Chapter V

PEGMATITES
Very extensive pegmatite activity is seen in most of the rock types, the biotitic limestones and the calc gneisses being the exceptions. In the biotite schists in particular the pegmatitic activity is copious.

The pegmatites occur in all sizes. They vary in width from a few millimetres to easily one or two kilometres. They do not have any particular relationship with the country rock, but the general trend of the pegmatites is broadly parallel to the strike of the country rocks. In a majority of the cases the pegmatites are parallel or very nearly parallel to the bedding/schistosity in the rock. In several instances they cut right across the strike of the schist rock. In between these two cases of extreme settings all variations can be seen, i.e., veins cutting the schistosity at different angles. The more common cases of pegmatites showing concordant relationships and interfoliar veins are obviously related to the favourable setting in the country rock (bedding and schistosity affording an easy path). It may also be noted that a pegmatite body having a concordant relation may change over to a discordant relationship. At times the pegmatite body is a kind of a clot or knot from which veins ramify into the country rock. It is difficult to convincingly argue whether the clot or knot is a result of a number of intersecting veins or whether the ramifying veins
originated from the clot. The pegmatites occur sometimes in the form of bosses with a diameter of a kilometre or more. The host rocks of even here scattered outcrops of a very small size are common. Pegmatites being more resistant to weathering compared to the surrounding schists give rise to bold hill features and some of the high peaks in the area are in pegmatite country (Pl. 25-d).

**Distribution of pegmatites:**

The distribution of pegmatites in the area under study very strongly suggest that their emplacement is controlled by factors such as structure and lithology. The paucity of pegmatites in the biotitic limestones and their copious presence in the biotite schist cannot be ignored. Heron (1953) also observed this factor and rightly attributed it to the lithology and structure.

Where the rocks were soft and laminated the pegmatites are seen in abundance. The biotite schists, the calc schists and garnet mica schists have proved to be the best host rocks for the emplacement of the pegmatites. The red quartzite also shows considerable pegmatite in it. The bedding planes and the axial surfaces of folds have afforded room for pegmatite emplacement. The biotitic limestone is free of pegmatites. Thus it looks that if a rock unit has a good cleavage/schistosity or bedding or even joints it has proved to be a good host rock.
for emplacement and if a rock unit is massive and does not possess any planes of weakness it has proved to be a poor host rock.

**Types of pegmatites:**

The pegmatites of the area can be differentiated on the basis of their mineral composition and their relationship to the host rocks. Three types have been recognised.

**Type I** - These pegmatites are essentially made up of quartz and felspar, and tourmaline and mica occurs in clusters or as dense aggregates and are not distributed throughout the rock. This pegmatite occurs mainly in the form of bosses. These are medium grained. The relation with the host rocks cannot be precisely stated.

**Type II** - In contrast to the pegmatites of the above class these are fine grained. Mineralogically they are distinct by the absence of tourmaline. Mica is disseminated throughout the rock. These are invariably concordant with the host rock and most of the interfoliar pegmatites are of this type. At a few places these pegmatites are seen cutting through the pegmatites of type I (Pl. 26-A).

**Type III** - These pegmatites are very coarse grained (coarser than type I & II) and are conspicuous by the abundance of tourmaline. Quite commonly the long axes of the tourmaline
crystals are aligned parallel to each other producing a strong lineation. In small veins, this lineation is always at right angles to the walls of pegmatite. This class invariably shows discordant relationships with the host rocks and not uncommonly cuts the pegmatites of types I & II (Pl. 26-B).

The broad mineralogical and grain size differences help in differentiating them and their interrelationships help in fixing their age relationships.

Mode of emplacement of pegmatites:

Any discussion on pegmatites would be incomplete without some comments on their mode of emplacement. In compliance of this need some observations made in the field which will throw light on this aspect of the problem are presented here. The origin of pegmatites, though broadly related to emplacement is not a major concern of the present study. At the very outset it may be remarked that a voluminous literature exists on pegmatites and some very detailed accounts on the mode of emplacement have also been published (Chadwick, 1959; Jahns, 1955; Anderson, 1931; Kemp, 1924) and an exhaustive discussion is beyond the scope of the thesis. The present study on this aspect of pegmatites is limited to structural criteria that throw light on the mode of emplacement. The study aims at seeing any difference that may exist in the mode of emplacement of the three types of pegmatites already described.

