CHAPTER II

DESCRIPTION OF DIFFERENT ASSOCIATIONS OF MALANI IGNEOUS PROVINCE

2.1. ASSOCIATION I (*MALANI VOLCANICS*)

The felsic volcanics of Gurapratap Singh and Diri belong to andesite-dacite-rhyolite association and are part of the Malani igneous province (*MIP*) of Rajasthan. These volcanics have been referred to as Malani volcanics (Srivastava, 1988). The area under study lies 30 km southwest of Pali, between North latitudes 25°35'-25°40' and East longitudes 73°-73°10' (Fig. 1.5). The volcanics are confined to hill ranges running NE-SW to NNE-SSW in semi arcuate fashion and have been extruded on a basement of mica schist and shale/slate belonging to the Aravalli or the Delhi Supergroup. Most of the rocks are aphyric to sparsely phyric with an obsidian like look. Flows generally have a dip 10° to 15° to NW.

The distribution of various rock types in the area is shown in Fig. (2.1). The main rock types include dacite, rhyodacite and rhyolite with minor occurrences of basalt and andesite. The rhyolites occupy lower ground while high silica rhyolites are seen on the top of hills. A very small isolated occurrence of basalt was found in the plains to the NE of village Bhavnagar. The field disposition of the basalt i.e. whether occurring in the form of a dyke or as a flow, could not be ascertained. The rhyolites are cut by numerous dykes of rhyolite porphyries and rarely by dolerite (Srivastava et al., 1989a).

Srivastava et al. (1989a,b) carried out detailed geochemical study (major and trace elements) of these volcanics. The chemical data of different rock types plotted on the Harker diagrams (Fig. 2.2) revealed a systematic variation in all major elements with the

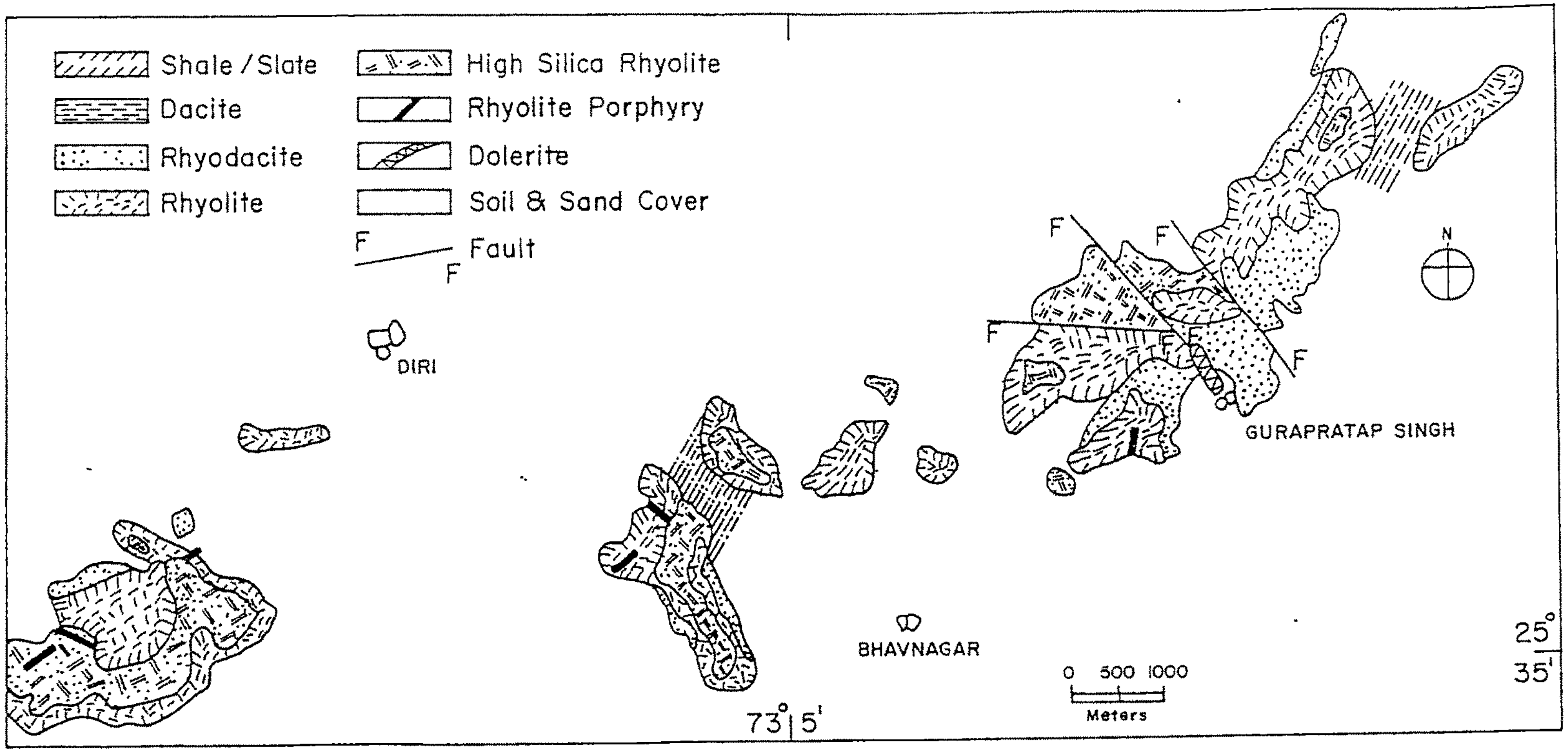

Fig. 2.1. Geological Map of Gurapratap Singh and Diri, Pali District, Rajasthan (After Srivastava et al., 1989a)

