CHAPTER VII

PETROGENESIS

The genesis of the granitoids still remains a matter of discord. There are two opinions. While some still believe them to be of magmatic origin, most others call them products of granitisation of pre-existing rocks. There are many potential sources which can give rise to a granitoid rock. Hence, investigations on any granitic body is likely to be interpreted differently.

Starting from Strachey (1859) to Heim and Gansser (1939) and Nautiyal (1941) and many others, the granitic rocks of Kumaun have considered to be of igneous origin, intrusives into the metasediments. Valdiya (1962 c) considered the granodioritic body as intrusive and the marginal augen gneisses as the products of granitisation. Pande et al. (1963) were the first to envisage a metasomatic origin for these rocks and called them migmatites and assigned Tertiary age. Since then a number of workers have favoured the view of metasomatic origin. Pande and Powar (1968) and Powar (1970,1983) visualised introduction of the migmatic material through a probable dislocation zone. Agrawal et al. (1972) suggested the introduction of the anatectic melt through foliation planes to form granites. Gansser (1964) and Sarkar et al. (1965) visualized a syngenetic granitisation.

Merh and Vashi (1965) postulated that the granitisation process synchronised with the F folding which continued beyond this deformation. According to them the granitic rocks occupied the core of F_1 folds. A similar view was expressed by Desai (1973), Patel (1971) and Shah (1972). Sharma (1970) postulated that the oligoclase-bearing granites are anatectic, while the albite bearing granites are metasomatic in origin. Pande and Powar (1969), Lal (1969), Das (1971), Powar (1972), Kashyap (1972), Powar and Bhale (1978) believed in introduction of granitic melt into the metasediments along 'priviledged paths'. Misra and Bhattacharya (1976) believed in their syntectonic origin.

Whereas the Lesser Himalayan granitoids were studied in greater detail, the information on these rocks of Central Crystalline has remained more or less hazy and most of the previous workers have given their views on the basis of generalised investigations.

The present study however endeavours to provide a natural follow up and construct a genetic picture of Central Crystalline granitoids by integrating field and laboratory data generated by structural, petrographic, metamorphic and geochemical studies. The following field observations are significant while discussing the petrogenesis of the granitoids of Kumaun Higher Himalaya:

1. The granitoids are mostly foliated and the large feldspar grains and the ground mass show parallel arrangement.
2. The granitoids are intimately associated with metapelites and psammites, and show structural similarity with the country rocks. The granitoids not only show a gradual transition from schists to gneisses and then to granites but there are several schistose bands which occur within the granitoids.
3. They show variation in the textures northward, schistose to augen and porphyroblastic, increase in the granularity in the same direction. Mineralogically, the granitoids become richer in feldspars, particularly K-feldspar and do not contain xenoliths.
4. The granitoids show lack of forceful injection, complete absence of brecciated contacts, presence of resisters (quartzite bands occurring as caps over the granitoid bands which have acted as barriers, not allowing feldspathic solutions to permeate through), presence of relicts of host rocks (generally the ribs of quartzites and occasionally

schists), pods of feldspar in the relicts similar to those of granitoids, all these favour the rocks left untransformed by the process of feldspathisation and it appears that the granitoids have formed by the process of metasomatism.

Under microscope, the granitoids show the following characteristics :

1. A decline in quartz and micas both biotite and muscovite with a corresponding increase in feldspar, relict flakes of biotite as inclusions in plagioclase and sieved plagioclase with inclusions of quartz and mica, increase in size of K-feldspar from metapelites to granites, saussuritized plagioclase, sericitized K-feldspar, growth of myrmekites and presence of garnet in various granitoid rocks.

2. The outlines of the porphyroblastic feldspars and quartz show intricate sutures. The specimen collected across the strike of the rocks i.e. northward show a very gradual change with increasing development of plagioclase and potash feldspars.