(The grain size described here as coarse, medium or fine is not in the usual sense of the term. In the general order of the grain size of pegmatites one is fine and the other is coarse or medium.)
Pegmatite emplacement is one of those topics on which several divergent opinions have been expressed. Anderson (1931) concluded that many pegmatites crystallise by forcibly intruding the country rocks or by permissively draining into openings. Chapman (1941) thought the pegmatites resulted from segregation in magmas and were emplaced by inflow of pegmatite liquids into fractures in a crystal mush or solid rock. Quirke and Kremers (1943) suggested that pegmatites formed by filling open spaces or by metasomatic replacement. Ramberg (1949, 1952, 1956), King (1949) and Barth (1952) stressed metasomatic replacement, metamorphic differentiation and secretion as modes of pegmatite emplacement. Jahns (1955) reviewed the origin of pegmatites including mode of emplacement. Chadwick (1958) reviewed and discussed mode of emplacement at length. He attempted to classify the modes of emplacement and presented field criteria for distinguishing the different modes of emplacement. His classification is as follows (p. 806):

Displacement
- Forceful
- Permissive

Mobility
- Introduction
- Local derivation
- Host rock breakdown

Non-displacement
- Introduction
- Residual segregation
- Local derivation

These criteria tabulated by him are supposed to be helpful in deciding the mode of emplacement although individually each
one of them has no more importance than a suggestion. Often the evidence shows that the mode of emplacement is transitional from one to the other.

It must be stated here that no single mode of emplacement is valid for all the pegmatites in the area. Further, on several occasions, individual pegmatites appear as though that a blend of more than one mechanism has been operative in their emplacement. Field evidence clearly suggests that type I pegmatites which occur as bosses covering squares of kilometres might have been emplaced by non-mobility mode under non-displacement category. That the non-mobility type of emplacement characterises the type I pegmatites is indicated by (i) the pegmatites contain relict textures and structures of the pre-existing rocks (Pl. 26-D), (ii) foliation and lineation of inclusions of country rocks in the pegmatite are concordant with the foliation and lineation of the wall rock. The pegmatite fluids were mainly introduced and partly locally derived. Extensive areas occupied by pegmatites and marked contrast in the composition of pegmatites and the country rocks suggest introduction (subclass of non-mobility type) mode of emplacement. The areas occupied by pegmatite show very little of the host rock (biotite schist) thereby indicating the dissolution of, and assimilation of the host rock by the introduced pegmatitic liquid.

Type II pegmatites which are generally interfoliar show structural features indicative of altogether a different manner
of emplacement. They show displacement mode of emplacement. Evidence of forceful as well as permissive type of emplacement is available.

Heron's description of the pegmatites very clearly points that he considered them as forceful injections into the schists. He wrote, "The Ajabgarh biotite-schists and the tremolitic 'calc-schists' are specially invaded by pegmatite, owing, I believe, to their easy penetrability along the foliation. Plates 19, Fig. 1; 20, Fig. 1; 25, Figs. 1 & 2; 28, Fig. 1 show the manner in which pegmatite frays out and wedges apart the folia of the schist, separating blocks of it." Undoubtedly, there are several examples agreeing well with Heron's description and these pegmatites may be regarded as forceful injections in the country rocks. The criteria of forceful emplacement are applicable to them in a large measure. Non-omission of wall rocks and their matching and deflection of foliation parallel to pegmatite contact (Pl. 27-A) are some of the features suggesting forceful emplacement although no deformation in the wall rocks could be seen. Several instances where the pegmatite cuts the schists at very oblique angles to the schistosity also possibly indicate forceful emplacement.

At places in the calc schists the pegmatites have been emplaced in the fracture planes indicating a permissive mode of emplacement.

Type III pegmatites indicate more than one contrasting
types of emplacement. When they are interfoliar their emplacement is identical with type II pegmatites. These pegmatites also show widening and wedging of schistosity planes and other features. They are also seen coming up along the axial surfaces of the $F_2$ folds (Pl. 17-D) although no cleavage or schistosity is developed ($S_2$ cleavage parallel to $F_2$ folds has a limited occurrence and pegmatites along the axial surfaces of the $F_2$ folds are seen even when there is no cleavage development). The schistosity and bedding which are folded by the $F_2$ folds show bending in the direction of movement (Pl. 27-B). These features clearly point out forceful emplacement. They also show not uncommonly orientation of the tourmaline crystals perpendicular to the wall rock which is regarded as a mobility criterion of a low importance of the non-displacement type. In the absence of other more important indications of mobility type emplacement this may be ignored.

