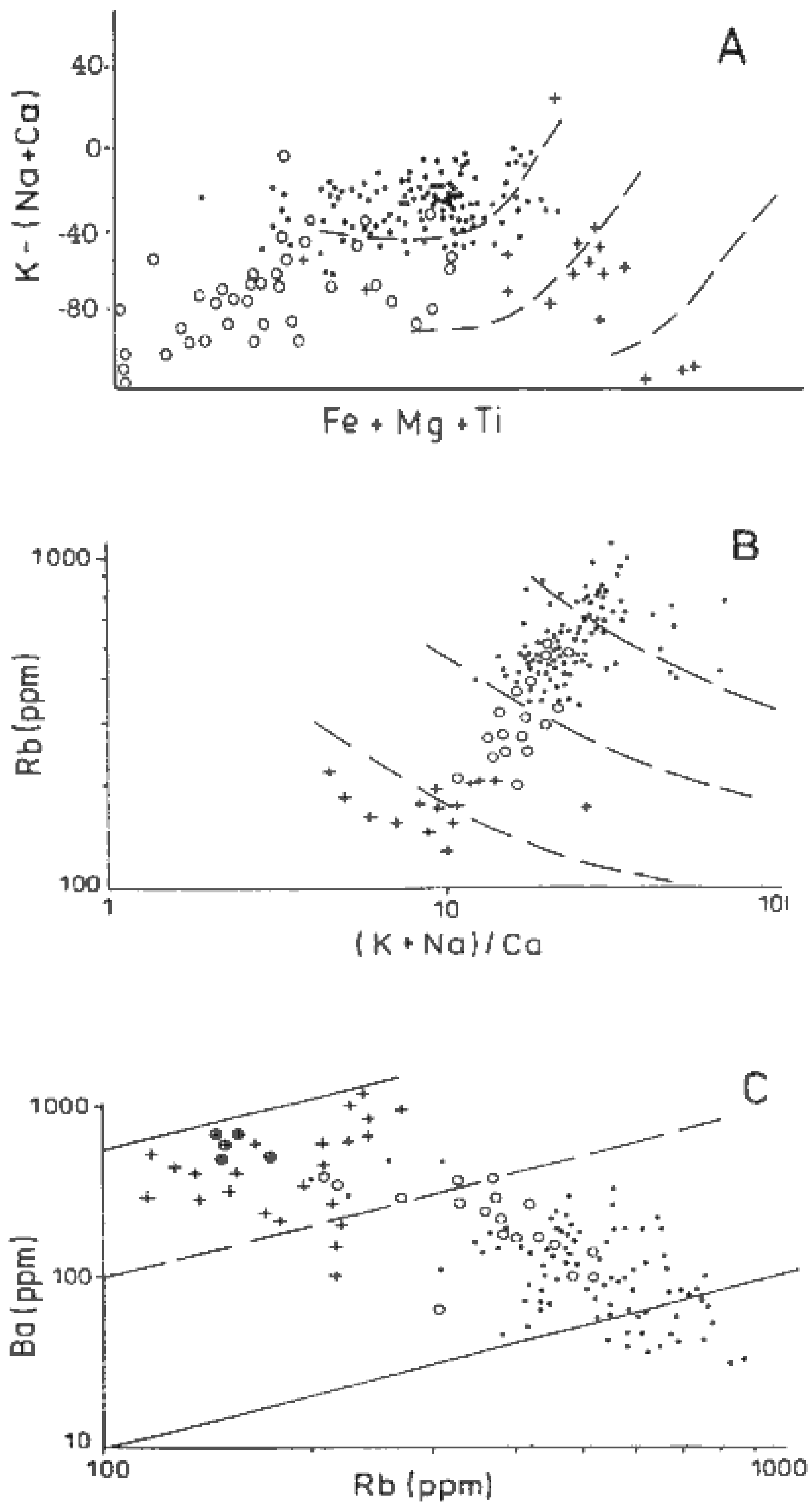

Fig. 29. Classification of leucogranites in the Himalayas and Hercynian Europe. Open circle – Vaikrita leucogranites, solid circle – Hercynian leucogranites in Europe, and plus – Karakorum granites.

2. 3. Comparison of Himalayan leucogranites with leucogranites in Hercynian Europe

General geological features

— The leucogranites both in the Himalayas (30-10 Ma) and Hercynian Europe (300-270 Ma) show intrusive relations, although some Himalayan granites in the Karakorum are mylonitized at their margins.

— The Himalayan leucogranites commonly contain tourmaline of varying content. The distribution of tourmaline differs from pluton to pluton. For example, in the Vaikrita and Cornubian leucogranites tourmaline is abundant within the granite body, whereas in the Krušné hory-Smrčiny batholith tourmaline is confined mainly to the contact zone of the granite intrusions (as earlier described).

— The Hercynian leucogranites are well known for their associated Sn-W mineralization, but there is no report of such mineralization from the Himalayan leucogranites.

— The space form of the Hercynian granites bodies (Cornubian and NW Bohemian batholith) is well known as a result of extensive geophysical and drilling prospecting for the associated Sn-W mineralization. On the other hand the space form of the granite batholiths in the Himalayas have not been studied (perhaps due to unknown economic significance of granites, politically disputed terrain, thick snow and ice cover, and difficult accessibility of the area). According to the present knowledge, the granites are capped by metasedimentary rocks in the Vaikrita thrust sheet in the central Himalayas. This appears to be comparable with the Hercynian leucogranites, as their roof zone almost coincide with the present level of erosion.

— The tectonic settings of the leucogranites differ from batholith to batholith. In the NW Bohemia, the leucogranites are associated with deep vertical faults; in Cornwall it is unclear; in the Karakorum Mts. granites lie close to the deep M MT and in the Vaikrita Thrust Sheet, they lie above the Main Central Thrust.

Cationic parameters of major oxides

Alumina balance [Al-(K+Na+2Ca)]

The alumina balance in the Vaikrita leucogranites and in the Hercynian leucogranites is comparable (Fig. 30 A). The Karakorum granites are characteristically low peraluminous and are not comparable with neither Hercynian nor Vaikrita leucogranites.

Alkali/calcium ratio [(Na+K)/Ca]

As the alumina balance, the alkali/calcium ratio is comparable between in the Vaikrita leucogranites and the Hercynian leucogranites, but the Karakorum leucogranites contrast with these (Fig. 30 B). The Karakorum leucogranites are richer in calcium than the Vaikrita and Hercynian leucogranites.

Ferro-magnesium ratio [Mg/(Fe+Mg)]

This ratio is comparable in all leucogranites, although the Karakorum leucogranites show a larger range of variation (Fig. 30 C).

Dark mineral constituents (Fe+Mg+Ti)

The Karakorum Leucogranites have a wide range of colour

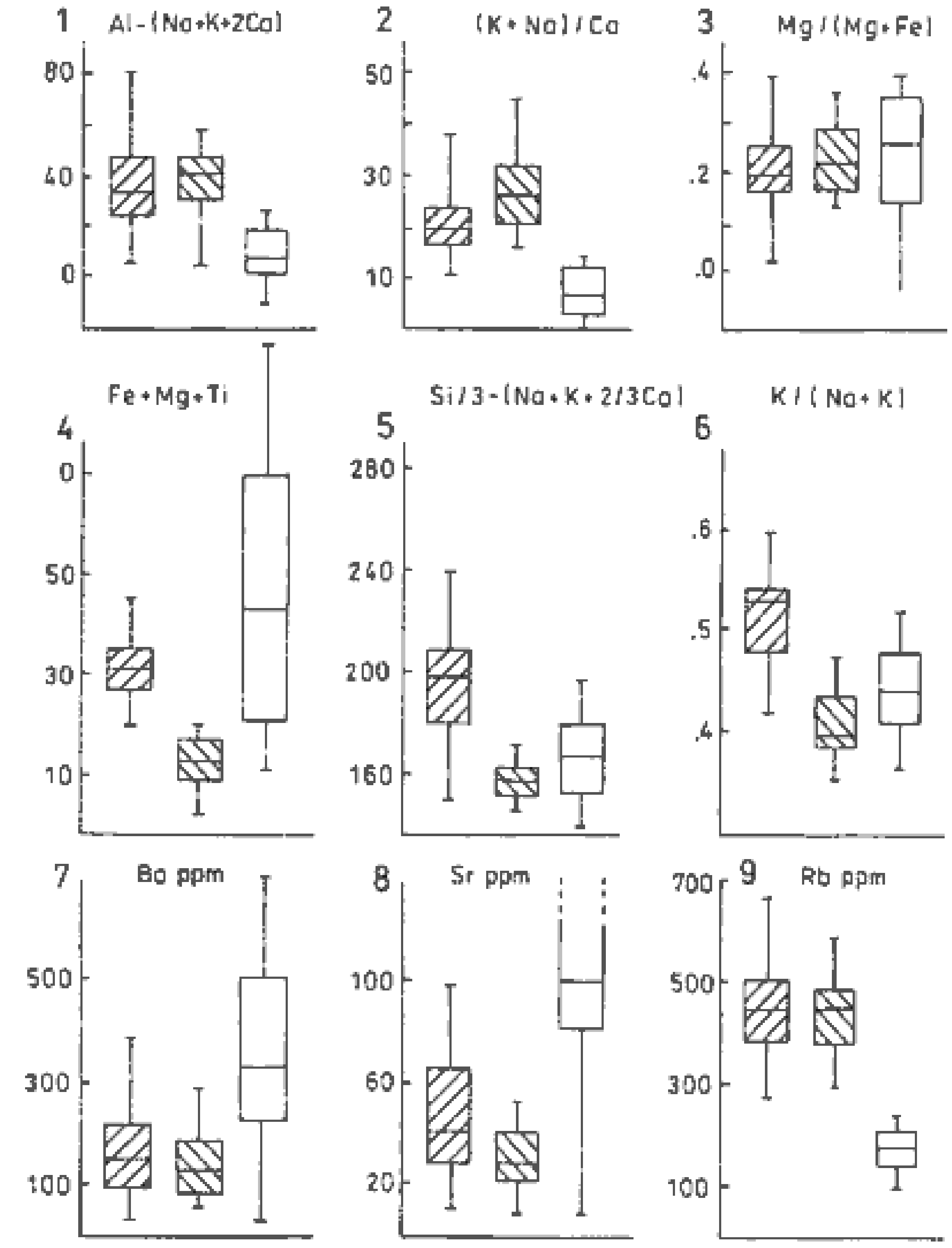

Fig. 30. Box and whisker plots of the Himalayan and Hercynian leucogranites. /// – Hercynian Europe, \\\ – Vaikrita Thrust Sheet, and blank – Karakorum axial bathoplith.

index, whereas the Vaikrita leucogranites are very leucocratic, even more than the Hercynian leucogranites (Fig. 30 D).

Free quartz [Si/3-(Na+K+2/3Ca)]

The Himalayan leucogranites are comparable to each other in respect of free quartz, but contrast with the Hercynian leucogranites (Fig. 30 E), which have higher free quartz.

