CHAPTER V

SUMMARY AND CONCLUSIONS

The data presented and discussed in this thesis represent the **first systematic geochronological effort**, using K-Ar, ^{40}Ar- ^{39}Ar and Rb-Sr systematics, on Malani volcanics and associated igneous rocks from southwest Rajasthan, India. The study was undertaken with a view to understand the evolution of Malani igneous province (***MIP***). Also we report for the first time reliable ^{40}Ar-^{39}Ar age data for the events related to the Deccan volcanism in Rajasthan. This chapter brings out the main findings and discusses the aspects which need further probe.

The present study indicates that the continental crust of this part of Indian sub-continent incorporates a number of volcanic and plutonic associations whose emplacement time spanned from about 780 to 670 Ma. Besides, the region has received wide spread thermal imprint between 500-550 Ma ago. Since then tectonically the region remained undisturbed until the youngest plutonic/volcanic events between 70 to 64 Ma, which emplaced differentiated igneous rocks at Mundwara and Tavidar of Sirohi and Jalore district, respectively.

The initial idea of La Touche (1902), Coulson (1933) and Heron (1953) that the Jalore and Siwana type granites represent the parent stock of the Malani rhyolites and all the different igneous rocks of the province including the basic rocks belong to a single Proterozoic magmatic event at 745 ± 10 Ma, supported in recent years by Pareek (1981), Kochhar (1984) and Bhusan (1984, 1985 and 1989), is belied by the present geochronological studies. This study gives new age determinations to felsic volcanics (Malani volcanics), peraluminous (Jalore) granites, peralkaline (Siwana) granites and rhyolites, mildly alkaline and alkaline rocks from different parts of the volcanic province.

The study clearly proves that the so called Malani igneous suite (i.e. ***MIP***) does not represent a single magmatic event and instead represent a polyphase igneous activity.

The felsic volcanics of Gurapratap Singh, Diri and Manihari belonging to basalt-andesite-dacite-rhyolite association constitute the oldest rock group in the province. These rocks were formed about 779 ± 10 Ma ago with initial $^{87}Sr/^{86}Sr$ ratio of 0.70612 ± 0.00046 indicating their crustal origin. The basalts, whose occurrences are confined to a small isolated outcrop, are contemporary to the other associated felsic volcanics but have different source (initial Sr ratio = 0.70385 ± 0.00062) and presumably have come from much deeper level in the mantle.

A few flows of ultrapotassic rhyolites are also found at Diri, Gurapratap Singh and Manihari alongwith other felsic volcanics. These ultrapotassic rhyolites do not conform to the main trend and presumably mark a different phase of magmatic activity (Srivastava et al., 1989a). The present study shows that these rocks were formed about 681 ± 15 Ma ago with an initial Sr ratio of 0.7135 ± 0.0025 and are, thus, nearly 100 Ma (at least 73 Ma) younger than the associated felsic volcanics, indicating a different magmatic episode. The high initial Sr ratio of these rocks indicates incorporation of radiogenic ^{87}Sr from the country rock into the residual fraction of the magma.

The granites and associated rhyolites (normal as well as peralkaline) constitute most important rock types of the complex. These rocks are mainly exposed around Jalore and Siwana area of the province. The Jalore granite is peraluminous, while the Siwana granite is peralkaline in nature. The peralkaline granites and rhyolites which occur as sub-volcanic ring complex within the ***MIP*** are very important because of their tectonic significance and mode of occurrence. The ring structure of these rocks has been attributed to cauldron subsidence and vertical intrusion of granites along the periphery of collapse structure (Murthy, 1962). These granites have been considered cogenetic and coeval (ca. 745 ± 10 Ma) to the Malani rhyolites (La Touche, 1902; Coulson, 1933; Heron, 1953, Kochhar, 1984, Bhusan, 1984, 1985 and 1989). However, the present study indicate, that these granites represent two different magmatic events and were emplaced about 727 ± 8 Ma and 698 ± 10 Ma ago, respectively. The initial Sr ratios of these granites are 0.70559 ± 0.00037 and 0.7067 ± 0.0041 respectively, which though indistinguishable, suggest lower crustal derivation of the magma. Further, the Siwana granite and associated peralkaline rhyolites (pantellerites) are coeval and cogenetic.