**Age of emplacement — A discussion:**

The pegmatites of the area show some very interesting relationships with the host rocks that throw light on the time of emplacement of the pegmatites. Heron (1953) distinguished the post-Delhi pegmatites from older ones which are largely confined to the Banded Gneissic Complex. The post-Delhi pegmatites described by Heron (1953) are massive, unfoliated and contain muscovite mica, rare earth minerals and tourmaline in abundance, while the pre-Delhi pegmatites (restricted to the
Banded Gneissic Complex) are foliated and devoid of tourmaline. According to Heron (1953, p. 20), the order of intrusion of the post-Delhi acid rocks in his own words is as follows: "Swarms of aplite veins seem to have been the first manifestations of this igneous activity, and these invade the Ajabgarh biotite-schists in lit-par-lit injection over large areas forming composite gneisses with them.

The first of the granites proper appears to have been the banded and streaky acid type, and the well-foliated biotitic type in sheet like intrusions, followed by bosses in which the foliation may be general throughout the body or largely marginal, and later, the large bosses of coarse unfoliated granite. The pegmatites were the latest phase with their end products — quartz veins."

The post-Delhi pegmatites have necessarily to be related with the Erinpura granite since there is no other granitic intrusion older than it recognised with which such extensive pegmatitic activity could be associated.

The geochronology of the Precambrians of Rajasthan cannot be claimed as too well known. The bulk of the radiometric dating of these rocks is done by Sarkar et al. (1964, 1968, 1972) and Crawford (1970). The earlier work of Sarkar et al. is mostly based on K-Ar ages whereas Crawford has dated the rocks by the Rb-Sr method. Greater reliance can be placed only in Crawford's data as K-Ar ages will only show the last thermal
event suffered by the rocks. The age of the Delhi sediments according to Crawford is over 1500 m.y. on two counts. The post-Aravalli granites have an age of 1900 m.y. and possibly as much as 2100 m.y. The age of the Alwar series and probably the entire system is, according to him, greater than 1650 m.y. Crawford and Compston (1970) have reported 1400 m.y. age for the base of the Vindhyan System confirming Tugarinov et al. (1965). Since the geological evidence shows that the Vindhyans lie unconformably over the Delhi System of rocks, their (Delhis) age should be more than 1400 m.y. From the available data it is obvious that the Delhi rocks cannot be older than say 2000 m.y. and younger than 1400 m.y. So it is not unreasonable to assume that the Delhi metasediments are approximately of 1700 to 1800 m.y. of age. If that is so the Delhi orogeny could be around 1600 to 1700 m.y.

Leaving the geochronological data for the moment, we may now consider the Delhi orogeny and deformation of the Delhi rocks. The Delhi rocks, wherever they have been studied show polyphase deformation (Sen, 1970, 1972; Mitra, 1970; Gangopadhyay, 1970-72; and Bhargava, 1972) etc. In the area under study as well, three sets of structures have been recognised. Whether these structures developed one after the other in quick succession or whether there has been considerable time gap can hardly be guessed. Even if a time gap is accepted for the sake of an argument we do not know the magnitude of the time gap. Further it seems not probable that any one of the later deformation/s
could be regarded as an imprint on the Delhi rocks but actually connected with the orogeny of a younger group of rocks. This is regarded unlikely because nowhere in the proximity of the Delhi rocks do any younger rocks occur whose deformation could be impressed on the Delhi rocks like the case of the Aravalli sediments. Crawford (1970) considered that the first folding of the Aravalli rocks occurred around 1900 m.y. and the second at 1200 m.y.; the second affecting the Aravalli as well as Delhi rocks in an area northeast of Udaipur implying that the second 1200 m.y. old folding episode is a Delhi orogeny imprint on the Aravalli. But in the case of the Delhi rocks all the different sets of structures should belong to the Delhi orogeny itself resulting from pulsating orogenic movements. Such polyphase deformation is not new to any orogeny and is in fact a common feature.