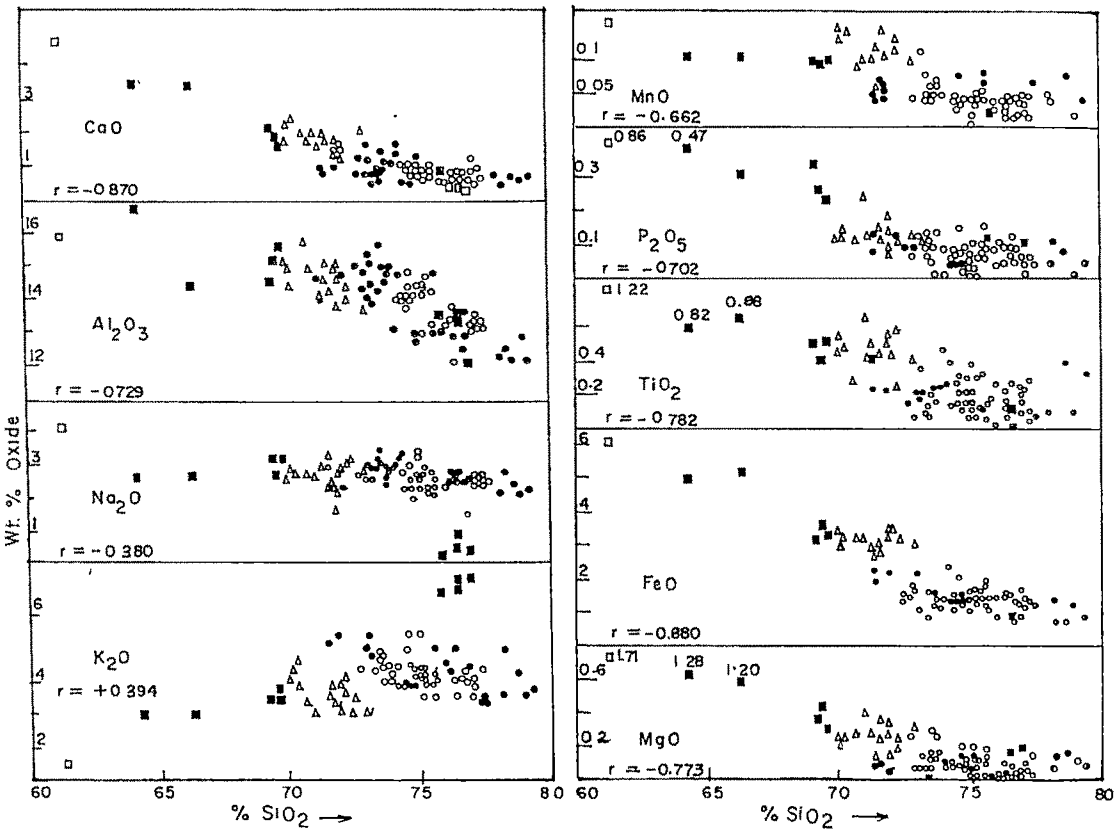

Fig. 2.2. Harker Diagrams of Gurapratap Singh and Diri Volcanics (After Srivastava et al., 1989a). Symbols : Open Square-Andesite; Solid Square-Dacite; Triangle-Rhyodacite, Solid Circle-Rhyolite; Open Circle-High Silica Rhyolite, Diagonally Filled Square-Ultrapotassic Rhyolite and Half Filled Circle-Rhyolite Porphyry.

progress of differentiation suggesting that the entire sequence except the ultrapotassic rhyolites is cogenetic and that the changes have been controlled by some sort of fractional crystallization mechanism. Srivastava et al. (1989a), further, carried out Principal Components Analysis (PCA) (Le Maitre, 1968, 1982; Till and Colley, 1973) of the data which revealed that in the early stages the fractionating phase was soda-lime plagioclase, amphibole and/or iron oxide but in the later stages, K-feldspar became a dominant phase. Very high inter-chemical correlations have been observed by these authors which is also indicative of the cogenetic nature of these rocks and a single process evolution.

When the compositions of these rocks are projected in the system Ab-Or-Q-H_2O (Fig. 2.3) (Tuttle and Bowen, 1958), majority of the rocks plot in the quartz field away from the cotectic minima at $pH_2O = 500$ kg/cm^2 and outside the low temperature **'valley'** of magmatic crystallization. Only a small number of samples plot close to the minima within the low temperature valley. Further, ultrapotassic rhyolites plot in a field of their own, quite away from the main field framed by majority of data points, and the andesite plots in the field of sodic feldspar close to the 3000 kg/cm^2 cotectic line.

Carmichael (1963) and Barth (1966) have pointed out that while the plots in the region of primary plagioclase represent the product of magmatic crystallization, plots in the primary field of quartz and K-feldspar do not appear to represent a residual liquid formed under conditions of equilibrium crystallization. These could either be a product of fractional crystallization of magma or the product of partial melting of crustal material. The role of fractional crystallization in developing the cogenetic sequence of andesite-dacite-rhyodacite-high silica rhyolite has also been supported by Harker diagrams and Principal components analysis of major elements.

Further, the behaviour of trace elements e.g. Rb, Sr and Ba (Fig. 2.4) and Zn, Cr Li, Ni and Co (Fig. 2.5) as well as that of elemental ratios e.g. Ni/Co, Fe/Zn and Mg/Li (Fig. 2.6) is also in keeping with a model of fractional crystallization (Srivastava et al., 1989b). The K/Rb relationship is most important in elucidating the evolutionary model of a cogenetic sequence. Gast (1968) and Schimizu (1964) have pointed out the usefulness of K/Rb ratio to distinguish the fractional crystallization from a batch of partial melting. According to Gast (1968), during fractional crystallization the K/Rb ratio

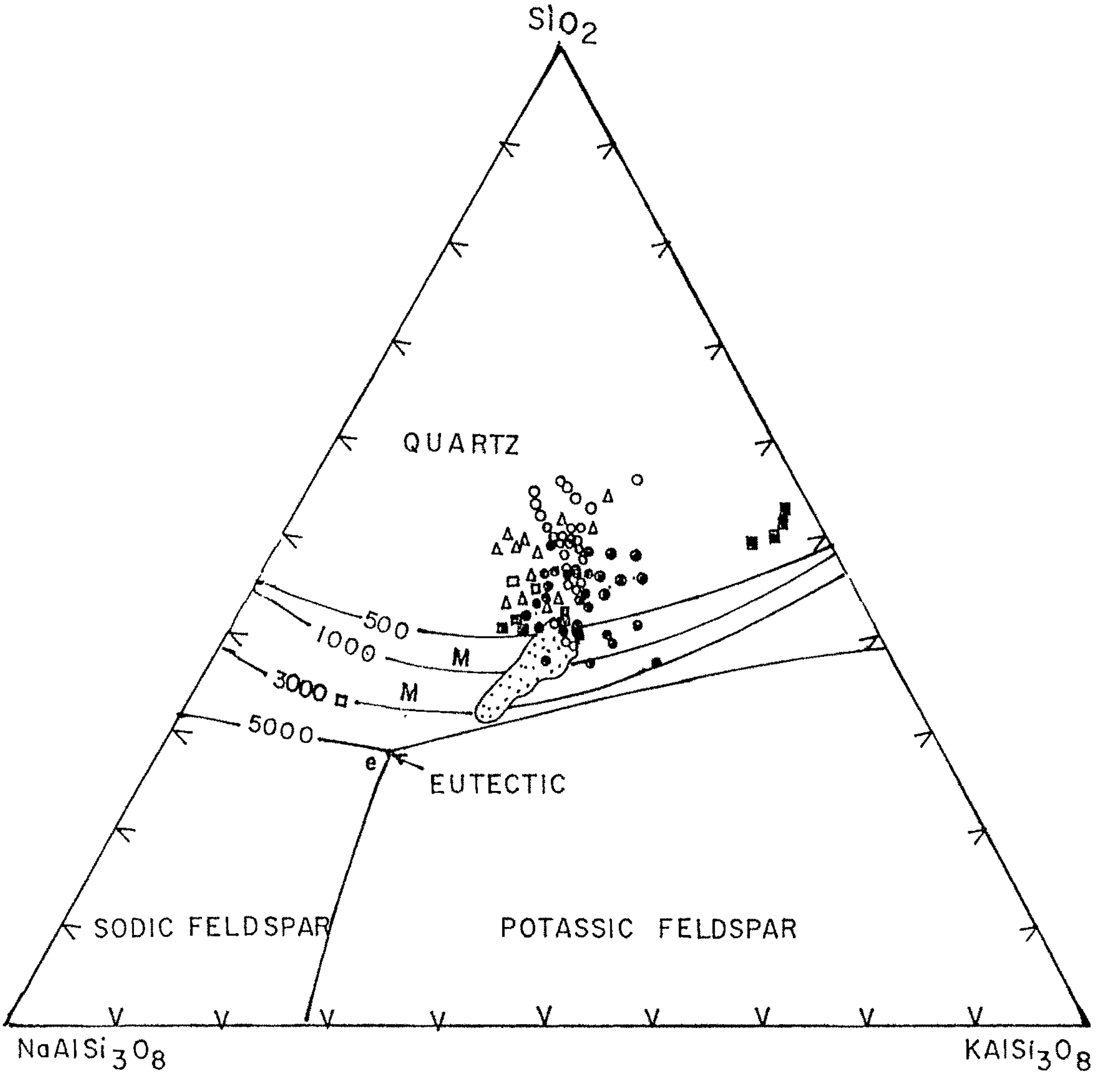

Fig. 2.3. Plot of Normative Q-Or-Ab-H_2O of Gurapratap Singh and Diri Volcanics (After Srivastava et al., 1989a) Symbols as in Fig. 2.2.