At the southern extremity of the ring structure around villages Kundal, Mubari, Jimpur, Mangi and Dhiran southwesterly dipping normal rhyolites are exposed which are generally referred to as the outer rhyolites of Siwana (Srivastava et al. 1988 and Yadav, 1988). These rhyolites represent the youngest activity at Siwana at 674 ± 25 Ma with a high initial $^{87}Sr/^{86}Sr$ ratio of 0.7110 ± 0.0066.

However, the age as well as initial Sr ratio of outer rhyolites are remarkably similar to that of the ultrapotassic rhyolites of Manihari, Pali district. The pooled isochron of these rocks give an age of 670 ± 11 Ma with an initial Sr isotopic ratio of 0.7145 ± 0.0021. This age and initial Sr isotopic ratio are similar to the age and initial ratio obtained for ultrapotassic and outer rhyolites separately.

This exercise indicates that the outer rhyolites and ultrapotassic rhyolites were probably, derived from the same magma and crystallized at about 670 Ma ago. It may, also, be possible that the outer rhyolites are cogenetic with the peralkaline rocks and probably represent the end phase of the peralkaline activity, as suggested by Jacobson et al. (1958) and Bowden and Kinnaird (1978) for the Nigerian younger granitic province. According to these authors the peralkaline magma at the start of the magmatic cycle may turn to metaluminous to peraluminous at the end, giving rise to close association of both the peraluminous and peralkaline rocks within a single ring complex, as observed at Siwana. However, in either of the cases, the high initial Sr ratios of outer as well as ultrapotassic rhyolites are attributed to crustal contamination of the residual magma.

The ^{40}Ar-^{39}Ar studies of basalt, dacite and rhyolite of Diri and Gurapratap Singh did not yield plateau ages but showed the spectra typical of rocks which have been reheated at about 500- 550 Ma ago subsequent to their formation about 780 Ma ago (Rb-Sr studies). Earlier Rb-Sr mineral ages determined on different granite bodies from Sendra, Sadri, Ranakpur and Sai have, also, indicated thermal event to reset the mineral ages around 500-550 Ma ago, which otherwise have the whole rock pooled Rb-Sr age of 800 ± 50 Ma (Choudhary, 1984). The effect of this thermal event in the rocks exposed further west and southwest of Aravalli range in Rajasthan is clearly brought out by the ^{40}Ar-^{39}Ar studies of these volcanics.

The thermal event between 500-550 Ma has also been elucidated by the ^{40}Ar-^{39}Ar studies of Jalore granites which otherwise have the formation age of about 730 Ma.

After the thermal event, about 500-550 Ma ago, this part of Indian sub-continent seems to have remained dormant until about 70 Ma ago when the different plutonic/volcanic events, possibly related to Deccan volcanism, took place in this region. We report for the first time ^{40}Ar-^{39}Ar age data for the events from Rajasthan which are coeval with the Deccan volcanism (Rathore and Venkatesan, 1991, 1993 and Venkatesan et al., 1990).

Mildly alkaline rocks of Tavidar, Jalore district constitute the younger association of trachy basalt-trachy andesite-trachyte and rhyolite. The K-Ar studies of these rocks gave an indication of younger magmatic event. The detailed ^{40}Ar-^{39}Ar studies have however helped to construct high resolution chronology of these differentiated rocks. Eight samples were analyzed for ^{40}Ar-^{39}Ar studies which included two potassic andesites, two trachytes, one rhyolite, one potassic rhyolite and two hawaiites.