Alkali ratio [K/(Na+K)]

The Hercynian leucogranites are characteristically potassic (>0.5), whereas, the Vaikrita leucogranites are "sodic" (<.45), and the Karakorum leucogranites are "sodi-potassic" (0.45-0.50) to "sodic" granites (Fig. 30 F). The Hercynian leucogranites are relatively potassic, because they are believed to have suffered by a late potassium metasomatism, while the Himalayan leucogranites appear to have been untouched by such metasomatic processes.

Trace elements distribution

High Ba and Sr, and low Rb is a distinct feature of the Karakorum leucogranites (Fig. 30). Ba, Rb, Sr are remarkably comparable between the Vaikrita and Hercynian leucogranites. Sr is inversely proportional to the alkali/calcium ratio in these leucogranites. The higher Ba and Sr in Karakorum leucogranites may indicate a higher crustal component and/or relatively less feldspar fractionation.

Fig. 31 shows the variation of Sr, Ba, Rb, and TiO_2 in the leucogranites. In the Sr vs Rb/Sr variation diagram, it can be seen that the leucogranites show a negative linear relationship. The

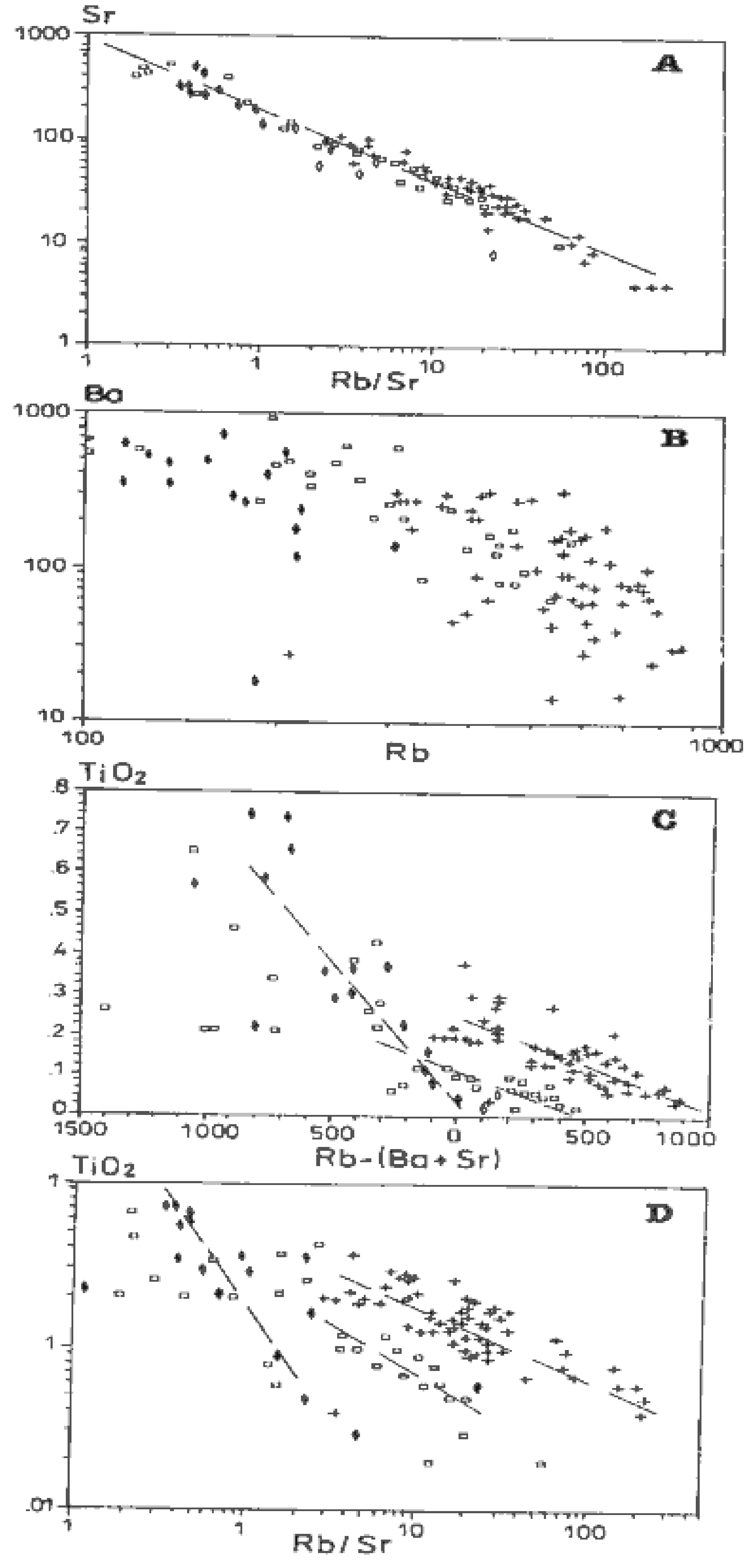

Fig. 31. Variation diagram of leucogranites. plus–Hercynian, box–Vaikrita, and diamond– Karakorum leucogranites.

well-differentiated Hercynian leucogranites have a close affinity with the Vaikrita leucogranites, but the Karakorum leucogranites are less differentiated. A similar relationship is seen in the Ba vs Rb plot (Fig. 31). In the TiO_2 vs Rb-(Ba+Sr) variation diagram (Fig. 31), all three leucogranites lie on different trends. The Vaikrita leucogranites are relatively poor in TiO_2, which may indicate, dark mineral deficiency. In the same variation diagram, Vaikrita and Hercynian leucogranites show parallel trend, whereas Karakorum granites lie along a different trend. A similar pattern is seen in the TiO_2 vs Rb/Sr variation diagram (Fig. 31).

Sr isotope ratio

The $^{87}Sr/^{86}Sr$ ratio is distinctly high in the Hercynian leucogranites (Fig. 32). The Karakorum and Vaikrita leucogranites

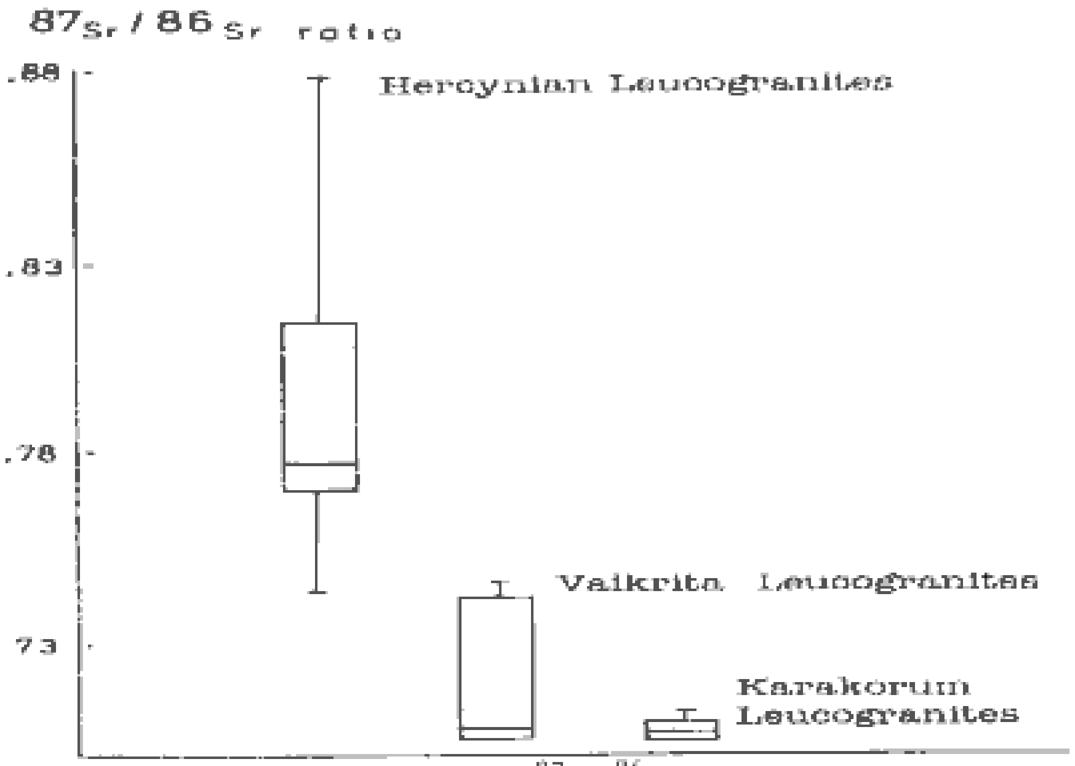

Fig. 32. box and whisker plot of $^{87}Sr/^{86}Sr$ *ratio.*

have comparable $^{87}Sr/^{86}Sr$ ratios. The high initial Sr ratio in the Hercynian granites may favour either a crustal origin for these granites or crustal contamination. A crustal source for the Himalayan leucogranites is not diswanted by the $^{87}Sr/^{86}Sr$ ratio, but is not fully supported.

Rare earth elements

The REE patterns of the Himalayan and Hercynian leucogranites also show some differences (Fig. 33). The Hercynian leucogranites have remarkably high negative Eu anomalies (Eu/Sm =.05-.13, Fig. 34), whereas the Himalayan leucogranites show low or no significant negative Eu anomalies (Eu/Sm=.17-.34, Fig. 34). Only one sample of the Manaslu leucogranite shows a sharp negative Eu anomaly (Vidal et al., 1982). The range of Eu/Sm ratio in Himalayan and Hercynian leucogranites shows marked difference, but the ratio in general does not exceed "moderate to negative" Eu anomaly (Eu/Sm=.20-.36 after Henderson, 1984). The LREE/HREE ratio in the Hercynian and Himalayan leucogranites also differs (Fig. 34) [e.g. $(La/Lu)_{cn}$= 8-18 in Hercynian leucogranites and 3-9 in Himalayan leucogranites]. However, complete variation in the LREE/HREE ratio in all these leucogranites also falls in the range of moderate Eu negative anomalies (Henderson, 1984).

It is interesting, that the Vaikrita leucogranites, which are comparable with the Hercynian leucogranites in most geochemical and petrographical aspects, are not comparable with respect to the Eu anomaly. Also, the Karakorum leucogranites, which contrast with the Vaikrita leucogranites in many geochemical aspects are comparable in respect of the Eu anomaly. This may lead to the assumption that the source material for the Himalayan leucogranites might originated in a common environment that was generally available for partial melting at different times and places.

The overall REE abundance is relatively low comparing with normal granites and suggests a consistent pattern of fractional crystallization. Low REE abundance is a common observation in the world wide distributed leucogranites of whatever age. The strong negative Eu anomaly in the Hercynian leucogranites supports other geochemical observations that indicate more fractionation than the Himalayan leucogranites.