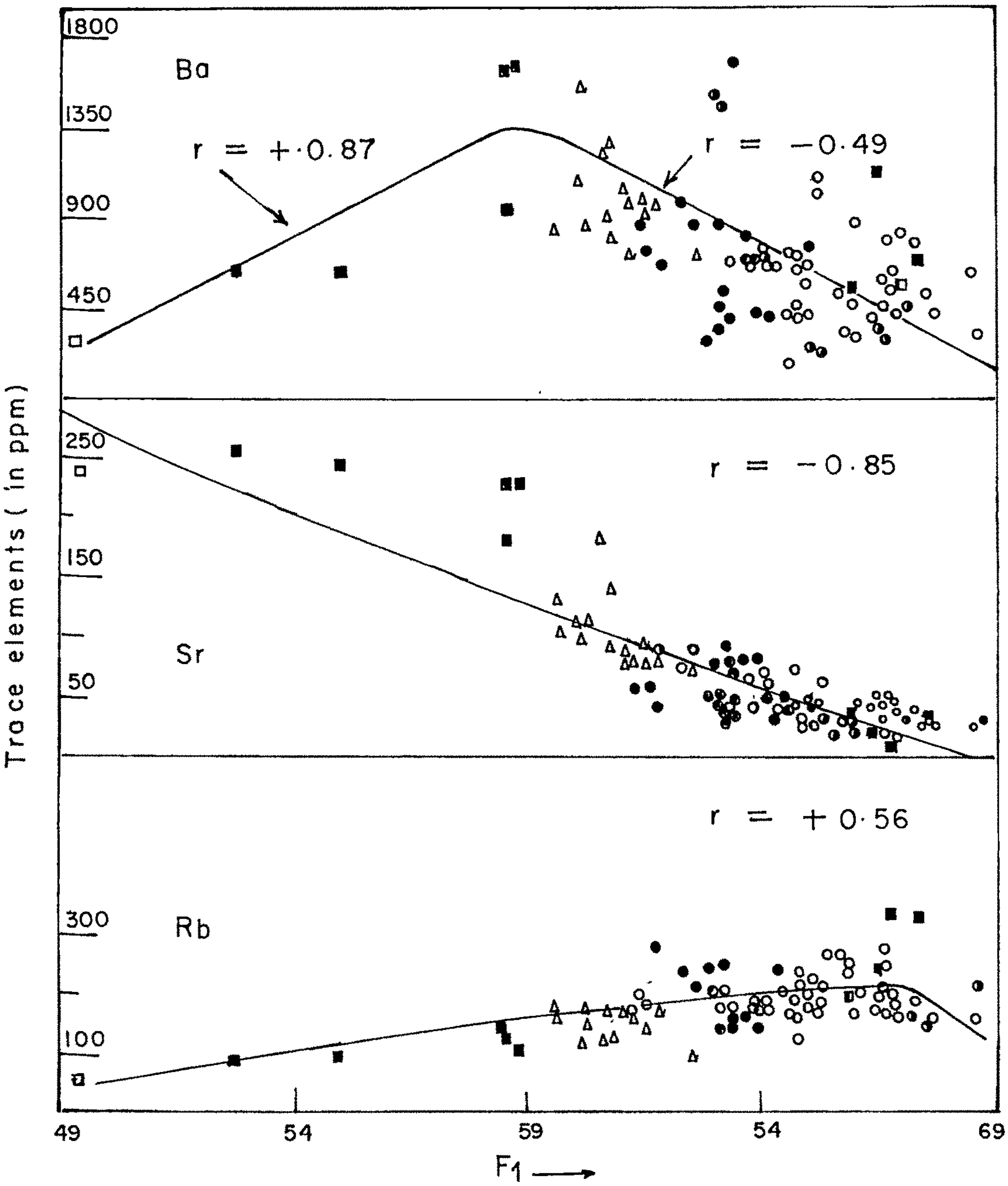

Fig. 2.4. **Variation of Rb, Sr and Ba with Progressive Differentiation in the Felsic Volcanics of Gurapratap Singh and Diri (After Srivastava et al., 1989b). Symbols: Open Square-Andesite; Solid Square-Dacite; Triangle-Rhyodacite, Solid Circle-Rhyolite; Open Circle-High Silica Rhyolite, Diagonally Filled Square-Ultrapotassic Rhyolite and Half Filled Circle-Rhyolite Porphyry.**