All the analyzed samples yielded good plateaus consistent with the fractional crystallization model resulting in the formation of different rock types from the same magma. The earliest differentiated rocks i.e. andesites were formed about 65.9 ± 0.4 Ma ago while the end member of the differentiated sequence i.e. potassic rhyolites were formed about 63.8 ± 0.8 Ma ago, suggesting a total span of about 2 Ma (at least 1 Ma) for the igneous activity (i.e. differentiation) at Tavidar, which resulted in the formation of a cogenetic suite of mildly alkaline rocks of andesite-trachyte-rhyolite-potassic rhyolite.

In addition to the differentiated rocks, two hawaiites were also dated which gave a mean age of 64.4 ± 0.5 Ma, thus, suggesting their contemporaneity with the associated mildly alkaline rocks of Tavidar. Initial Sr ratios of these rocks, calculated assuming an average age of 65 Ma, are indistinguishable, mainly because of large errors associated with the K-rhyolites. However, the mean initial $^{87}Sr/^{86}Sr$ ratio of differentiated rocks is 0.70525 which is different from the mean of 0.70441 obtained for the hawaiites, suggests generation of magma at different levels in the upper mantle.

The Mundwara alkali igneous complex is one of the plug like bodies occurring in

the western and northwestern part of the Indian shield from the Deccan volcanic province. The complex exhibits a complete suite of differentiated rocks with the syenites representing the end member of differentiation. Six whole rock samples were analyzed by ^{40}Ar-^{39}Ar method to constrain the emplacement time of the Mundwara alkali igneous complex. The dated samples include four from Musala hill and one each from Mer and Toa hills of the complex. Out of the six samples analyzed, only two syenites one each from Musala and Mer hills yielded good plateaus which are concordant at 64 Ma. This suggests that these syenites are contemporary and were emplaced about 64 Ma ago. The remaining samples, however, have exhibited saddle shaped spectra owing to the presence of excess argon with their minima ranging from 70 to 74 Ma. These minima mark the upper limit to the time of their formation. However, least square regression analysis of all the data points of a gabbro and a basalt sample, having excess argon signatures, yielded ages of 69.8 ± 2.1 Ma and 69.7 ± 0.8 Ma, respectively, which can be considered as their formation ages.

Recently Basu et al. (1993) have reported laser heating ^{40}Ar-^{39}Ar weighted mean age of 68.53 ± 0.16 (2σ) Ma for the biotites separated from alkali olivine gabbro of Toa hill of the complex. Further, these authors have also reported saddle shaped spectra for two hornblendes separated from melagabbro of Toa hill with their minima at 71 Ma, exactly similar to the minima of 71.2 ± 2.4 Ma obtained for the gabbro from the same hill in the present study.

In view of the above observations, it is proposed that the igneous activity at Mundwara started around 70 Ma ago. The differentiation continued and the activity seems to have culminated at 64 Ma ago, as indicated by concordant plateaus of syenites from Musala and Mer hills, suggesting a total span of about 6 Ma for the igneous activity. The initial $^{87}Sr/^{86}Sr$ ratios, calculated assuming an age of 64 Ma for the syenites and 70 Ma for the other rock types, vary from 0.70384 to 0.70551. The variation in the initial ratios may probably be due to freezing of fractionated magma, with different Rb/Sr ratios, at different levels within its chamber and subsequent remelting and extrusion onto the surface without mixing.

The average initial $^{87}Sr/^{86}Sr$ ratio for the Mundwara complex is 0.70457, which lies

in the *'source region of basalt'* on the Sr evolution diagram, suggesting an upper mantle origin of the magma.

The initial Sr isotopic ratios of Tavidar volcanics as well as that of Mundwara complex are similar to those of the least contaminated Deccan tholeiitic lavas, such as those of the Ambenali, Mahabaleshwar and Panhala Formations of the upper sequence (Mahoney, 1988). The genetic relationship between Mundwara, Tavidar and Deccan volcanism cannot be ascertained from Sr isotopic studies alone. However, based on present geochronological studies it can only be construed that these are coeval events.