We may now look into the pegmatites of the area and what their relations are with the host rocks and the deformational structures seen in them. Type I pegmatite that occurs as bosses or domes does not show any clear relation with the schist rocks. Type II pegmatites occur as concordant and interfoliar veins. These have been folded along with the country rocks and any number of outcrop sized \( F_2 \) and \( F_3 \) folds in which the pegmatites are folded with the country rocks can be seen (Pl. 16-A, B; 18-B; 19-A; 20-B; 27-C; 30-C). Type II pegmatites cut type I pegmatites and so type I pegmatite must also have been emplaced before the type II pegmatites emplaced
and folded with the rocks. Excellent boudinage of the pegmatites in biotite schists is a common feature (Pl. 28-A, B; 29-A, B, D; 30-A, B). Pinch and swell structure of pegmatite veins is a very common phenomenon which should be the case in view of the extensive boudinage seen in the area. Type III pegmatites cut type II as well as type I pegmatites and they have been at several places observed coming up along the axial surfaces of the $F_2$ folds. The type III pegmatites also have been folded by the $F_3$ folds of the area. It is interesting to note that Heron has also observed pinch and swell structures an early stage of boudinage phenomena but regards it as an intrusive feature. Heron (1953, p. 368) wrote, "Introduction proceeded quietly without violent disturbance of the folia with irregular swelling and pinching out of both the layers of the intruded rock and the intrusives." Pl. 28, Fig. 2 of his memoir shows clear pinch and swell structure and is actually quoted by him in the above context.

Thus there is unequivocal evidence in the area to show that the pegmatites irrespective of the type have all suffered deformation along with the rocks in which they occur. If they have been emplaced after the Delhi orogeny the boudinage and the folding seen in the pegmatites can hardly be explained.

Earlier it has been argued that the whole deformation seen in the Delhi rocks should belong to the Delhi orogeny rather than of its likelihood of being in part a later deformational
impress. On this assumption the pegmatitic emplacement must have been synchronous with the deformation and metamorphism of the Delhi rocks or syntectonic with the Delhi orogeny. Heron considered that the pegmatites, aplites seen in the Delhi rocks are different phases of the Erinpura granite. Earlier it has been shown that the Delhi rocks are around 1800 m.y. old and the Delhi orogeny date can be reasonably assumed to be around 1600 m.y. If so the pegmatites in the Bhim area should also be approximately as old as the Delhi orogeny.

We may now consider the age data of Erinpura granites. It may be noted that this granite has an enormous extent and that all of it had been emplaced at one time throughout the area where it is exposed is very unlikely. Heron too argued on similar lines (1953, p. 368) and wrote, "In the south-west of the synclinorium, however, signs of movement and disturbance in pegmatites are the rule rather than the exception, showing that the intrusion of pegmatite did not completely post-date folding movements and that their periods of duration overlapped.

It is not necessary to suppose that the folding commenced and ended simultaneously at all parts of the synclinorium, or the various types of intrusion were each contemporaneous throughout. In such a great length it is only natural that similar phenomenon did not happen at quite the same time everywhere though a general sequence seems to have been maintained."
At the time at which Heron wrote his memoir (on Central Rajputana) he conceived that Erinpura granite immediately followed the Delhi orogeny and conceded that part of the folding movement and intrusive activity overlapped in some areas.

Crawford (1970) dated a number of samples believed to be Erinpura granites (please refer to 'Crawford' for locality of samples, p. 99). The granites supposed to belong to the Erinpura group give contrasting results. The Untala granite, an Erinpura group granite in the Banded Gneissic Complex, gave an $\text{Sr}^{87}/\text{Sr}^{86}$ isochron age of 950 m.y. Every credit should be given to Heron for recognising it as a member of Erinpura granite group. The granites at Chhapol and Ajmer also believed to be Erinpura granites gave ages of 1010 m.y. and 935 m.y. consistent with the isochron date of Untala granite. The Bairat granite indicated an age of 1650 m.y. Dadikar granite from near Alwar gave an age of 2200 m.y. Crawford considers it probable that the Dadikar granite is not post-Delhi.

From the limited data available, it is obvious that whatever has so far been believed to be Erinpura granite is not of the same age. The Bairat granite which intrudes the Alwar quartzites dates 1660 m.y. This could be slightly older than the age of the Delhi orogeny and the pegmatites seen deformed with the Delhi rocks may be related to this phase of igneous activity and not to Erinpura granite as is known today. It is
interesting to note that Sarkar (1972) regards the 1660 m.y. age of Bairat granite as indicative of the closing of the Delhi cycle. The author is in full agreement with Sarkar in fixing the closing time of the Delhi cycle.