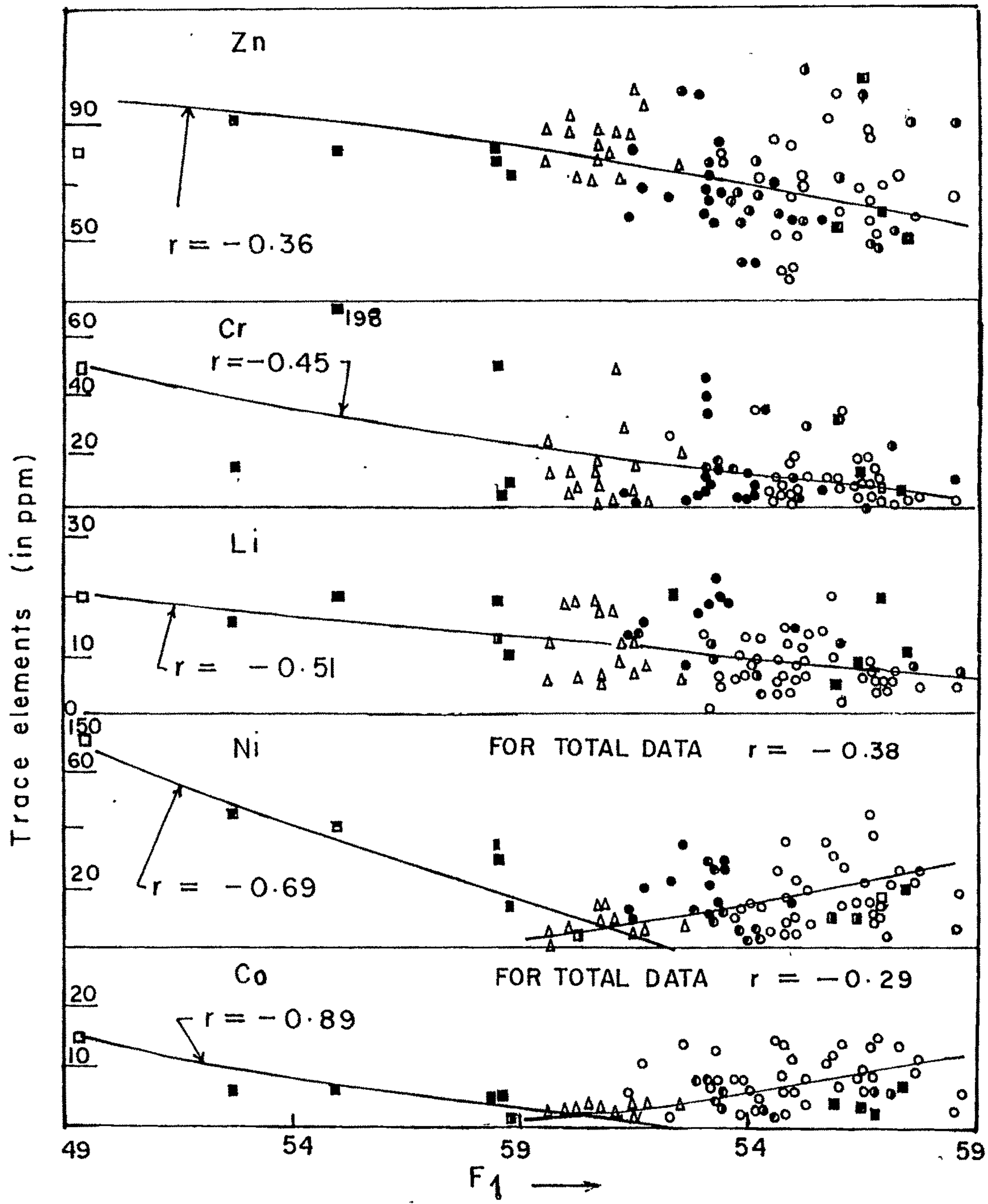

Fig. 2.5. **Variation of Zn, Cr, Li, Ni and Co with Progressive Differentiation in the Felsic Volcanics of Gurapratap Singh and Diri (After Srivastava et al., 1989b). Symbols: Open Square-Andesite; Solid Square-Dacite; Triangle-Rhyodacite, Solid Circle-Rhyolite; Open Circle-High Silica Rhyolite, Diagonally Filled Square-Ultrapotassic Rhyolite and Half Filled Circle-Rhyolite Porphyry.**

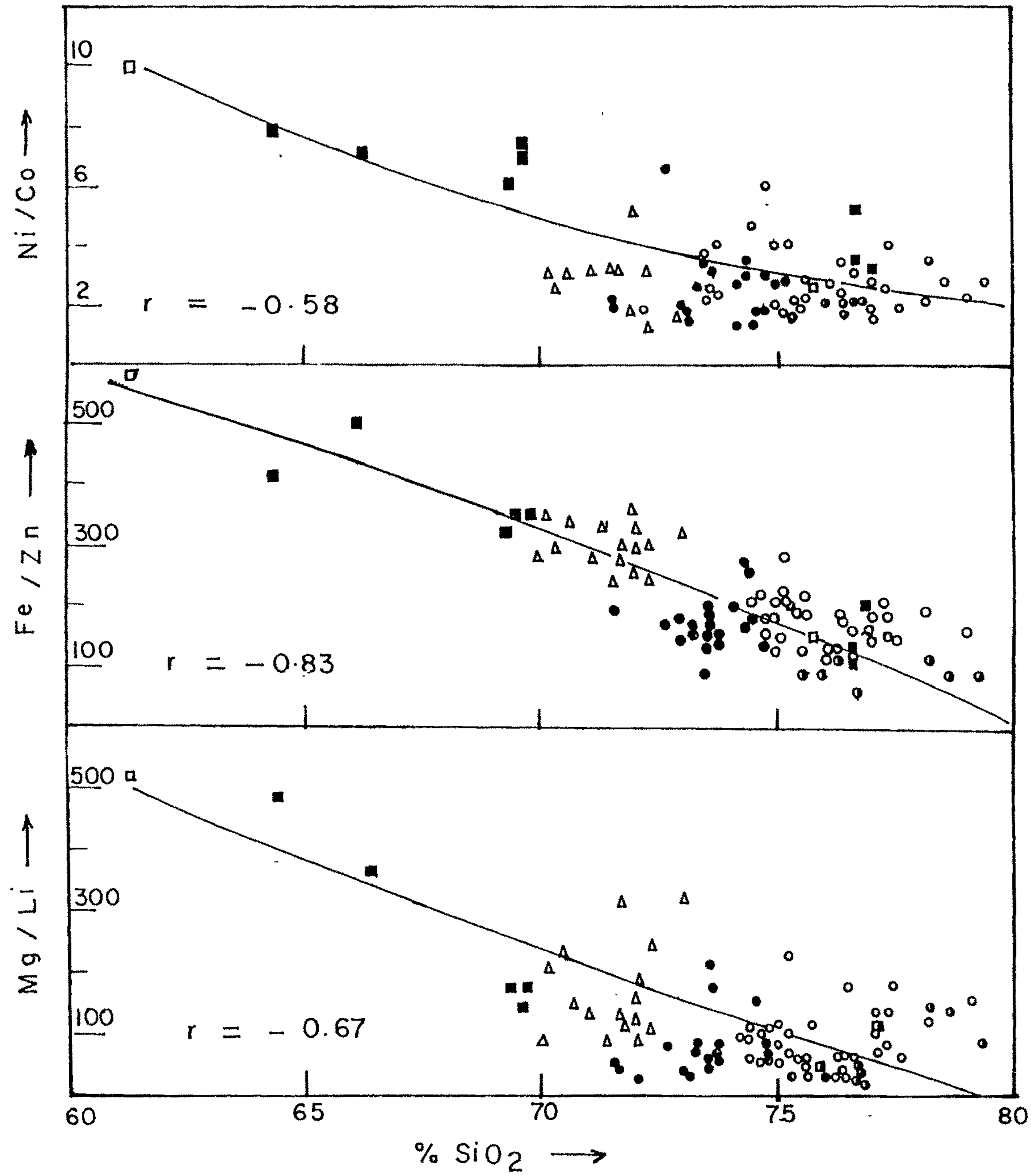

Fig. 2.6. Variation in Ni/Co, Fe/Zn and Mg/Li with Progressive Differentiation in the Felsic Volcanics of Gurapratap Singh and Diri (After Srivastava et al., 1989b). Symbols: Open Square-Andesite; Solid Square-Dacite; Triangle-Rhyodacite, Solid Circle-Rhyolite; Open Circle-High Silica Rhyolite, Diagonally Filled Square-Ultrapotassic Rhyolite and Half Filled Circle-Rhyolite Porphyry.

does not change. The K/Rb ratio of all the rocks of the present area is 202 ± 40 (Srivastava et al., 1989b) which is similar to median value of crustal rocks (Heier and Adams 1964), pointing to the crustal nature of the source for these rocks.

2.2. ASSOCIATION II (*GRANITES AND ASSOCIATED VOLCANICS*)

The most important rock types of ***MIP*** are the granites. These granites are mainly exposed around Jalore and Siwana area of the province. The Jalore Granite is peraluminous, while the Siwana Granite is peralkaline in nature. Kochhar (1984) and Srivastava et al. (1988) have considered these granites as anorogenic or A-type granites. After detailed field work in the area, Bhusan (1991) identified fifteen plutons of granites/granitoids in the *MIP* covering cumulatively an area of about 8800 sq. km. Out of these, six ring dykes and a pluton, covering an area of about 1100 sq. km, are composed of riebeckite/aegirine granite (Siwana Granite) and seven plutons, covering a total area of about 7600 sq. km, are of biotite granite (Jalore Granite). Bhusan (1991), further, identified two small plutons of hornblende granite, covering an area of about 70 sq. km, which he called as Malani Granite.