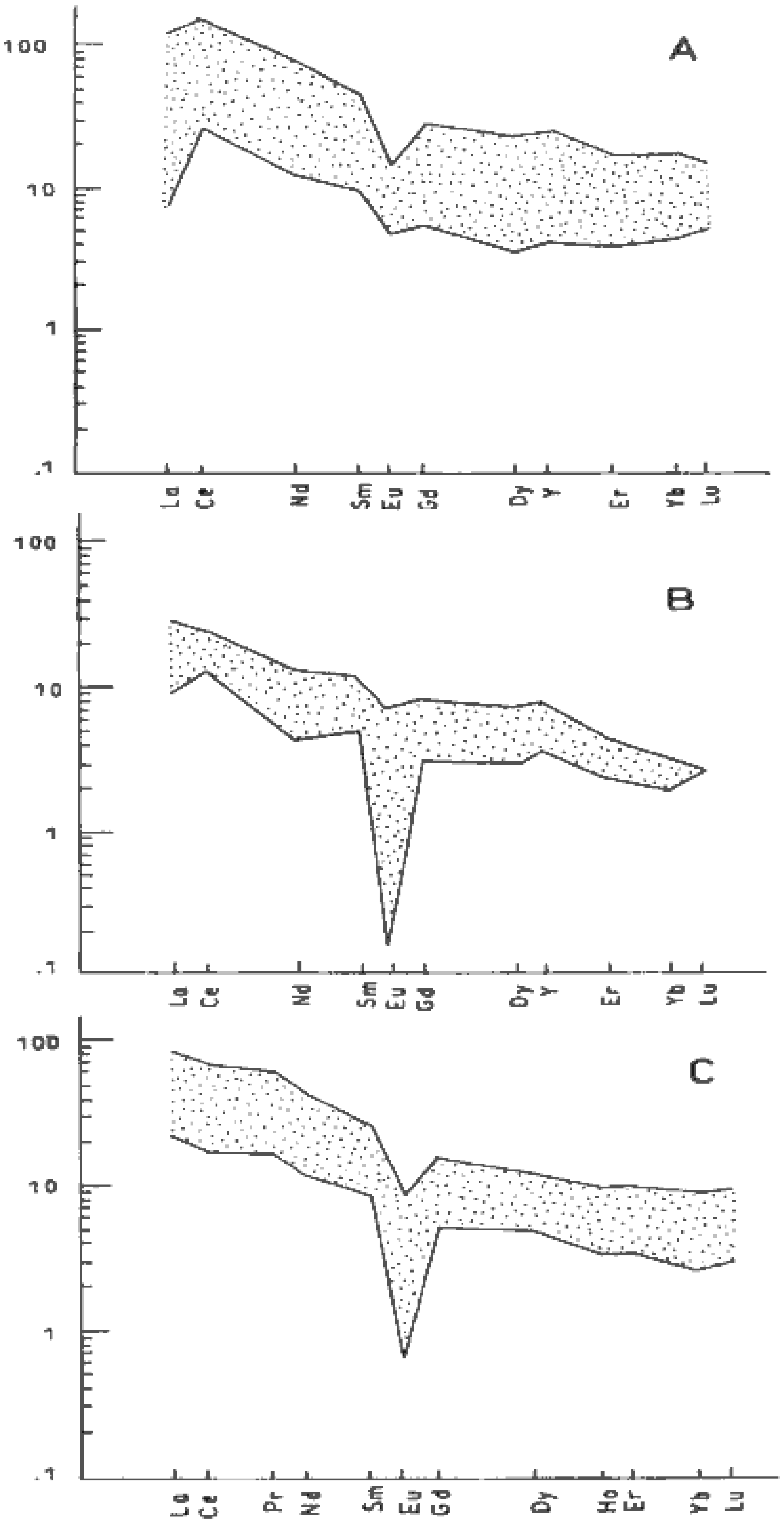

Fig. 33. REE patterns in leucogranites of Karakorum (A), Vaikrita (B) and Cornwall (Hercynian Europe) (C).

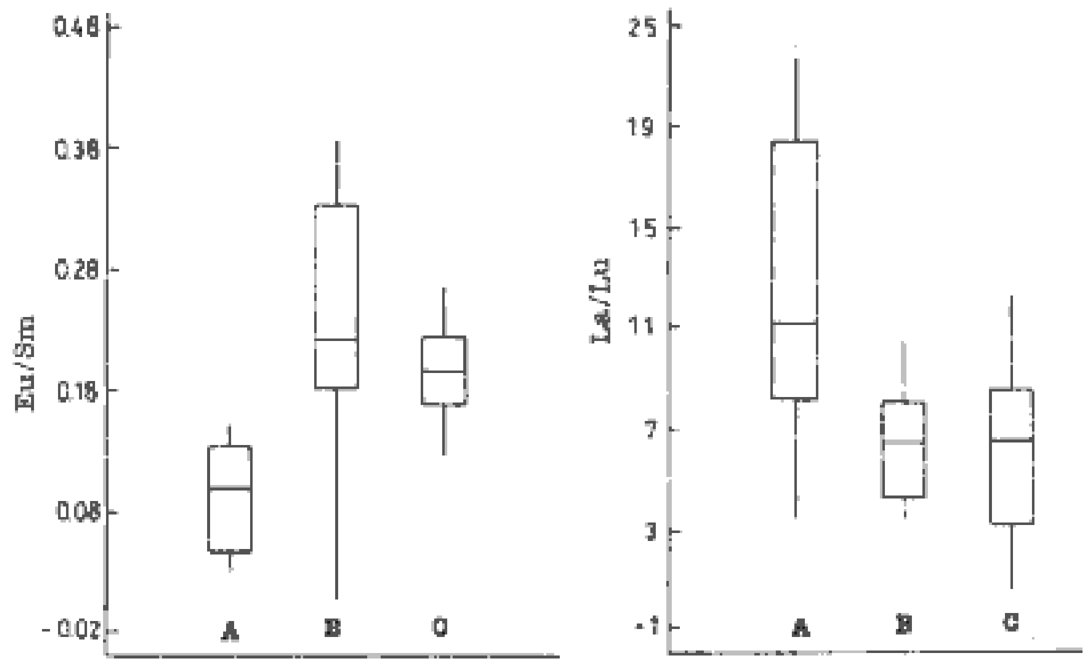

Fig. 34. Box and whisker plot of Eu/Sm and La/Lu ratios. A-Cornubian leucogranites, B-Vaikrita leucogranites, and C-Karakorum leucogranites.

Origin of leucogranites

From the given comparison, it is clear that the Vaikrita leucogranites are geochemically closer to the Hercynian leucogranites than they are to the Karakorum leucogranites.

The Vaikrita leucogranites are structurally located above the Main Central Thrust. The low $^{143}Nd/^{144}Nd$ and high $^{87}Sr/^{86}Sr$ (.745) ratios suggest that the granitic magma developed by anatectic melting of crustal rocks. Similar such observation has been drawn by many authors working on Himalayan leucogranites. Generally, the Vaikrita leucogranites are geochemically related to the gneisses of the Vaikrita thrust sheet (Le Fort, 1981, Vidal et al., 1982, Cuney et al., 1984; Deniel et al., 1985), which were brought up from deeper level and thrust southward along MCT. The subsequent dehydration and decarbonation of these sedimentary rocks released a large amount of fluid, which fluxed the overlaying gneisses and gave rise to wet melting. In this model, it seems that the heat required to produce leucogranite melt is not clear. Stern et al. (1989) suggested that the Indian continental crust was preheated, and the heat might have been supplied from hot asthenosphere, which replaced the continental lithosphere.

The origin of the Hercynian leucogranites can be compared with this model. It is essential to consider that the Vaikrita leucogranites formed during crustal thickening (60–70 km), whereas such crustal thickening in the Hercynian leucogranite provinces is beyond speculation. Therefore, the assumption of a crustal source for the leucogranites in European Hercynian, which was supplied not only by heat but also with some material from the mantle, seems to be logical (as earlier discussed). The similar supply of heat and material from mantle to the similar type of leucogranites in Vaikrita thrust sheet might not be achieved due to the very thick crust.

3. Lesser Himalayan granites and their comparison with Hercynian Older Granites

The Lesser Himalayan Zone (LHZ) extends from Himachal Pradesh in the west to Arunachal Pradesh in the east. The Lesser Himalayas have sub-mature to mature topography with evidence of neotectonic rejuvenation. The LHZ is separated from the Higher Himalayan Crystalline Zone by the Main Central Thrust (MCT) in the north, and from the Siwaliks in south by the Main Boundary Fault (MBT). The LHZ includes sedimentary and metamorphic rocks, which in places have been intruded by granitoids, which are polyphasally deformed (Divakar Rao, 1983). From south to north (from MBT to MCT) successive older-developed steep thrusts of Gondawana rocks can be recognized. They occur all along the Lesser Himalayan zone. The Lesser Himalayas can be divided into three parts based on state borders, viz. the Himachal Lesser Himalayas, the Uttar Pradesh Lesser Himalayas (Kumaun-Garhwal) and the Nepal Lesser Himalayas. The granites in the Lesser Himalayas of Himachal, Kumaun, or Nepal show no contrasts in the major geochemical constituents (Fig. 35), except for varying amounts of dark mineral constituents (which are higher in the Himachal granites).

A detailed study of the history of deformation, metamorphism, and granite magmatism in the Almora Crystalline rocks, Kumaun Lesser Himalayas has been carried out by team of workers at Department of Geology, Kumaun University. A summary of the first authors contribution is presented here in order to show the tectonic evolution of the granitoids in the Lesser Himalayas, which resemble the older Hercynian G1 and G2 granites (330 to 300 Ma) in the Krušné hory-Smrčiny Mts. (Central Europe) and in SW England. In this article, the term "Hercynian older granite" refers to the G1 and G2 granites described in part I.

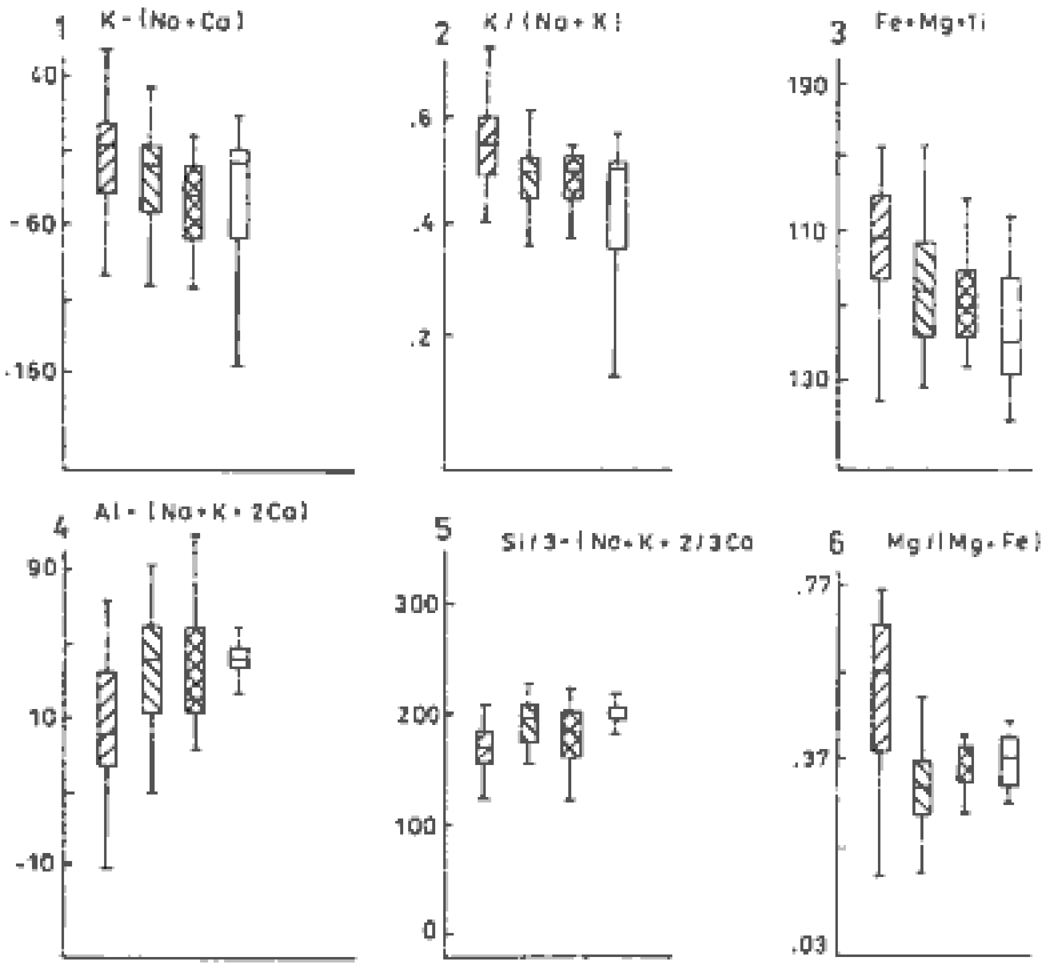

Fig.35. Box and whisker plots of cationic parameters in the Lesser Hiamalayn granites. (///) – Himachal, (\\\) – Garhwal and Kumaun, (corss) – Almora, and (blank) – Nepal granitoids.

