CHAPTER V

CONCLUDING COMMENTS

In this work, I presented the findings of stable and radioisotopic studies on six Mesozoic carbonatite-alkaline complexes of India (Amba Dongar, Mundwara and Sarnu-Dandali from Deccan Flood Basalt Province and Sung Valley, Samchampi and Swangkre from Assam-Meghalaya Plateau). Summaries of different studies are provided in the closing notes of each of the respective investigations in the Chapter-IV. The intention of this final chapter is to bring out the ideas developed from this work on the formation and evolution of carbonatites and associated alkaline rocks in general and the Mesozoic Indian complexes in particular and to recommend the areas for future study.

An attempt has been made to understand the source regions of carbonatites and the magmatic and post magmatic process involved in their evolution using different geochemical tracers such as Sr-isotopes, trace and rare earth elements and stable isotopes in these rocks and the associated alkaline rocks with the available experimental facilities. Theoretical models were developed in order to track down the effects generated by different geological processes such as liquid immiscibility, crustal contamination, fractional crystallization and secondary alteration. Although the findings of this work are based on a small database, nevertheless, these provide interesting information on the evolution of carbonatites and form a foundation for future investigations on Indian carbonatites. From this study I make the following general conclusions for the evolution of carbonatites.

5.1. GENERAL CONCLUSIONS

5.1.1. Recycled Carbon

Carbonatites incorporate recycled carbon. Though many earlier workers have suggested this but there has been no direct conclusive evidence as the stable carbon isotopes in carbonatites of most of the complexes in the world showed large variations. The homogeneous nature of $\delta^{13}C$ value of carbonatites from Assam-Meghalaya plateau (average value = -3.2‰) suggests an incorporation of recycled crustal carbon ($\delta^{13}C$ =

0 - 2%, Nelson et al., 1988) in the primary melt, which is supposed to carry an average mantle-like $\delta^{13}C$ value (-5.0‰, considering the highest value) under normal circumstances. As there is no other evidence for alteration of the primary carbonatite $\delta^{13}C$ value (inferred from Sr and O isotope results) by any magmatic (fractional crystallization or crustal contamination) or secondary (fluid related alteration) processes, I am inclined to believe that the primary magmas for these complexes did carry recycled carbon. In most of the carbonates of the world this kind of evidence is not found because of the fractionation of ^{13}C during their evolutionary processes. However, proper modelling of these fractionating processes can help the identification of recycled component (if present). Doing such an exercise in Amba Dongar complex of Deccan province, I found an evidence of recycled carbon in a particular batch of parent melt. However, the evidence from Amba Dongar is not as conclusive as that from the three complexes of Assam-Meghalaya plateau.

5.1.2. Plume Origin

The temporal, spatial relationship of the Mesozoic carbonatite-alkaline complexes of India with the plume derived flood basalts (Deccan and Rajmahal) and the initial strontium isotopic ratios suggest that these complexes were derived from plumes (Reunion & Kerguelen). They represent either early or late magmatic activity relative to the flood basalts, a finding that fits well with the proposed models for plume related carbonatite-alkaline magmatism (Wyllie, 1988; Sen, 1995). The above results also substantiate the findings of Basu et al. (1993). It is possible that carbonatites in general are related to plume activities. Evidence is mounting in favour of such a hypothesis, particularly with the help of multiple radioisotopic studies.

5.1.3. Common Parentage for Carbonatites and Associated Alkaline Rocks

There has been a lot of controversy over the linking of carbonatites with the associated alkaline silicate rocks. The coeval nature of these two rock types and the similarity of their minimum initial Sr isotopic ratios in Amba Dongar and Sung Valley complexes suggest a genetic link and most likely they have a common parentage. Such a finding along with the results from many other complexes of the world suggests that carbonatites and associated silicates represent a single magmatic event and are derived from a common parent magma.

5.1.4. Assimilation Fractional Crystallization Coupled with Liquid Immiscibility

One of the major contributions of this work is a model that treats elemental and isotopic evolution of a carbonated-silicate magma (parent magma for carbonatite-alkaline complexes) which undergoes simultaneous assimilation of country rocks, fractional crystallization of silicates and separation of carbonate melt. I have applied this model only to Sr-isotopes in this work but it can be applied to other systematics as well. Using the model, I showed that even if there is a crustal contamination of the parent carbonated silicate magma (which is usually small owing to its fast ascent) the effect of contamination will be negligible (particularly for Sr isotopes) in the separated carbonate magma provided the carbonate melt does not get contaminated during its emplacement after liquid immiscibility. However, the alkaline rock will record the contamination effects. Hence, in order to establish crustal contamination in a given complex, the study of both the carbonatites and alkaline rocks are needed.

5.1.5. Stable Carbon and Oxygen Isotopes

Contrary to general belief, I found that magmatic processes like liquid immiscibility and fractional crystallization of carbonate melt can fractionate carbon and oxygen isotopes. The measured carbon isotope fractionation factor between a carbonate melt and a silicate melt is too small (Mattey et al., 1990) to cause any equilibrium isotopic fractionation; however, if the fractionation process is of Rayleigh type during immiscible separation (which is likely, considering the fast separation of carbonate and silicate melts as observed by Wyllie, 1989) then the heavier carbon isotope can get incorporated into the carbonate melt and increase the $\delta^{13}C$ of the carbonate melt with respect to the original mantle value. Fractional crystallization of carbonate magma can generate $\delta^{13}C$ and $\delta^{18}O$ variations if the crystallization process occurs in presence of magmatic fluids (CO_2 + H_2O). A model developed by me to treat such a process (called Rayleigh isotopic fractionation from a multicomponent source), which successfully explains the $\delta^{13}C$ and $\delta^{18}O$ variations in primary carbonatites of Amba

Dongar, Mundwara and Sarnu-Dandali complexes, can be applied to many other complexes of the world where fluid-associated fractional crystallization is suspected.