The Jalore Granite is conspicuous by its pink colour and range in composition from pegmatite granite to granodiorite. The Sankara pluton is the largest with an area of about 3700 sq. km (Fig. 1.2) followed by Jalore pluton covering 3300 sq. km. The other plutons range between 50 to 250 sq. km.

Discontinuous outcrops of the Siwana Granite occur as an elliptical pattern (ring shaped) around Siwana, covering an area of about 290 sq. km (Fig. 2.7). The continuous exposures on the southern periphery provide a thickness of about 8 km from outer to inner contact with the rhyolites.

The peralkaline magmatism has attracted attention of the earth scientists world over for a variety of reasons. The most important amongst them are their tectonic significance and mode of occurrence. Normally, peralkaline volcanics have been associated with the peralkaline granites. The peralkaline silicic rocks are commonly found in non-orogenic continental regions which have been subjected to crustal swelling

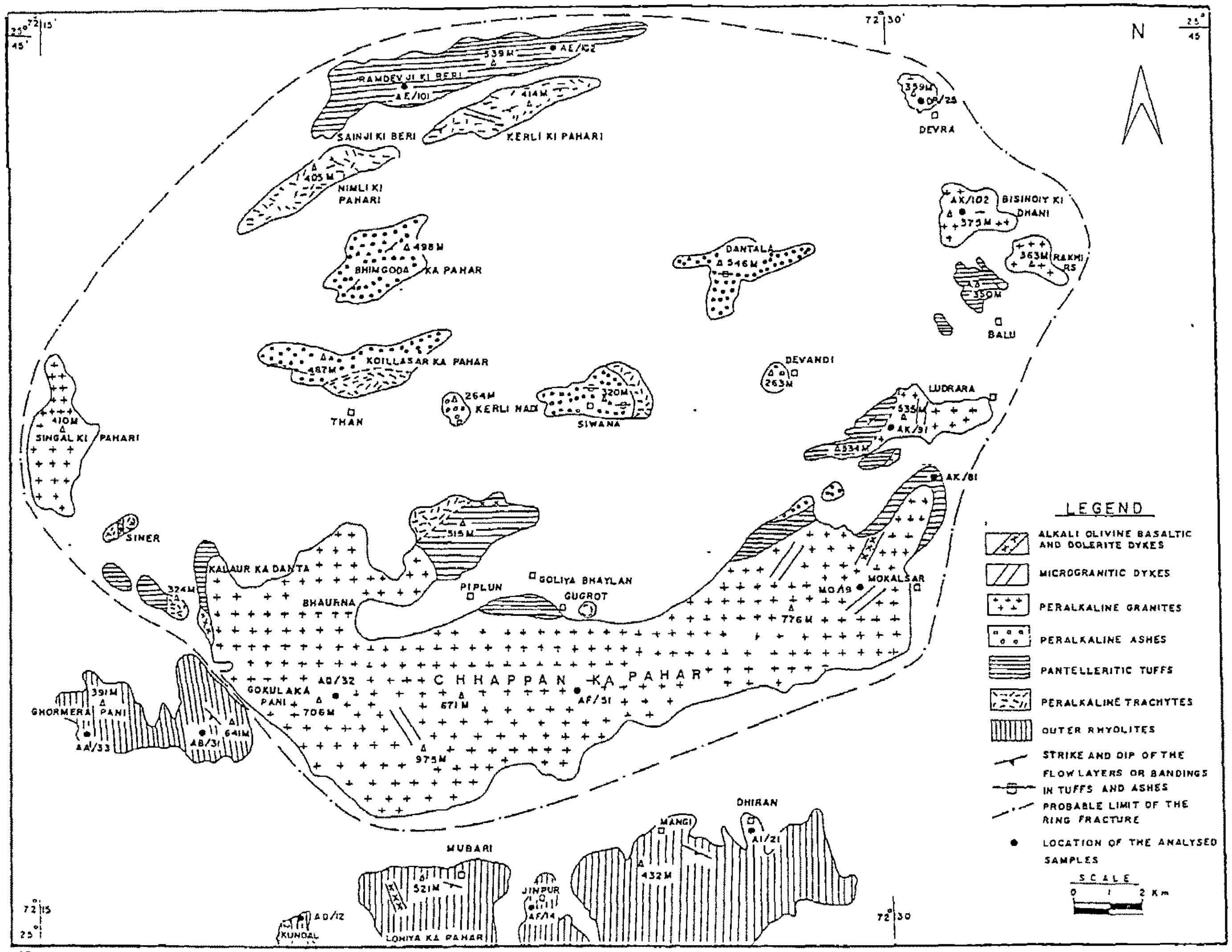

Fig. 2.7. GEOLOGICAL MAP OF SIWANA GRANITES AND ASSOCIATED VOLCANICS (AFTER YADAV, 1988)

and rifting (Le Bas, 1971). Peralkaline magmatism can occur during pre-rifting (e.g. epeirogenic doming), initial rifting (development of linear fractures and beginning of crustal attenuation) and continued rifting (extensive crustal attenuation leaving little or no sialic crust on the rift floor) (Bowden, 1974). Each event appears to be characterized by particular suites and varying proportions of peralkaline siliceous and associated rocks.

Comendites frequently occur in sub-volcanic ring complexes associated with non-peralkaline volcanics. Comenditic associations are typical products of epeirogenic doming exemplified by the elevated domes of vitreous to granophyric peralkaline and alkaline lavas in Tibesti (Vincent, 1970). In rift valleys, comendites are more closely linked with peralkaline trachytes and pantellerites. Examples of these associations are found in Kenya. However, the proportion of comendite becomes diminished as the rift evolves and in well developed rift systems (e.g. Ethiopia), where crustal attenuation is more extensive, comendites are virtually absent (Mohr, 1970).

Pantellerites are related to the development of rifting. The Ethiopian rift system consisting of the main Ethiopian rift and the Danakil depression provides good example of pantelleritic volcanism and its relationship with the extent of rifting (Tazieff et al., 1969; Barberi et al., 1970).

Further, Bowden (1974) suggested that the Peralkaline granites are common on continental regions of epeirogenic doming (Pre-rift tectonic environment) and are frequently displayed as sub-volcanic ring structures. Bailey (1974) considered regional uplift and alkaline magmatism as characteristic feature of continental rifts. Greenburg (1981) concluded that the younger granites of Egypt represent magmatism associated with the rift mechanism.

The intrusive nature of Siwana granite was first indicated by La Touche (1902) and Coulson (1933). Subsequently, various theories have been put forward for the ring structure and emplacement of the peralkaline granites. Mukherjee (1958) suggested a doubly plunging syncline for a subsidence structure. Pascoe (1960) speculated that the circular plan at Siwana has a connection with the roots of a volcano. Murthy (1962) for the first time interpreted this as a feature of cauldron subsidence, having a similarity to the Nigerian ring complex. Narayan Das et al. (1978) related the alkali magmatism of trans-Aravalli region to crustal dislocations. Bhusan (1984) also suggested that the alkaline granites of Siwana and Barmer have been emplaced as ring dykes due to cauldron subsidence. Kochhar (1984) attributed this structure to an intra-cratonic hot spot activity. Sinha Roy (1984) suggested that the Malani acid and calc-alkaline volcanics and associated plutonic episodes are possibly the result of low angle subtraction of the south Delhi oceanic crust beneath the ancient crustal block. Bhusan and Mohanty (1988) suggested that the Siwana granite has intruded along a collapse structure as a low-angle cone intrusion. Further, they envisaged that the peralkaline granites and associated trachytes and rhyolites at Siwana indicate the zone of active rifting in a distinct late Proterozoic crustal regime. Srivastava (1988) correlated sub-volcanic ring complexes to a period of crustal upwarping before the commencement of Gondwana rifting.