3.1. Almora Crystalline rocks

The Precambrian polyphasally deformed and polymetamorphic medium pressure schist and associated granitoids in the Kumaun Lesser Himalayas form part of the Almora group (Fig. 36). The Almora group lies between heights of 1000 to 2500 m. It includes the best studied rocks of the Kumaun Himalayas, however geotectonic evolution of the area still remain for discussion. Heim and Gansser (1939) agreed with Auden (1937) and retained the Almora Crystalline rocks as a nappe with its root zone in the Central Crystalline Zone. The "North Almora Thrust" and the "South Almora Thrust" form the northern and southern limits of the Almora Crystallines. A large number of workers agree with the concept of the Almora Nappe (Valdiya, 1980, 1984; Merh and Vashi, 1965; Merh, 1968; Powar, Gairola and Dixit, 1969; Gairola and Joshi, 1968). Others cast doubts on the existence of the Almora Nappe as a "Thrust Sheet" (Misra and Sharma, 1972; Mehdi et al., 1972; and Saxena and Rao, 1975).

Valdiya (1979) postulated that the Almora Crystallines form a part of a huge recumbent nappe and identified the root zone in central Himalayas (Munsiari Formation). These deformed rocks preserve evidence for at least four fold phases. The F1 and F2 folds are related to D1a and D1b deformations respectively, while F3 folds are related to the D2 deformation. The F4 folds are warps related to the D3 deformational episode. The F1 folds with NE-SW to ESE-WSW axial planes are related to the D1a deformation, while the F2 folds with NW-SE to E-W axial planes are related to the D1b deformation. A Very feeble signature of the D3 can be deciphered in some of the petrofabric diagrams and which is related to the F4 folds with N-S axial planes (Rajpoot, 1989). The upthrust planes are also folded by the F4 folds. The North Almora Thrust is a well-established high-angle fault (Heim and Gansser, 1939; Valiya, 1980; Mishra and Sharma, 1972; Mehdi et al., 1972; Saxena and Rao, 1975; and Bhattacharya, 1987). The South Almora Thrust is also inclined at a high angle of 48^0 or more. Therefore, it is better to call these faults the North Almora and South Almora Upthrusts.

Petrography of the metamorphites

The Almora group comprises schists, micaceous quartzites, amphibolites, migmatites and mylonites. The S1 and S2 axial plane schistosities are defined by the preferred orientation of micas (Fig. 37a). Kyanites of two generations related to the two schistosities are observed (Fig. 37b.). The later kyanite shows a cross cutting relationship with the earlier kyanite and S1 schistosity. Three types of garnet have been recognised, viz. stretched, spiral and fresh idioblasts (Fig. 37C,D). The stretched garnets are pretectonic with respect to the D1 deformation, while garnets showing spiral trails are syntectonic with respect to the D1 deformation. Fresh idioblastic garnets are post-tectonic with respect to the D2 deformation. Sometimes, the garnets with spiral trails have developed fresh overgrowth rims (Fig. 37d). The S1 and S2 schistosities are related to the D1a and D1b deformations. The mica flakes defining the S3 is related with the D2 deformation.

The common schists are mica schist, garnet - mica schist, and kyanite - garnet - biotite schist. The migmatites are commonly exposed in the contact zone of the granites with kyanite - biotite schist. They are mainly composed of quartz, K-feldspar, plagio-

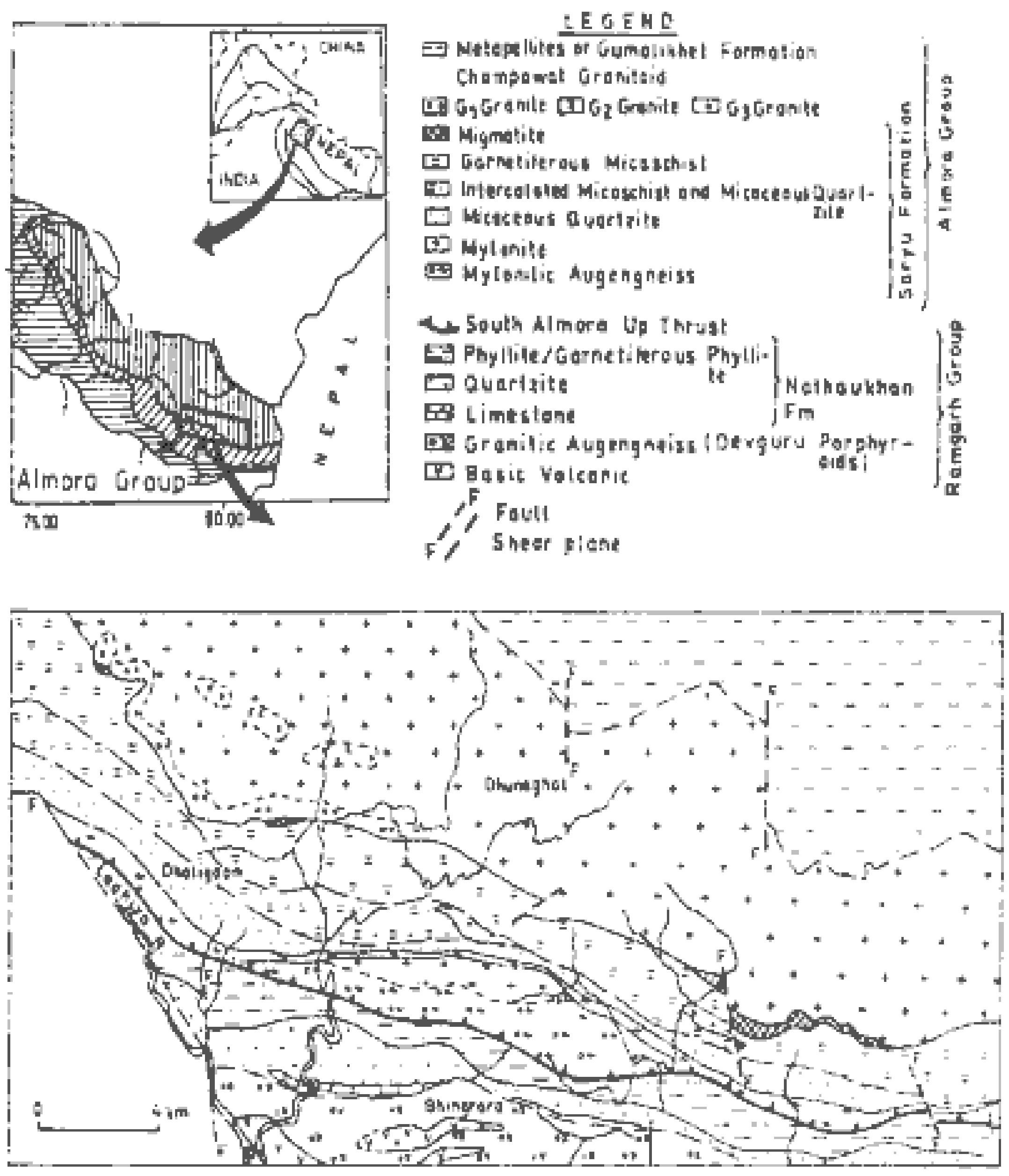

Fig. 36. Geological map of Devidhura area, Almora Crystallines in the Kumaun Lesser Himalayas (India).

clase, muscovite, garnet and kyanite. At some places tourmaline is common in migmatites. Several thin bands of graphite schist are confined to the garnet biotite zone. These schists constitute mainly graphite, garnet, quartz and biotite. Two types of mylonite have been distinguished, namely mylonitic schists and mylonitic augen gneisses. Both show evidence of crushing and retrogression. The augen in hand specimens of mylonitic augen gneiss range from 0.5 cm to 2 cm. Quartz ribbons and mica flakes commonly flow around the porphyroblast. Perthite and myrmekites are also common. Sericite, epidote and chlorite are common retrograde products in the mylonites.

Metamorphism

The following three zones have been delimited on the basis of the first appearance of equilibrium assemblages (Fig. 38) ; *Zone I (Chlorite -Biotite Zone), Zone II (Garnet -Biotite Zone), and Zone III (Kyanite -Biotite Zone)*

The metamorphic zones are truncated at the shears and are continuous throughout the area due to post-tectonic shear movements. This also explains the isolated patches of kyanite - biotite zone in the area (Fig. 38). The metamorphic isograds are not parallel to the South Almora Upthrust and are truncated against it. This does not support the hypothesis of inversion of zoning due to nappe movement (Valdiya, 1980 and Gansser, 1964).

Chlorite – Biotite Zone is characterized by the biotite-chlorite equilibrium mineral assemblage. The other minerals are quartz, K-feldspar and plagioclase. This zone is demarcated on the southern extremity of the metamorphites (Suryu Formation) and extends from the South Almora Upthrust in the south to the garnet - biotite isograd in the north. The mineral assemblages observed in the zone are ; chlorite - biotite - K-feldspar; chlorite- biotite - quartz; and chlorite- biotite - muscovite (phengite).

Garnet – biotite Zone is characterized by the garnet - biotite stable assemblage. The other common minerals are muscovite, quartz and zoisite. The mineral assemblages common in pelitic schists are garnet - biotite - quartz; garnet - biotite - muscovite; and garnet - zoicite - quartz.