The main conclusions arrived at based on the present studies are as follows:

(i) *The Malani igneous province (MIP) of southwest Rajasthan does not represent a single magmatic event as hitherto believed and instead represents a polyphase igneous activity.*

(ii) *Basalt-andesite-dacite-rhyolite association of Pali district are the oldest one in the Malani province. These rocks were formed about 780 Ma ago from the magma generated in the lower crust. The basalts, though contemporary to other associated felsic volcanics, have different source and presumably have come from much deeper level in the mantle.*

(iii) *The Jalore and Siwana granites represent two different magmatic events and were emplaced about 730 and 700 Ma ago, respectively. The initial Sr ratios are indistinguishable but indicate derivation of the magma from the lower crust. Further, the Siwana granites and associated peralkaline rhyolites (pantellerites) are coeval and cogenetic.*

(iv) *The outer rhyolites exposed south of the Siwana ring structure represent the youngest activity at Siwana about 670 Ma ago. These rocks have a very high initial $^{87}Sr/^{86}Sr$ ratio of 0.7110 due to incorporation of radiogenic ^{87}Sr in the residual magma.*

(v) *The ultrapotassic rhyolites exposed at Manihari of Pali district have similarity in the age and initial Sr ratio with those of the outer rhyolites of Siwana, suggesting possible derivation of these rocks from the same residual magma.*

(vi) *^{40}Ar-^{39}Ar studies of basalt, dacite and rhyolite from Diri and Gurapratap Singh as well as of Jalore granites have indicated existence of a thermal event around 500-550 Ma ago.*

(vii) *^{40}Ar-^{39}Ar studies of mildly alkaline rocks of Tavidar have indicated a span of 2 Ma from 66 to 64 Ma for the differentiated rocks, ranging in composition from andesite to potassic rhyolites. Less voluminous basic rocks (hawaiites) are contemporary to the mildly alkaline rocks but have low initial Sr ratio of 0.70441 as compared to an average of 0.70525 for the latter and indicate derivation of the magmas at different levels in the mantle.*

(viii) *At Mundwara, the igneous activity commenced around 70 Ma ago and culminated about 64 Ma ago. The average initial Sr ratio of the complex is 0.70457, suggesting an upper mantle origin of the magma.*

It is very important to explore the source of heat which caused wide spread secondary isotopic equilibration in the Malani volcanics as well as granites around 500-550 Ma ago, as revealed by ^{40}Ar-^{39}Ar studies from the province as well as by mineral Rb-Sr ages from central and southern extremity along the axial zone of Aravalli mountain chain by Choudhary (1984).This thermal imprint does not seem to be a localized event, instead it is probably related to a some large scale tectonic episode.

However, none of the rocks analyzed so far in Rajasthan have yielded primary crystallization time in the range of 500-550 Ma but the formation ages in this time band have been recorded from several granitoid plutons in the north from a long linear belt parallel to the Himalayan strike (Jager et al., 1971; Mehta, 1977; Le Fort et al., 1980, 1981, 1983; Trivedi et al., 1984 and Trivedi, 1990) and in south from southwest coast in Kerala (Nair et al., 1985; Santosh et al., 1989 and Santosh et al., 1994).

The emplacement of these younger granites in south have been correlated with the Pan-African thermo-tectonic episode (Santosh et al., 1994), which has resulted in wide spread crustal accumulation throughout Gondwana land prior to fragmentation and drifting (Kennedy, 1964). The thermal imprint as observed in southwest Rajasthan may also probably be related to the same Pan-African tectonic episode and the magma which caused resetting of Rb-Sr and ^{40}Ar-^{39}Ar clocks might have crystallized at certain depth to form early Paleozoic granites and might not have been exposed so far in Rajasthan. However, this enunciation needs further probe.