2.3. ASSOCIATION III (*TAVIDAR VOLCANICS*)

The mildly alkaline rocks from Tavidar and Karara (Jalore district) and Sarnu-Dandali (Barmer district) have been grouped together in association 3 (Fig. 1.3). These volcanic rocks have been considered to belong to Malani igneous province (Coulson, 1933). In the present study, only the rocks from Tavidar have been selected for geochronological and Sr isotopic studies. The area lies 35 km SW of the Bhinmal town of Jalore district between North latitudes 24°46'10"-24°54'10" and East longitudes 72°05'40"-72°10'29" and cover an area of approximately 70 sq. km. The volcanics have their northern limit near the village Chatwara and extend 15 km to the south upto the villages Pal and Jalerakurd (Fig. 2.8). The region consists of a number of hills trending NE-SW and are surrounded by vast arid desertic plains. Most of the hills have heights between 300 to 330 m. The chain of hills appear in two rings, one to the north of the village Tavidar and the other to its south. The northern ring is breached in the east but the southern ring is more or less complete. The central part of the southern ring is filled with sand and alluvium. The distribution of various rock types occurring in the area is given in Fig. (2.8). Dashora (1981) and Ranawat and Dashora (1984) have given preliminary account of the rocks occurring in the north of the village Tavidar and have

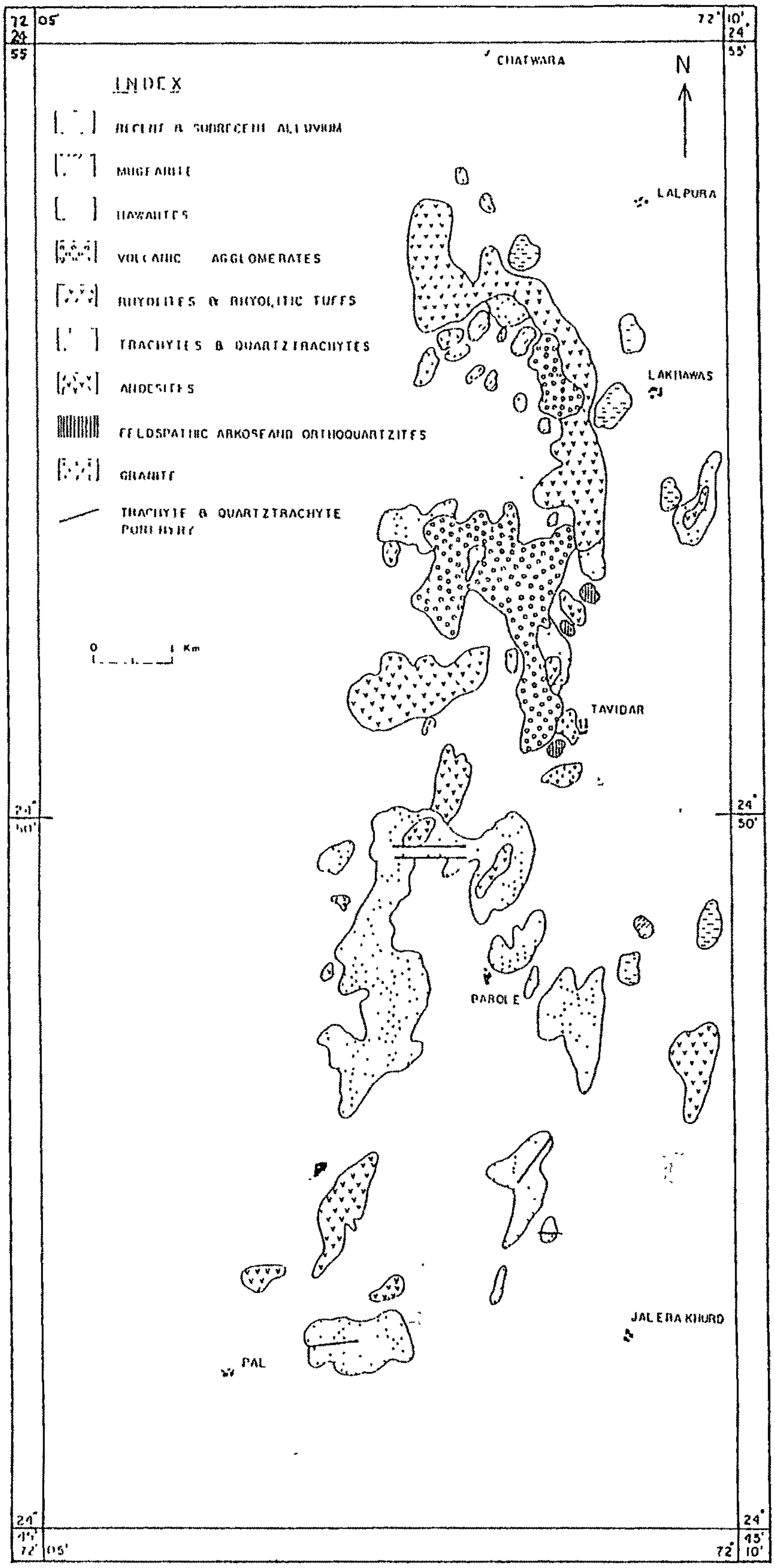

Fig. 2.8. Geological Map of Tavidar Volcanics, Jalore District, Rajasthan (After Agrawal, 1984).

reported presence of basalts, andesites, trachytes and rhyolites besides pyroclastic rocks. The work of these authors was mainly on the fluorite mineralization found in these rocks. Agrawal (1984) has carried out extensive field mapping, petrographic and geochemical studies of these rocks with a view to understand the genetic process or processes responsible for the development of different rock types in this area. He observed that the basic rocks (hawaiites and mugearites) occur in very small proportion and also their field relationship with other rocks of the area is not clear, as they occur in isolated patches.

With the introduction of modern methods of chemical data analysis like multivariate statistical analysis (Davis, 1973; Le Maitre 1968, 1982; Till and Colley, 1973), it has become possible to evaluate very efficiently the available chemical data for classifying and understanding the genesis of the rocks. In the conventional methods of classification it is difficult to deal with vast quantity of data e.g. the variation diagrams, which utilize a few oxides at a time, in effect, ignore the correlation of these oxides with other oxides, leading to under utilization of the informations contained in the data. Further, petrologists normally apply variation diagrams using two or more variables at a time to study qualitatively the inter-relationship between various components. The relationship between various oxides can also be studied by using the linear correlation coefficient (r) which is a quantitative measure of the same (Chayes, 1960; Le Maitre, 1982). Upadhyaya et al. (1988) have determined correlation coefficients between all possible pairs of elements for the data with and without basalts. They found that SiO_2 correlates negatively with all the elements except K. High correlation found in the Tavidar rocks are indicative of their cogenetic nature and of the operativeness of a single stage process during the evolution of these rocks. These authors have also presented the application of various statistical methods to Tavidar volcanics for better understanding of the classification and genesis of these rocks from chemical analysis alone. By applying the clustering method based on distance coefficient (Davis, 1973; Le Maitre, 1982), the rocks have been classified as belonging to basalts, andesites, trachytes and rhyolites. The splitting of trachytic rocks into three sub-clusters, indicate considerable variation in the trachytic rocks of the area.