Kyanite – Biotite Zone - falls between the G1 granite gneiss in the north and the garnet - biotite zone in the south and is characterized by the stable kyanite - biotite association. The other common minerals are garnet, muscovite, K-feldspar, plagioclase

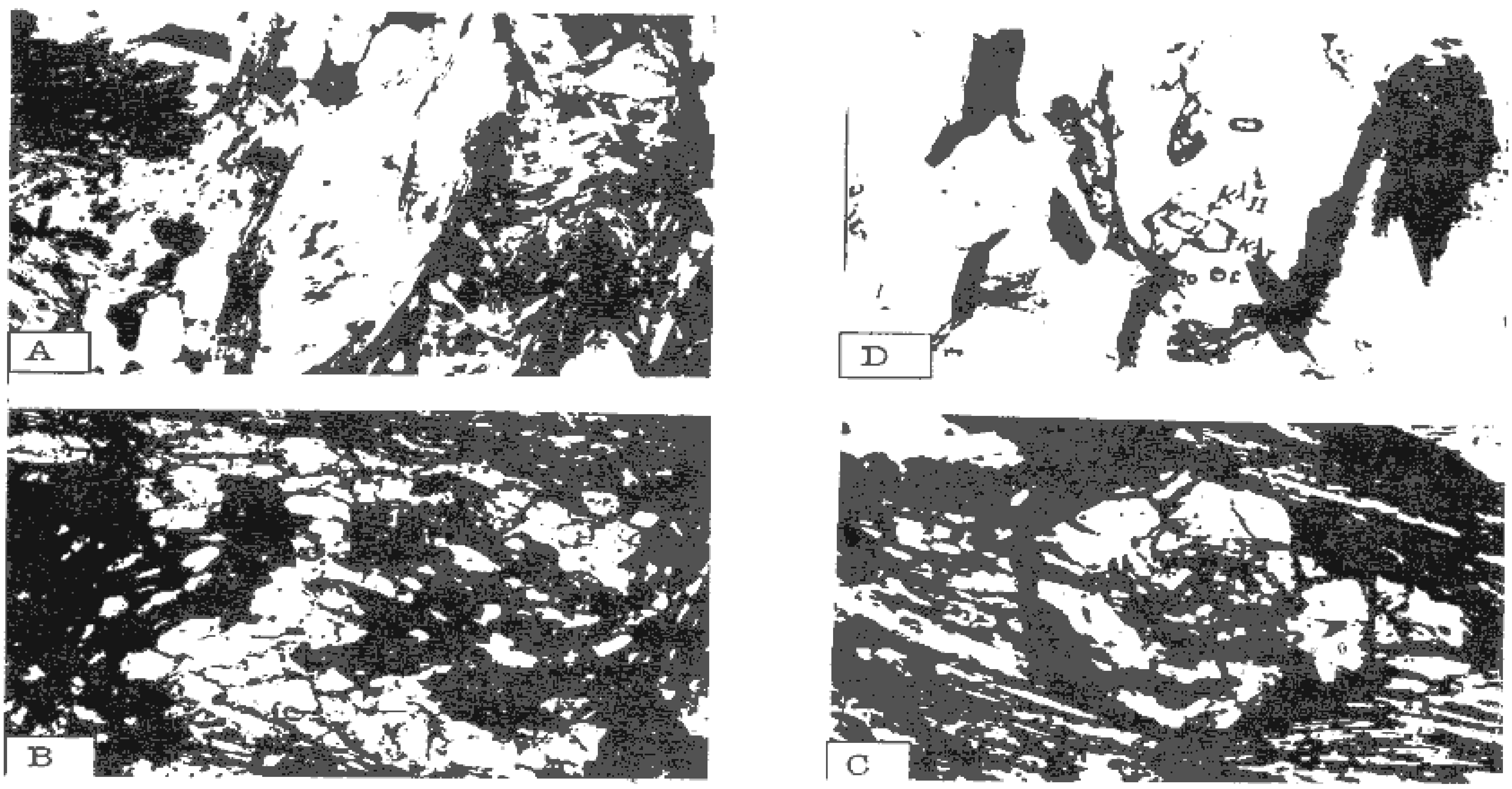

Fig. 37. *A- Microstructures in schist rocks, B– Sigmoidal garnet, C– Overgrown garnet, and D– Cross cutting kyanites.*

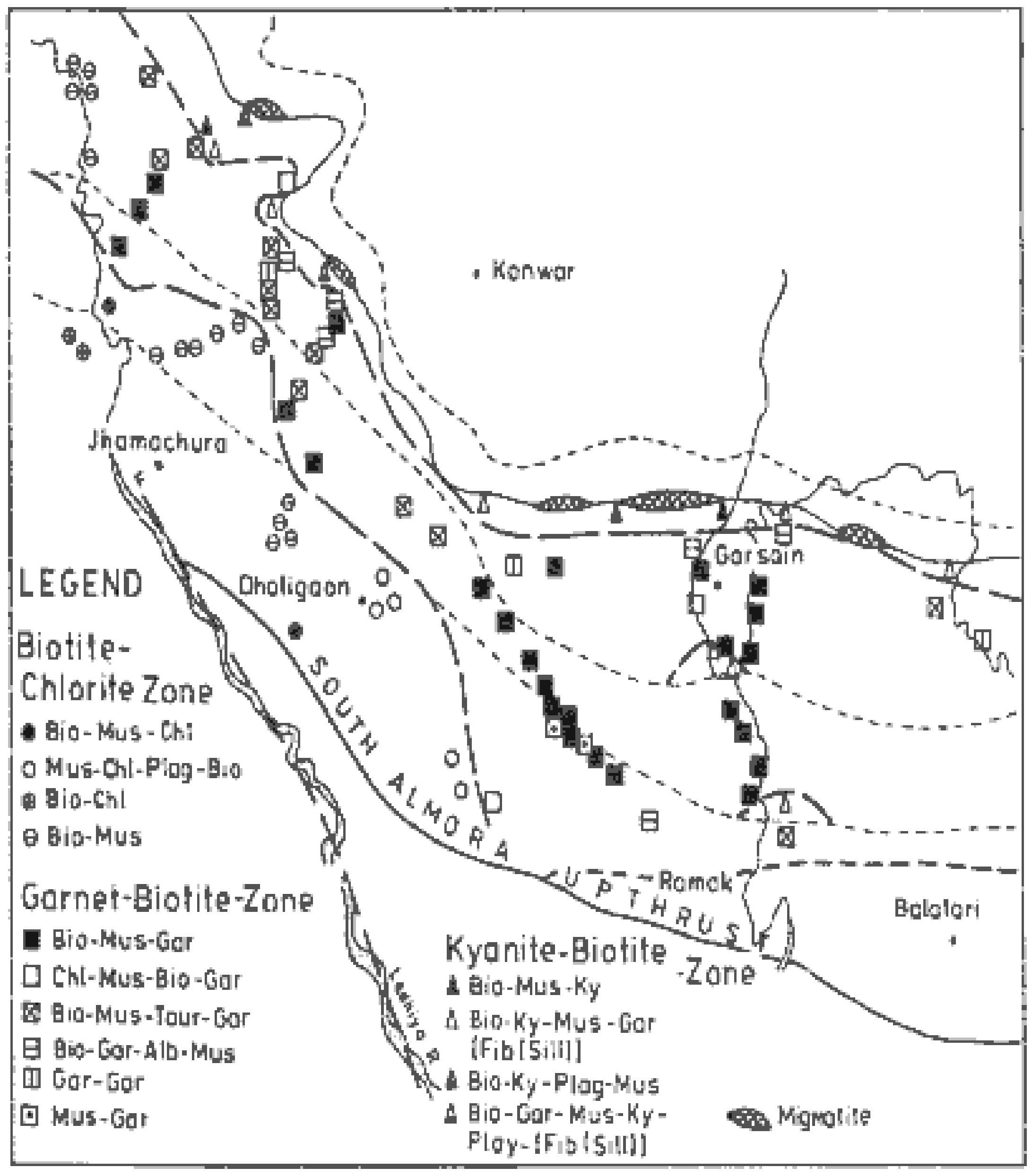

Fig. 38. Metamorphic zones in the Devidhura area of Kumaun Lesser Himalayas.

tourmaline, and apatite. Tourmaline is common in this zone and decreases towards zone I. Migmatites are exposed at places along its northern limit of this. The grade of metamorphism increases towards the north, where first phase granite is exposed. The common mineral assemblages in this zone are; kyanite – biotite – quartz; kyanite – biotite – muscovite – quartz; kyanite – garnet – quartz; and kyanite – sillimanite (fibrolite) – biotite – quartz.

Physical conditions of metamorphism

Two phases of metamorphism have been recognised in the Crystalline rocks of Kumaun Lesser Himalayas. During the first metamorphism (M1) the rocks were subjected to a more intensive phase of regional metamorphism which reached up to sillimanite – almandine – muscovite subfacies of the amphibolite facies conditions and anatectic first phase granite was formed. The temperature calculated for the M1 metamorphism is about 950 ^{0}C at 5 kb using garnet–biotite thermometer after Ferry and Spear (1978) and Hoinkes (1986). During the second metamorphism (M2), the highest grade metamorphism represent the assemblage - garnet + biotite + kyanite + quartz, but garnet stability will require pressures higher than 4 kb (Hirschberg and Winkler, 1969). Temperature calculated for the M 2 metamorphism varies from 600 – 800 ^{0}C at 5 kb, using the similar garnet – biotite thermometer (Rajpoot, 1992). However, the second metamorphism M2 reached only up to the garnet – biotite zone of the greenschist facies and fresh idioblasts of garnet are developed. The M2 metamorphism outlasted the deformation.

3.2. Granitoids

In the Almora crystalline rocks many bands of granite are exposed. The most studied granite bands occur in areas around Dhudhatoli, Almora, Ranikhet, Devidhura, and Champawat. Two main phases of granite magmatism have commonly been reported viz. Precambrian the "First Phase Granites" (FPG) and Cambrian the "Second Phase Granites" (SPG). The FPG are mainly foliated, show feldspar augen and are mylonitized at their margins. These granitic gneisses are characterized by the presence of metamorphic minerals e.g. garnet, kyanite, sillimanite, and cordierite. Along the boundaries of the granite body, lens of migmatite are common in the other parts of Lesser Himalayas and in Nanga Parbat-Peshawar plains. The FPG granitic gneisses have Rb/Sr date of 1859 ± 200 Ma (Bhanot et al., 1981). The SPG granites are characterised by undeformed texture and the presence of tourmaline. They are intruded into the FPG and give Rb/Sr age of 550 Ma (Trivedi et al., 1981).

Typology of the granites

The classification of the Almora Granitoids is shown in Fig. 39 and simplified in Table 10. The FPG and SPG sometimes fall into different clusters and sometimes overlap. It can be seen that in many classification schemes the Hercynian older granites correspond with the Almora granites. The geochemical definition of the first phase and second phase of Almora granites can be defined as follows;

Table 10. Classification of Older Hercynian granites in Europe (G1 and G2) and Almora granites in Himalayas.