3. The plagioclase first appears in the feldspathic schists as a slightly bigger grain than the rest of the mass. Then its size is seen to gradually increase. The borders of the porphyroblasts are highly sutured and partly include the adjoining micas and quartz. With further increase in size and

content, it forms regular augens, and finally as big porphyroblasts lying across the foliation.

4. The granitoids show replacement of plagioclase by potash feldspar, presence of garnet porphyroblasts with abundant inclusions of pre-existing quartz and mica, and selvages of recrystallised biotite and muscovite around the porphyroblasts.

5. Predominance of cross-hatching in K-feldspar (as also confirmed by XRD), muscovite over biotite, slightly coloured and feebly pleochroic muscovite, sub-rounded zircons, presence of tourmaline and a high value of 2Vx, no significant variation in the anorthite content of plagioclase, presence of hydrous silicates and development of myrmekitic texture are some of the further important petrographic characteristics.

The overall petrographic features favour the granitisation through fluid medium and active participation of liquid diffusion in rocks, which could be the likely explanations for the evolution of the granitoid rocks of Kumaun Himalaya in general and Higher Kumaun Himalaya in particular.

The metamorphic studies of the granitoid rocks (see petrography and metamorphism) indicate a progressive increase in the grade of metamorphism from green schist facies to upper amphibolite facies. The sediments which gave rise to the granitoids were subjected to orogenic stresses which deformed them into a large scale isoclinal/reclined folds (F_1). This folding synchronised with the progressive regional metamorphism and gave rise to a number of mineral assemblages, characterising moderately high pressure and temperature (Chapter V). The granitisation appears to have closely followed the regional metamorphism and the granitising solutions perhaps invaded the rocks along the axial plane foliation S_1. The fact that the quartzo-feldspathic veins which show tight folds, suggest that there was yet another fold event of similar nature (F_2) which folded the granitised rocks. Thus in a broad sense granitisation was synchronous to F_1 folding and the progressive metamorphism. The various granitoid bands showing isoclinal/reclined folds are seen involved in subsequent coaxial fold event (F_2).

The geochemical data on the granitoid rocks of the study area also supports granitisation as the cause of formation of these rocks. That the granitisation occurred is evidenced by the following observations:

1. The excess of alumina is evidenced by their high peraluminous nature and moderate normative corundum (2 -3%). The molecular A/CNK values are also more than 1.1 confirming their peraluminous nature which is a characteristic feature of sedimentary rocks.

2. Despite their high peraluminous nature these rocks plot in the granite field in the ternary diagram of O'Connor (1965).

3. The Niggli value plots of si against mg, fm+c, ti, p, al, k and alk reveal a common source for all the granitoid varieties as they form a single cluster.

4. The Harker diagrams for the major oxides reveal the behaviour of various oxides with changing silica content. It is observed that while P_2O_5, CaO, Al_2O_3, TiO_2, MgO, MnO and Fe_2O_3(T) decrease with increasing SiO_2; Na_2O remains more or less constant and that K_2O increases with increasing SiO_2. Hence, enrichment of K_2O content and moderate Na_2O content with increasing granitisation is observed. This also depicts enrichment of K_2O over Na_2O.

5. The AFM diagram as well as the log(CaO/Na_2O + K_2O) versus SiO_2 (Figs. VI.8 and 9) substantiates the calc-alkaline nature of these rocks. The AFM diagram also reveals progressive enrichment in alkalies with concomittant depletion in magnesia and total iron.

6. In the Na_2O/Al_2O_3 versus K_2O/Al_2O_3 diagram (Fig. VI.11) which delineates the sedimentary granitoids including schists and quartzites fall in the sedimentary field with all amphibolites plotting in the igneous fields.

7. White and Chappel (1977) used alkalies as the parameter to delineate between I- and S-type of granites. Hence, in the K_2O versus Na_2O diagram the granitoid rocks fall in the S-type field indicating a sedimentary parentage (Fig. VI.12).

8. Complementary diagram of de la Roche (1978) clearly distinguishes parent sedimentary domains and it was observed that the granitoid rocks plot in the arkosic field.