The host rock of these volcanics is generally not seen, but in the village Tavidar and in a nala immediately to its south, exposures of granites are seen (Fig. 2.8). Similar granitic rocks are also found in the north of Raniwara town which is about 15 km SE of Tavidar. The Raniwara granite is supposed to be a part of Jalore granite (Agrawal, 1984).

Besides the granite, in the Tavidar village and in the nala to its south, there are three small occurrences of sedimentaries also, comprising feldspathic arkose and ortho quartzites. One outcrop of feldspathic arkose is found almost above the granite near Tavidar and other outcrop is in the plains to the north of the village. The orthoquartzite is confined to low ground and is visible even from distance as a shining white rounded patch. The field relationship as it appears is that the granites are overlain by the feldspathic arkose and orthoquartzits, which in turn have been intruded by the volcanics. The succession, as it appears in the area, is as follows (after Agrawal, 1984).

Volcanic agglomerates

Rhyolites and rhyolitic tuffs

Trachytes, quartz-trachytes and their porphyries

Andesites

Orthoquartzites and feldspathic arkose (probably of Cretaceous age)

Granites (probably equivalent to Jalore Granites)

The feldspathic arkose and orthoquartzite are lithologically very similar to Barmer sandstone and orthoquartzite of the lower Cretaceous age (Agrawal, 1984). If the present orthoquartzites and arkose are of the same age, then the volcanics cannot belong to the Malani volcanic activity as has been hitherto believed and instead, they may have an age similar to Mundwara alkaline complex (Srivastava, 1983). However, in the absence of any radiometric date, or definite correlation between the Barmer sandstone and the othoquartzites and the present occurrences, the question of the age of the Tavidar volcanics remains uncertain.

2.4. ASSOCIATION IV (*MUNDWARA ALKALI IGNEOUS COMPLEX*)

The Mundwara alkali igneous complex constitute the association 4. The complex first reported by Coulson (1933), occupying an area of 12 sq. km, is one of the plug like bodies occurring in the western and north western part of the Indian shield in the Deccan volcanic province. In conformity to the other alkaline occurrences, this complex also occurs as ring shaped and plug like intrusion within the Erinpura granite terrain and is situated about 35 km NW of Mount Abu in the neighborhood of Mer-Mundwara village (24°50':72°33') in the Sirohi district of Rajasthan.

The Mundwara complex along with a few other alkaline occurrences e.g. Kadi, Panwad, Netrang and Jawahar etc. (Fig. 2.9) fall along the N-S trending Rajasthan-Gujarat rift and west coast rift in contrast to the majority of the other similar occurrences which fall along the E-W trending Narmada lineament and its easterly extension (Bose, 1980). The distribution of the plugs define belts of alkaline magmatism which are intersecting near the gulf of Cambay (Khambat). Bose (1980) attributed plume generated fracture zones responsible for the alkaline magmatism.

The various rock types of the complex are distributed in three distinct physiographic units viz. Toa (max. height 436 m), Mer (max. height 584 m) and Musala (max. height 509 m) hills (Fig. 2.10) and each of them contain undisturbed and complete suite of mafic to felsic derivatives. While, Toa and Mer are circular chains of hills, Musala is an isolated hill of conical shape rising precipitously from the plains. These hillocks are denuded relics of laccolith like bodies and are riddled profusely by radial and concentric dikes (Sharma, 1967) ranging in composition from hawaiites, through mugearites to phonolites. In fact, this suite of rocks is a field museum of igneous petrology and contains an abundant variety of rocks ranging from ultrabasic to alkalic and acidic (Subrahmanyam and Rao, 1972).

Studies on petrology and geochemistry of the complex have earlier been carried out by various workers viz. Bose and Das Gupta (1973), Chakraborty and Bose (1978), Chakraborty (1979, 1984), Das Gupta (1974, 1975), Lebas and Srivastava (1989), Sharma (1967), Srivastava (1989), Subrahmanyam (1986), Subrahmanyam and

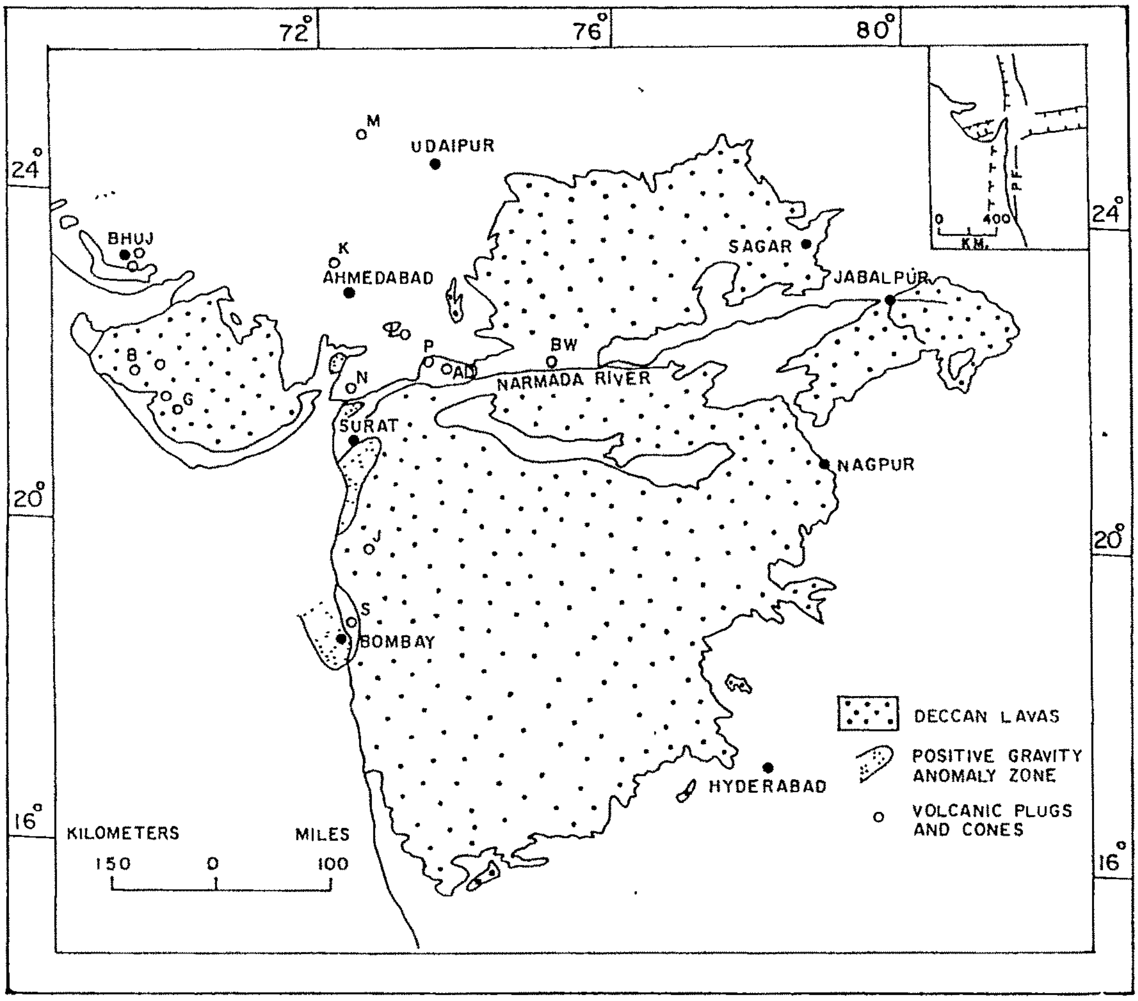

Fig. 2.9. The Deccan Volcanic Province Showing the Distribution of Plugs and Alkaline Intrusions (open circles). AD = Amba Dongar, B = Barda, BW = Barwaha, G = Girnar, J = Jawahar, K = Kadi, M = Mundwara, N = Netrang, P = Panwad, PV = Pavagad, S = Salsette. Inset shows the alignment of Plume generated rift zones controlling the tectonic setting for alkaline magmatism. PF = Panvel Flexure (After Bose, 1980).