	Hercynian older granites	First phase granites	Second phase granites
Nomenclature			
Hatchinson (1979)	*Syenite*	*Syenite*	*Granodiorite*
Cox et al. (1979)	*Gra./ Grd.*	*Monzonite*	*Granite*
Middlemost (1985)	*Granite*	*Granodiorite*	*Granite*
Le Matre (1989)	*Granodiorite*	*Granodiorite*	*Monzogranite*
Debon and Le Fort (1983)	*Adamellite*	*Gd./Adam.*	*Adamlli./Gr.*
Jensen (1976)	*C.A.Grd.*	*CA Granite*	*CA Granite*
Winchester & Flyod(1977)	*Grd./Diorite*	*Gra.(adamelli)*	*Granite*
Harpum (1963)	*Adamellite*	*Adamellite*	*Granite*
Rajpoot (1992)	*Gd./Mgd.*	*Gd./Mg.*	*Mg./Sg.*
Petrographic Types			
Peccerillo and Taylor(176)	*High K*	*High K*	*High K*
Debon and Le Fort (1983)	*Two Mica*	*Two mica*	*Mus. Granite*
La Roche (1980)	*Mesocratic*	..	
Ishihara (1977)	*Mainly I*	*N.C.*	*N.C.*
Irvine and Baragar (1971)	*Sub-alkaline*	*Sub-alkaline*	*Sub-alkaline*
Chappell and White (1974)	*S & I*	*N.C.*	*S type*
Whalen et al. (1987)	*OGT*	*OGT*	*OGT*
Bouseily & Sokkary (1975)	*NG*	*AG*	*NG*
Olade (1980)	*Tin barren*	*Tin barren*	*Tin barren*
Tectonic discriminations			
Pearce et al. (1984)	*VAG*	*Syn-colli/VAG*	*Syn-colli/VAG*
Bathlor and Bowden(1985)	*LOG*	*PPC/Syn-colli.*	*PPC/Syn-colli.*
Maniar and Piccoli (1989)	*IA/CA/CC*	*N.C.*	*N.C.*
Rajpoot (1992)	*LOG*	*Syn. Collision*	*Syn-Post coll.*
Rajpoot (1992)	*VPD*	*VPD*	*MD*

Abbreviations in Table 10 are similar to the abbreviation in Table 5.

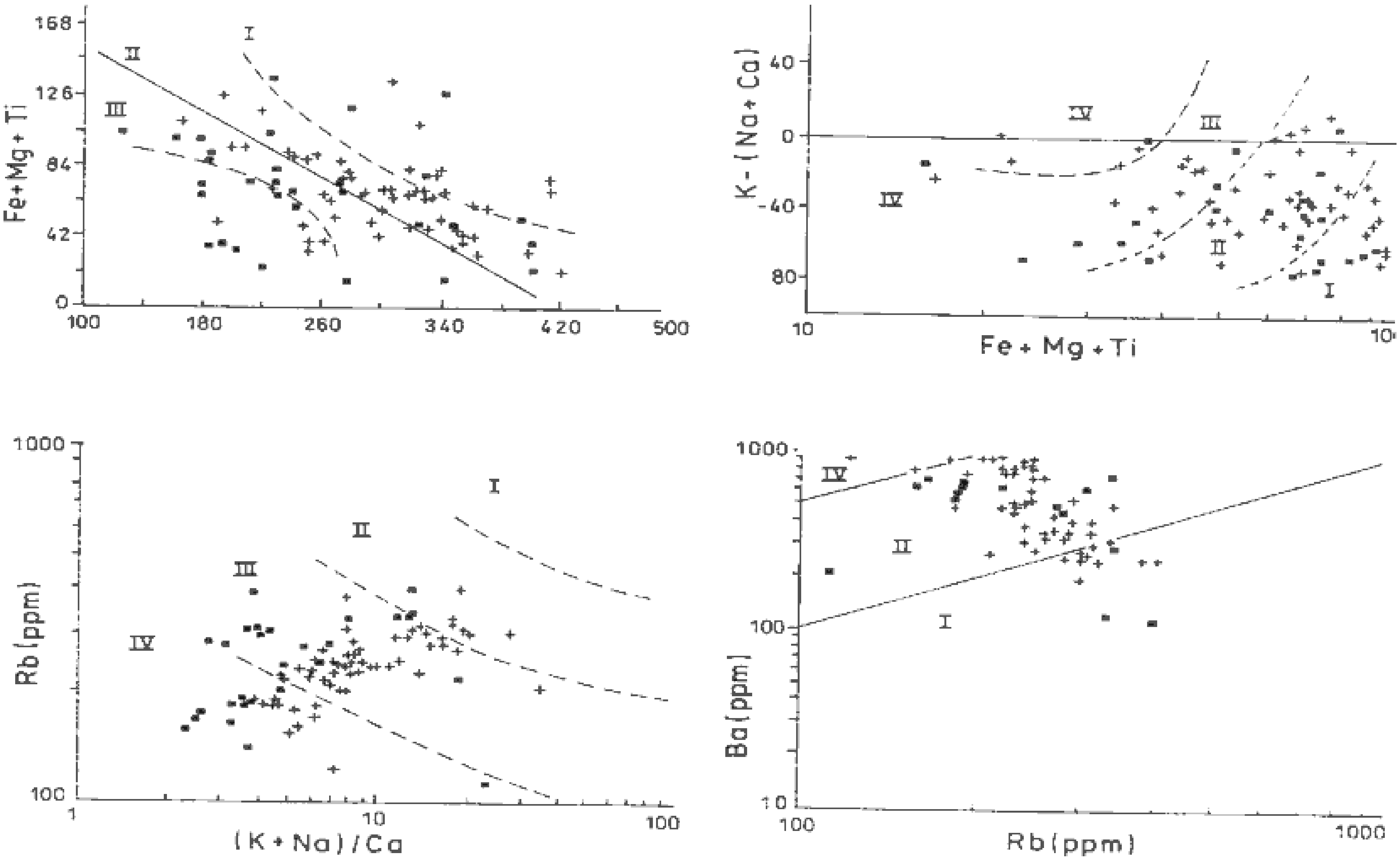

Fig. 39. Classification of Almora and Hercynian older granites after Rajpoot and Klominský (1992).

First Phase Granites are calc-alkaline, low peraluminous, biotite rich, undifferentiated to poorly differentiated, syn-collision granodiorite to monzogranite. Second Phase Granites are sub-alkaline, peraluminous, two mica, moderately differentiated, syn- and post-collision monzo- syenogranites.

Relation between deformation, metamorphism and granite formation in the Almora crystalline rocks

An attempt to correlate the metamorphic episodes (i.e. M1 and M2), the deformational events (i.e. D1, D2, and D3) and granitic activity (i.e. FPG and SPG) with time ± is shown in fig. 40 and leads to interesting conclusions. The development of cross-cutting kyanite blades during the D1a and D1b deformation has to be related to the M1-metamorphism. Either the M1-metamorphism was prolonged or the direction of stress to which the rocks were subjected altered rather quickly. It seems far-fetched to evoke two successive orogenies would reach identical P – T condition. The change in direction of stress during D1 deformation can be explained either by "change in the orientation of the layering relative to the axes of the incremental strain ellipsoid" or "subjection to a constructive type of two dimensional stress" (Ramsay, 1967). The oldest Rb/Sr radiometric dates available for the Almora granites cluster are around 1800± 200 Ma (Bhanot et al., 1981; Trvedi et al., 1984) and can be best tied with the M1-metamorphism. This culminated in anatexis forming FPG granite.

The second metamorphism (M2) reached only into upper greenschist to lower amphibolite facies and outlasted the D2 deformation, as evidenced by survival of fresh garnet idioblasts. The tourmaline- bearing SPG and genetically related pegmatites and aplites were intruded in the waning stage of the M2 metamorphism, as these granites are porphyritic in hand specimens and do not register any signature of ductile deformation in the quartz C-axis orientations (Rajpoot, 1988). These granites have been dated for 560 ± 20 Ma (Rb/Sr) by Trivedi et al. (1984). Baig et al. (1988) concluded that the late Precambrian to early Paleozoic deformation in the Hazara Himalayas in Pakistan (D2 deformation in the present area) occurred somewhat prior to the Cambrian intrusion of Mansehra and related granites (SPG).

If the foregoing argument is accepted, then no metamorphic episode can be related to the Himalayan orogeny in Lesser Himalayan crystalline formations. This holds good, at least, in the Almora Crystalline rocks. Of course, the D3 deformation has folded the upthrust plane. The E – W stresses can be attributed to the larger movement of the Indian plate in the eastern margin compared to the western margin.

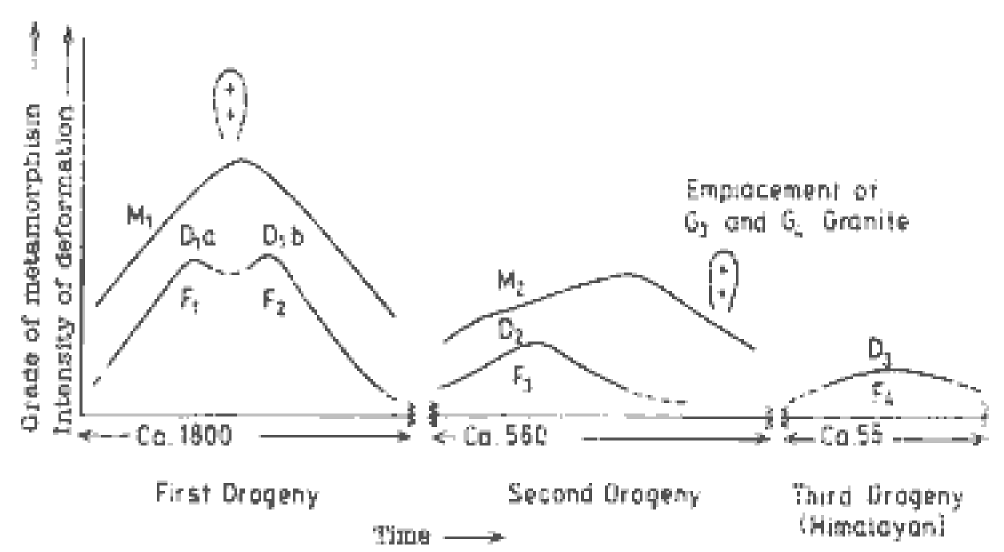

Fig 40. Sketch showing relationship among deformation, metamorphism and granite formation in Almora Group, Kumaun Lesser Himalayas.

One serious question remains to be answered that concerns the Tertiary radiometric dates from the Kumaun Lesser Himalayas, obtained by Crawford, (1981); Ashigirei et al., (1975); Nagpal et al., (1973); and Krummencher et al., (1978). These dates come mostly from biotites and some hornblendes. They can be explained by moderate heating of the Kumaun Lesser Himalayas during the Tertiary orogeny with temperatures never exceeding 400 – 450 ^{0}C. In fact, even a modest increase in temperature of 100 – 200 ^{0}C may have drastic effects on the parent - daughter relationships of natural decay schemes (Faure, 1977). The conclusion that the temperature for these rocks did not exceed the temperature of 400 – 450 ^{0}C during the Tertiary orogeny is brought out by a careful screening of the available mineral dates for the lower Himalayas by Krummenacher (1978). All the biotite samples from the lower Himalayas and the Kathmandu nappe give dates close to Tertiary but hornblendes give Precambrian to Palaeozoic ages (696 ± 25 Ma, 411 ± 16 Ma). Only one amphibole gives a Tertiary date and this perhaps come from close to a shear zone. The hornblende clock is set at about 450 ^{0}C. It is concluded that the Almora Crystallines has not undergone significant Tertiary metamorphism during Himalayan Orogeny and only moderate heating has occurred. The hypothesis that the Almora Nappe explains the inversion of metamorphic zoning in the Himalayan metamorphism and large scale horizontal transport.