9. In the molar Al_2O_3 $(Na_2O + K_2O)$ versus $Al_2O_3/(CaO + Na_2O + K_2O)$ diagram (Fig. VI.15) the granitoid rocks fall in the continental collision granite zone and are also peraluminous.

10. Low concentrations of trace elements like Cu, Co, Ni and Ga in the granitoid rocks are comparable to the continental crustal values.

11. Rb concentrations are rather high and predominate over Sr concentration. Rb/Sr ratios are also high of the order of 0.8-7.79. Even the Rb/Ba ratio is very high (7.3) and is more than that of the crustal ratios. These are indicative of pelitic source.

12. Trace element variation diagrams reveal that while Zn and Zr decrease, Y and Ga remain more or less unchanged with increase in SiO_2. Increase of Rb with decreasing MgO indicates action

of fluid phases. Sr is found to increase with increasing CaO confirming compatible nature of Sr.

13. K and Rb furnish a positive correlation and low K/Rb ratios. These are indicative of fluid interaction processes.

14. Th has remained almost unchanged with increase in Zr.

15. In the Rb-Sr diagram which helps in discriminating various granite types the granitoid rocks all plot in the S-type field of granites.

16. Using trace element diagrams Y vs SiO_2 and Nb vs SiO_2 the granitoids were found to firstly fall in the VAG, COLG and ORG fields. Whereas, in the Nb vs Y and further in Rb vs SiO_2 diagrams they got separated into VAG, syn COLG and then finally into syn COLG field. Pearce et al. (1984) define the syn COLG as typically muscovite bearing peraluminous and that they exhibit most of the features associated with S-type granites.

17. The REE deviation from the average continental crust could be attributed to the mobility of REE'S during metasomatism.

18. The granitoids are characterised by moderate REE contents with negative Eu anamoly which is not much pronounced. The REE

patterns correspond to those REE patterns representatives of the continental crust.

The field, petrographic and geochemical evidences, thus point to crustal source and more specifically a sedimentary parentage as a source material for the genesis of the granitoid rocks of Higher as well as Lesser Kumaun Himalaya. The highly peraluminous nature of these rocks also points to a sedimentary parentage. Barbarin (1990) compared the twenty most frequently used petrogenetic classifications of granitoids and brought out petrographic, mineralogical and chemical characteristics of each. He also brought out strong relationship between the types of granitoids, their origin and tectonic setting. The granitoids of the study area are also of crustal origin, peraluminous and have an orogenic setting.

In the absence of any evidence of igneous intrusion, granitisation is invoked as the cause of genesis of these rocks. The granitisation was brought about by the metasomatic action of alkali rich emanations. This is supported by the enrichment of potash and little soda as revealed by the field, petrographic and geochemical data. The strong positive correlation of K_2O with SiO_2 with increased granitisation and depletion of Fe_2O_3 (T) and MgO with increasing SiO_2 from schists to gneisses and further to granites also supports this fact.

The first stage of granitisation is marked by the development of plagioclase due to Na_2O metasomatism in the metapelites. With increased granitisation causing a general increase in size of the plagioclase grains; augens and porphyroblasts of plagioclases were formed. The Na_2O metasomatic phase was followed by K_2O and replacement of plagioclase grains by K-feldspars, thus forming K-feldspar porphyroblasts. The last and late Na_2O metasomatism once again formed plagioclases and also resulted in the formation of myrmekitic rim around the K-feldspar grains. This stage also comprised debasification of the country rocks and was accompanied by tourmalinization. The pattern of progressive alkali increase fully supports the view put forth by Lapadu Hargues (1945) that regional metamorphism leading to granitisation consists of a progressive calc-alkali influx. According to him, with increasing metamorphic grade there is an influx of alkalies from deeper zones. In the lower grades there is an accession of soda, in higher grades the accession of alkalies continuous with domination of potash. Both the alkalis come from the same deep source, soda moving further due to its smaller ionic radii, while potash on account of having larger ionic radii remains confined to the inner zones.