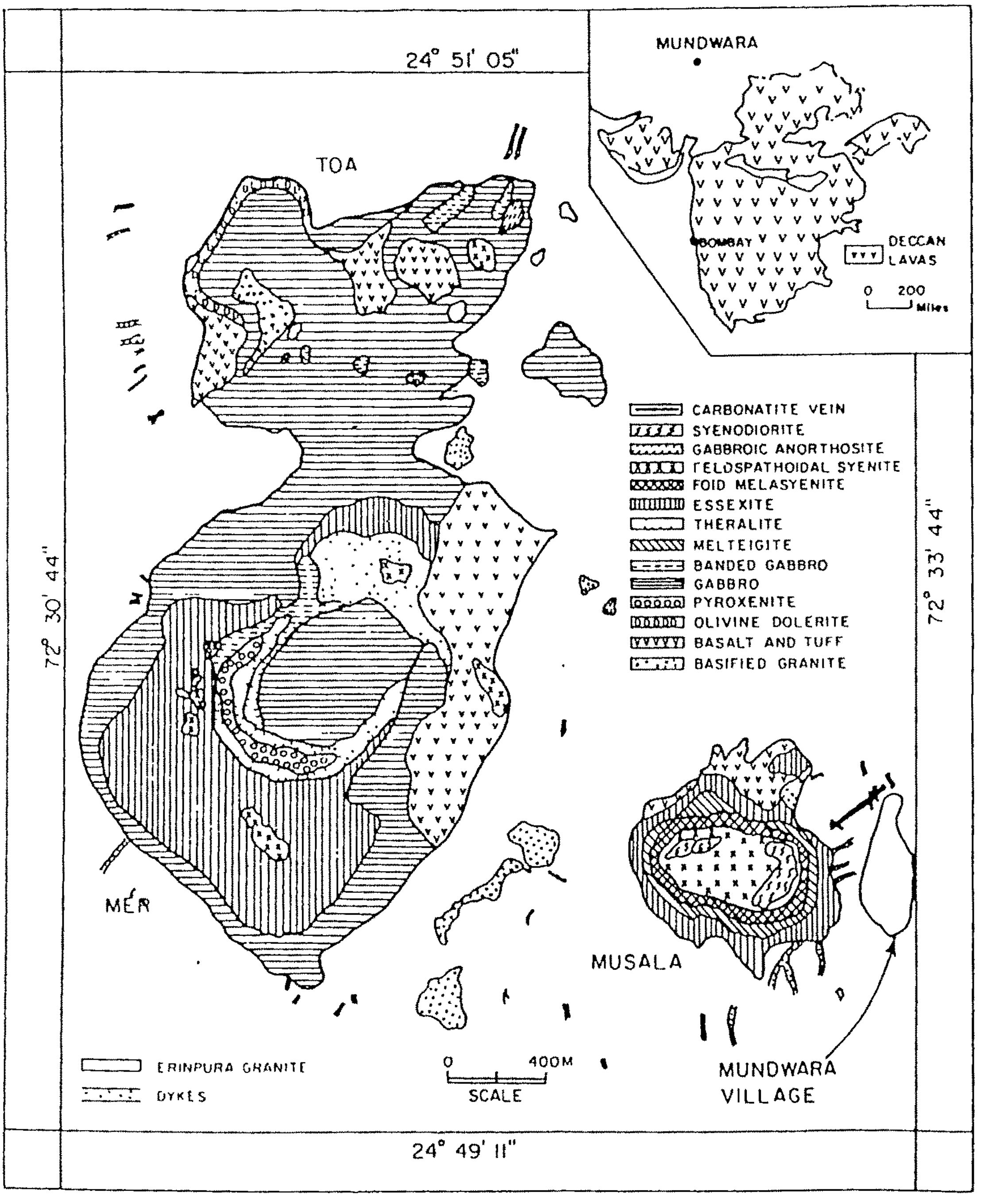

Fig. 2.10. Geological Map of Mundwara Alkali Igneous Complex, Rajasthan (After Subrahmanyam and Leelanandan, 1989).

Leelanandam (1989, 1991) and Upadhyaya and Srivastava (1987). These authors, though have presented different models to explain the genesis of the diverse rock types, are unanimous in their view about alkali basalt being the parental source for these rocks. Based on petrochemical studies of the complex, Sharma (1969) has discerned two trends (alkaline and calc-alkaline) of differentiation. Yadava and Karkare (1976) have envisaged a variety of processes such as differentiation, assimilation and mixing of magma to explain the diversity of rock types in this complex. Chakraborty and Bose (1978) tried to explain the origin of different rock types by subsidiary trends of differentiation. Chakraborty (1984) considered that the plugs may represent successive channels of a fractionating magma at depth or they may manifest different levels of differentiating columns of the magma in synchronous plugs with different degree of subsidence. Chakraborty (1984), however, also concedes that the three plutons may represent separate crystallization columns with normal fractionation processes operative in the individual plugs.

Petrological studies by Subrahmanyam (1986) indicate that the emplacement of the magma took place in three pulses and was spurred by volatiles released during the ascent of the magma. Subrahmanyam and Leelanandam (1989), further, suggest that differences in the volatile contents of the magma in the three plutons are responsible for different trends of differentiation. Due to differential solubility of CO_2 and H_2O in the magma, the earliest pulse, emplaced at Musala, predominantly contained the less soluble CO_2. The last pulse of magma containing more soluble water was emplaced at Toa with the Mer pluton being formed from the intermediate pulse of the magma containing moderate amounts of both CO_2 and H_2O. Variable volatile contents of the magma in the three plutons have brought about three different trends of differentiation and, hence three distinct suites of rocks.

High water content in the magma of the Toa pluton has resulted in a cumuloporphyric suite of rocks. High CO_2 content in the magma of the Musala pluton has induced immiscibility in the parental magma and the two immiscible liquids, one hawaiitic liquid and the other phonolitic, subsequently followed independent courses of fractional crystallization resulting in the formation of essexites, hawaiites, mugearites, melteigites and phonolites, feldspathoidal syenites, respectively. Moderate and approximately equal amount of water and CO_2 in the magma of the Mer pluton have brought out a calc-alkaline trend of differentiation under high oxygen fugacity conditions and the residual carbo thermal solutions have given rise to carbonatite veins. Srivastava (1989) attribute fractional crystallization of primary hydrous basanitic liquid responsible for different rock types.