3.3 Comparison of the Almora granites with the Hercynian older granite

General Geological Features

- The FPG (Precambrian) of the Almora group show polyphase deformations as do the surrounding host rocks. The SPG (Cambrian) are undeformed and intruded into the FPG. This aspect of the Almora granites is similar to the Hercynian older granites, where the G1 granites show micro- features of deformation whereas G2 is undeformed.

— The formation of Almora FPG corresponds with the peak of the M1 metamorphic event. The source, metamorphites of the granites, have been brought up by late upthrusts. But, such relationships between the metamorphism and magmatism in the Hercynian fields are not clear. However, it seems that the G1 and G2 granites are intruded into crystalline rocks in NW Bohemia. Also, the source rocks may not outcrop owing to the absence of upthrust tectonics.

— The Almora granites contain relics of metamorphic minerals and xenoliths of metasedimentary rocks. The Hercynian older granites also show similar features. But, the Hercynian older granites contain low pressure metamorphic minerals (andalusite, and cordierite) while the Almora granites contain relatively high pressure metamorphic minerals (kyanite).

— The Hercynian older granites post-date the main Hercynian orogeny and were emplaced in structurally controlled conditions. Moreover, they have not suffered by later deformation. The Almora granites were generated in two different syn-tectonic deformation events, one is the Precambrian and other is the Cambrian. The granites of the first event were deformed during a late Cambrian phase of deformation.

— The Almora granites and the Hercynian G1 and G2 granites are mainly granodiorite to monzo-syenogranites, poorly differentiated to undifferentiated, syn-collisional, calc-alkaline to sub-alkaline granites.

Cationic features

According to the comparison made between the geochemistry of the Almora granites and the Hercynian older granites, they are comparable. The range of variation in cationic parameters between the Almora FPG and SPG is nearly same as the Hercynian G1 and G2 granites have.

Alumina Balance [Al-(Na+K+2Ca)]

Both of the granites (i.e. Almora granite and Hercynian G1 and G2) are peraluminous (Fig. 41), but they are less peraluminous than the leucogranites of the Vaikrita Group and Hercynian Europe. The Karakorum leucogranites show a similar range of alumina balance as the Almora or Hercynian Older granites (Fig. 41 and 31)

Alkali/Calcium ratio [(Na+K)/Ca]

Both the granites are comparable in their alkali/calcium ratios (Fig. 41). This ratio is higher in the leucogranites, although the Karakorum leucogranites show a similar range of alkali/calcium ratio as the Almora or Hercynian older granites (Fig. 41 and 31).

Ferro-magnesium ratio [Mg/(Mg+Fe)]

This ratio is comparable in both granites (Fig. 41). The Ferromagnesium ratio is higher in these granites relative to the leucogranites (Fig. 31). This aproves the higher Mg biotite in the older granites of the Hercynian Europe and Lesser Himalayas.

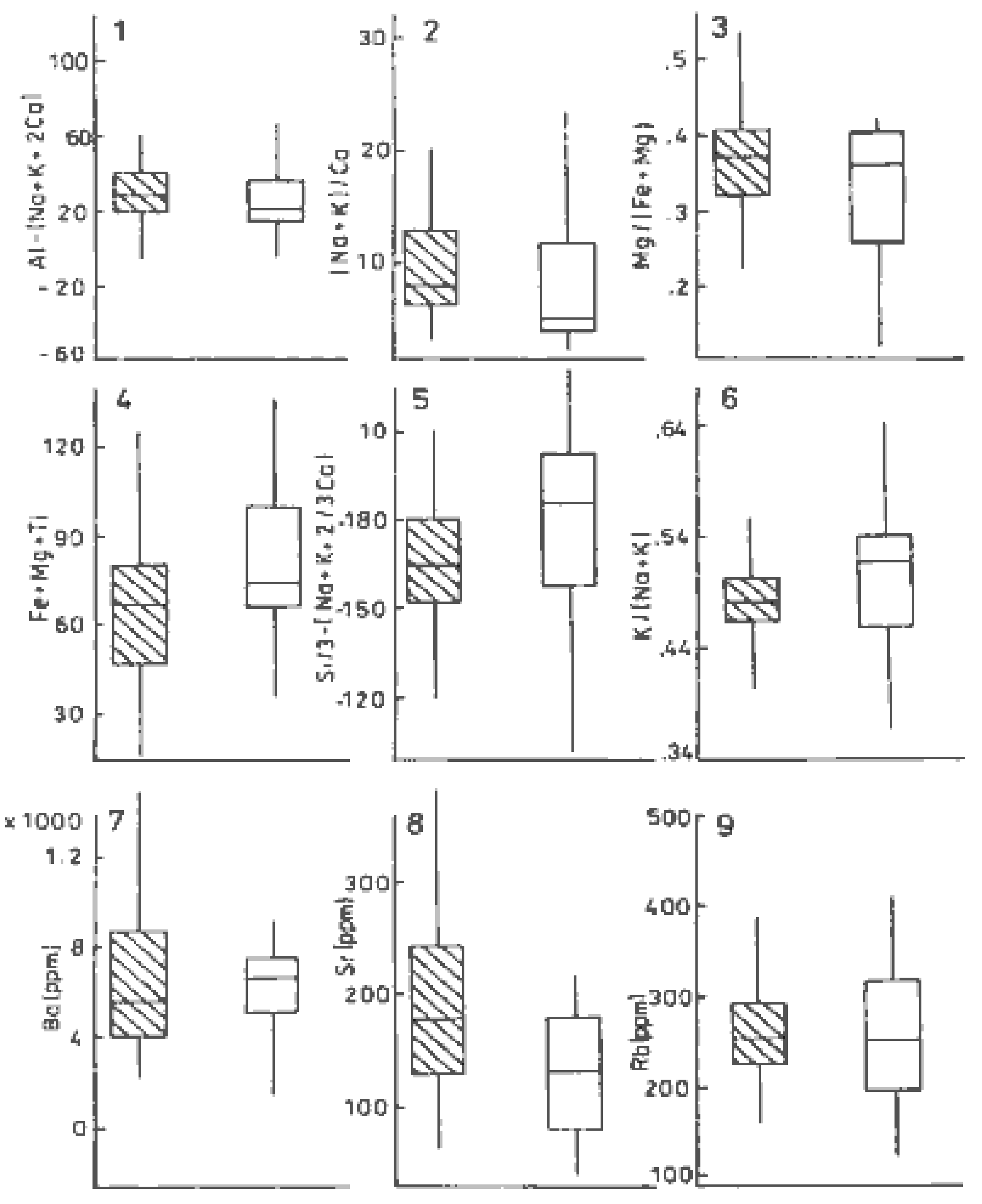

Fig. 41. Box and whisker plots of cationic parameters in the (\\\) – Hercynian older granites in Europe, (blank) – Almora granites.

Dark mineral constituents (Fe+Mg+Ti)

This value is also comparable in both granites (Fig. 41), and the range of Fe+Mg+Ti is significantly higher than the leucogranites of Vaikrita Group and of the European Hercynian (Fig. 31). The range of dark mineral constituents in the Karakorum leucogranites is similar to that in the Hercynian older and Almora granites.

Free quartz [Si/3-(Na+K+2/3Ca)]

This is also comparable between both the granites (Fig. 41). The Karakorum leucogranites have a similar range of free quartz (Fig. 31) as the Hercynian older granites and Almora granites.

Alkali ratio [K/(Na+K)]

The alkali ratio is also comparable between both the granites (Fig. 41). These granites range from sodi-potassic to potassic.

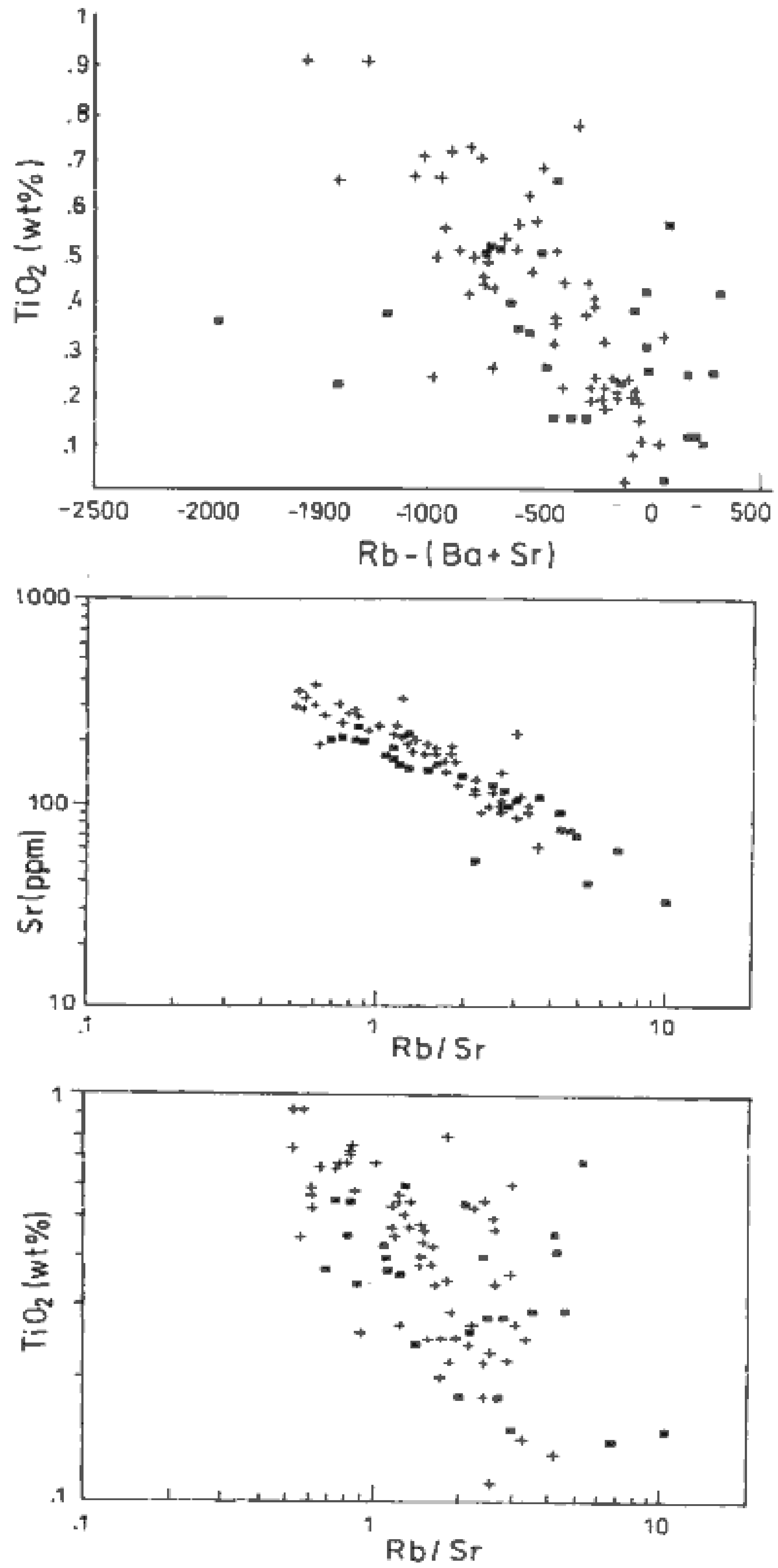

Fig. 42. Variation diagram of the granites. (solid boxes) – Almora granitoids and (plus) – Hercynian older granites (G1 and G2).