The granitisation of the metasediments commenced prior to isoclinal reclined folding episode and this is supported by the fact that the granitoids show their involvement in the F_1 folding, which was accompanied by a progressive metamorphic phase. The granitoids formed under upper amphibolite facies, and exhibit progressive metamorphism from south to north. The granitoids appear to have formed during some late Precambrian orogeny that affected the rocks to the south of Himalaya and formed the basement for the deposition of the younger Himalayan sediments. The geo chronological data also support this contention.

The Himalayan granites according to Valdiya (1983) occur in four tectonically distinct and lithostratigraphically diverse settings; (i) porphyritic granites of Precambrian age (~ 1900 m.y.) in the Lower Himalayas (ii) tonalite granodiorite with marginal augen gneisses of granitic composition emplaced upon the epi-metamorphic nappes, compositionally different and younger in age (~ 600 m.y.) (iii) porphyritic granites within the epi-metamorphics and the trondjhemitic suite of the mesometamorphics intruded by leucocratic adamellites (syntectonic granodiorites_ assignable to the Early Paleozoic (400-500 m.y.) age. Also batholiths, stocks, dykes and veins of granites and aplites, post-tectonic, occurring within kata-metamorphic assemblages of the Higher Himalayas are of Middle Tertiary age (iv) granodiorite quartzdiorite bodies associated with calc-alkaline volcanics occupying the Indus-Tsangpo Suture Zone of Tertiary period. Thakur (1983), on the other hand has classified the Himalayan granites into pre-Himalayan and Himalayan. He has categorised pre-Himalayan granites into three age groups; (i) 1800-2000 m.y. (ii) 1200-1400 m.y. and (iii) 500 m.y. The Tertiary granites according to this worker, on the other hand are of Eocene and Miocene ages. The tourmaline granites of the Higher Himalayas are post-Himalayan orogeny granites of Miocene-Pliocene age (Gansser, 1964). Powar (1983) has however invoked three periods of granitoid formation; corresponding to the emplacement of the Ramgarh-Amritpur granitoids, the granitoids of Almora nappe and the leucocratic tourmaline bearing granites and aplites. He has further argued that the dates, of 1880 ± 40 m.y. and 1330 ± 40 m.y. for the Amritpur granites (Varadarajan, 1978) and 1170 ± 20 m.y. for the Koidal granitoids (Bhanot et al., 1976) from the Krol parautochthon. Bhanot et al. (1977 a, b) have assigned point isochron ages of 1895 ± 200 Ma and 1960 ± 100 Ma for gneisses from the Central Crystallines of Kumaun. Bhanot et al. (1980) obtained an Rb-Sr dating of 1883 ± 80 Ma from the gneisses of the Askot Crystallines. A younger age for large parts of the Himalayan crystallines have also been determined (Frank et al. 1976; Mehta, 1977; Powell and Conaghan, 1973). Lefort et al. (1986) showed that the majority of granitoids in Nepal Himalaya of the Lesser and Main Himalaya yielded ages between 520 and 480 Ma.

The Himalayan crystalline rocks with associated granitoids are now more or less considered by most workers to comprise the northern extension of the Indian Precambrian Shield (Gansser, 1964; Naqvi et al., 1974; Crawford, 1974; Sarkar, 1980; Merh, 1984; Chamyal et al., 1984; Merh et al., 1986; Chamyal and Vashi, 1989; Fuchs, 1992). The crystalline barrier which came into existence during the Hercynian orogeny separated the Lesser Himalaya from the

Tethys. The rocks of the barrier are correlatable with Delhi system of Rajasthan (Merh et al., 1986). Bhanot and his associates work on the Precambrian gneisses of Himalaya (Bhanot et al., 1977 a, b and 1980) thus appear to provide a more dependable geochronological picture. The age 1830 $\pm$ 200 m.y. for the granitoids of Munsiari area of Higher Kumaun Himalaya thus seems to be in conformity with the other evidences.