Trace element distribution

The Ba, Sr and Rb is comparable in both granites (i.e. Almora and Hercynian older granites, Fig. 41). These elements are not comparable in the leucogranites of Hercynian Europe or the Vaikrita group but the Karakorum leucogranites are comparable with the Hercynian older and also with the Almora granites.

The variation diagrams Sr vs Rb/Sr, TiO_2 vs Rb-(Ba+Sr) and TiO_2 vs Rb/Sr show similar distribution of Hercynian G1 and G2 and the Almora granites (Fig. 42).

Isotope ratio

The $^{87}Sr/^{86}Sr$ ratio is high in both the granites and comparable (Fig. 43). This initial Sr isotope ratio is also comparable with that of the Himalayan leucogranites (Fig. 33).

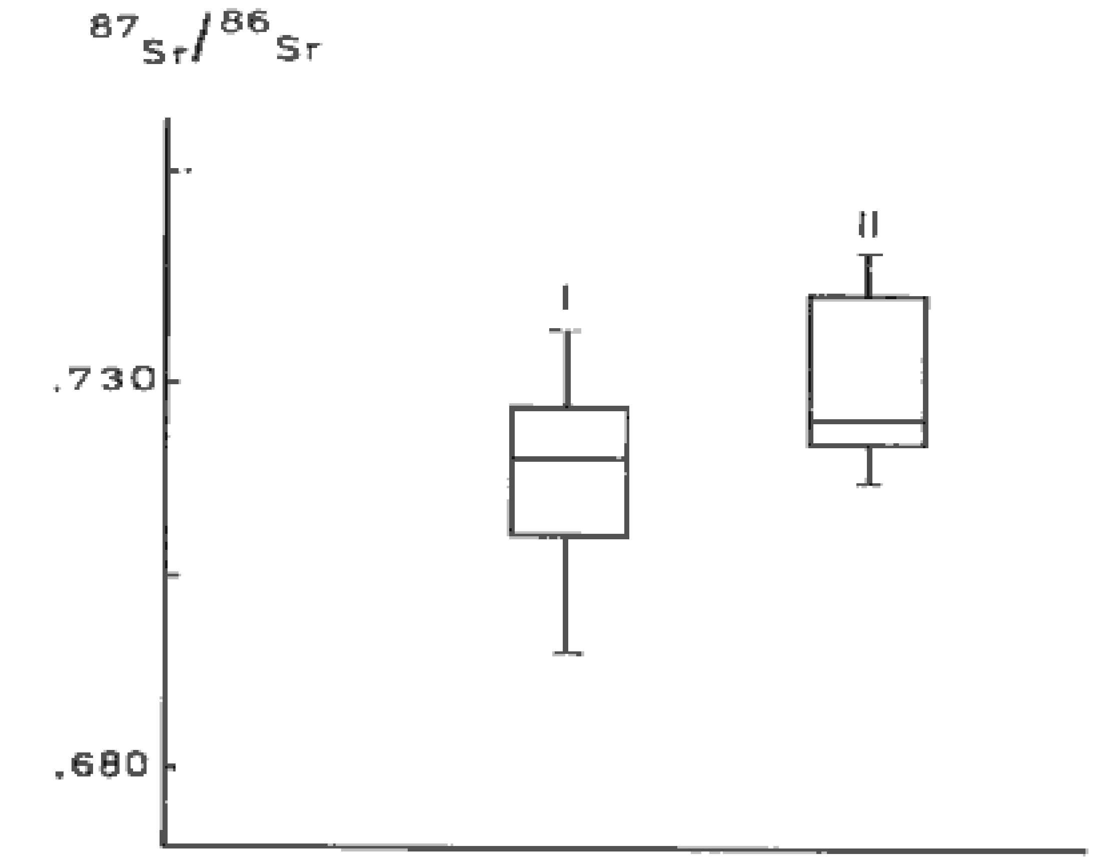

Fig. 43. Box and whisker plot of $^{87}Sr/^{86}Sr$ ratio. (I) – Almora granites and (II) – Hercynian older granites.

Rare earth elements

The REE patterns of both granites (Almora and Hercynian G1 and G2) are significantly comparable (Fig. 44a). The LREE/HREE ratio is also comparable (Fig. 44b). The only contrasting feature in the REE distribution is that the Hercynian G1 and G2 have relatively higher negative Eu anomalies (Fig. 44b).

Implications of similarities between the Almora granites and the Hercynian older granites

Although the Hercynian older granites are well studied rocks, there are several uncertainties regarding their genesis. For instance, the composition of the source rock, the approximate distance of transport of magma from source to the place of emplacement. Because of the above-mentioned similarities between the Precambrian and Cambrian Almora granites and the Hercynian older granites (in NW Bohemia and SW England) it is proper to apply the genetic model of evolution of the former granites to the Hercynian older granites.

The source rock composition of the older granites in Hercynian Europe is most probably pelitic rock, as they have similar chemistry, trace and REE distribution and $^{87}Sr/^{86}Sr$ ratio to the Almora granites, which have been derived as a

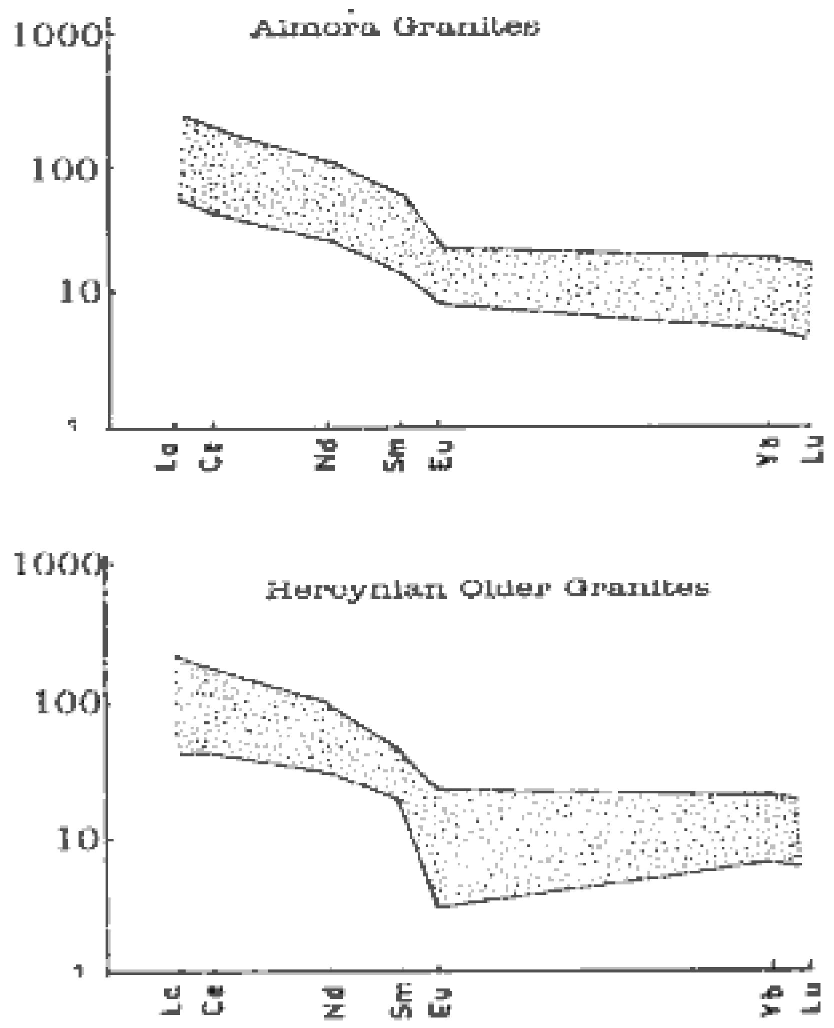

Fig. 44. REE patterns in Almora granite and Hercynian older granites in Europe.

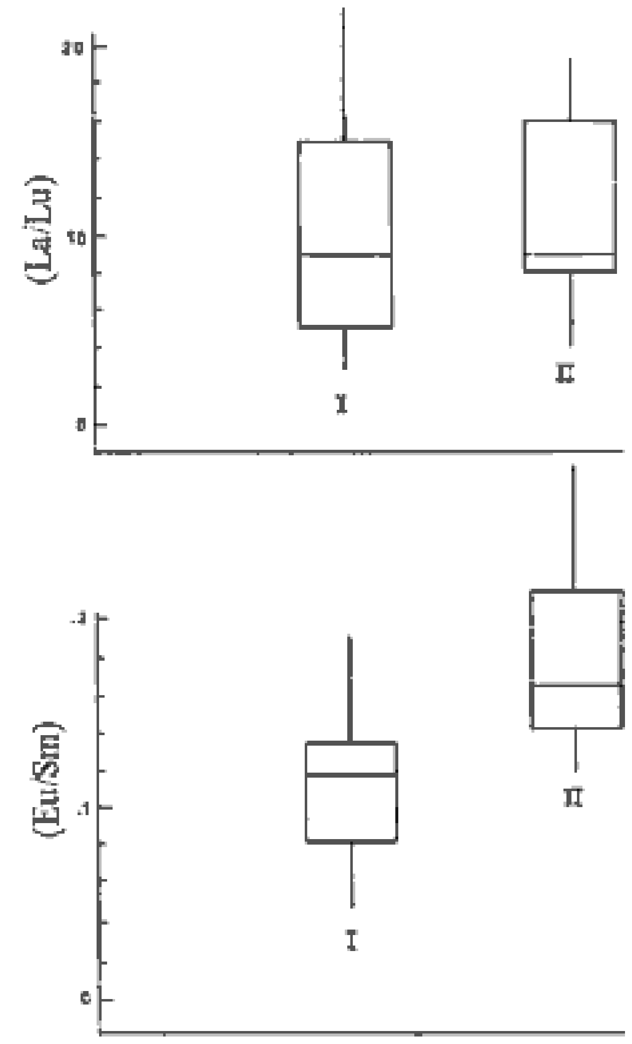

Fig. 45. Box and whisker plot of Eu/Sm and La/Lu ratios in Almora (I) and Hercynian older granites (II).

consequence of progressive metamorphism of pelitic sedimentary rocks. The pressure conditions for the formation of magma might have been different for the Hercynian older granites and the Almora granites as they show different suits of relict metamorphic minerals. It seems that in the case of the Almora granites, the magma did not move for a great distance from the source to the place of emplacement, as the granites are not sufficiently differentiated or fractionated and contain large undigested xenoliths of metasedimentary rocks (similar to the upthrusted surrounding metamorphites).