5.1.6. Evolution of carbonatite-alkaline complexes

From the present work, a general scheme for the evolution of carbonatite-alkaline complexes has evolved. I believe that the evolution of such complexes is a two stage process. Separation of a carbonate melt and simultaneous fractional crystallization of silicate rocks take place from the parent melt at stage one, probably within the crust. After immiscibility is complete, the carbonate melt moves up and crystallizes fractionally, at stage two, to generate different types of carbonatite. Crustal contamination may take place at both the evolutionary stages. At stage one, it is the parent magma which gets contaminated, whereas at stage two, the carbonate magma gets contaminated.

5.2. SITE SPECIFIC CONCLUSIONS

Of the six Mesozoic complexes studied in this work, Amba Dongar and Sung-Valley complexes were studied in detail, whereas only the stable isotopic studies were done in the rest of the complexes. As mentioned earlier, summary of each method of investigation has been provided at the end of each section in Chapter-IV. Here, I will be presenting the important findings of this work on different individual complexes in light of my observations.

5.2.1. Carbonatite-Alkaline Complexes of Deccan Province

Amba Dongar complex has been dated to 65.0 Ma. This is the first reliable age for this complex. The age, spatial relationship with the Deccan flood basalts and the minimum strontium isotope ratios of the three complexes studied from Deccan Province support the hypothesis of Reunion plume origin of these complexes. Amba Dongar carbonatites and other such complexes of Chhota Udaipur subdivision of Baroda District, Gujarat (covers an area of ~1200 km^2), being emplaced just at the K/T boundary (this work and Basu et al., 1993) could have enhanced the catastrophic effects leading to mass extinctions, by rapidly pumping a substantial amount of CO_2 into the already disturbed atmosphere.

The strontium isotopic study on carbonatites, associated alkaline rocks and country rocks of Amba Dongar complex suggests that the liquid immiscibility had played a major role in the formation of this complex. It was also found that the parent magma of this complex had assimilated basement gneisses (up to ~4%). This contamination effects are readily observed in the strontium ratios of the alkaline rocks, and not in carbonatites. The rare earth element abundances in carbonatites and alkaline rocks of Amba Dongar also support their generation by liquid immiscibility.

The stable carbon and oxygen isotopic compositions of primary melts of Amba Dongar, Mundwara and Sarnu-Dandali complexes show average mantle values except for a particular batch of melt at Amba Dongar which bears a signature of recycled crustal carbon. Fractional crystallization of fluid rich carbonate melts is found to be the main process responsible for the correlated variation of $\delta^{13}C$ and $\delta^{18}O$ in unaltered calcite carbonatites from these complexes. Extreme variations of $\delta^{13}C$ and $\delta^{18}O$ compositions shown by some carbonatites in all these complexes are found to be a result of fluid related (CO_2 bearing magmatic or hydrothermal or meteoric) secondary alteration processes.

5.2.2 Carbonatite-Alkaline Complexes of Assam-Meghalaya Plateau

Sung Valley complex has been dated to 107 Ma. This is the first reliable age data for this complex. The age, spatial relationship with Rajmahal Traps, Sylhet Traps and Bengal Basin magmatisms and the initial strontium isotopic ratio of this complex suggest its generation from Kerguelen plume.

Sung Valley carbonatite-alkaline complex is found to be an unique complex as it showed a closed system behaviour for strontium as well as stable isotopes. The Rb-Sr isochron age (which includes samples of carbonatites and an alkali pyroxenite) 106±11 Ma of this complex is same as the more reliable ^{40}Ar-^{39}Ar age of 107 Ma. The rocks of this complex also show homogeneous initial $^{87}Sr/^{86}Sr$ ratio and which is same as the intercept value in the Rb-Sr isochron diagram. The stable C and O isotopic compositions (except two samples, which are altered by meteoric water) are also found to be homogeneous in the entire complex. These observations rule out the possibility of any crustal contamination.

The $\delta^{13}C$ values of the primary carbonate melts for all the three complexes (Sung Valley, Samchampi and Swangkre) were found to be higher than that of an average mantle (by 1.8‰). This has been attributed to the contamination of the source regions by recycled crustal carbon. A conservative calculation shows that the primary melts for these complexes incorporated around 26-36% of the recycled crustal carbon.

5.3 RECOMMENDATIONS

Though most of the carbonatites in India were discovered in nineteen sixties and seventies, not much work has been done to understand the formation and evolution of these complexes. Except for a few complexes isotopic studies are absent in these. There are many interesting complexes such as Newania (which is a dolomitic carbonatite complex) of Rajasthan and many metamorphosed Precambrian carbonatite complexes of Southern India, which can be taken up for isotopic studies in order to understand many magmatic and post magmatic processes in these complexes. However, in the ongoing discussion about the Mesozoic (Cretaceous, as indicated by my work) complexes, I recommend some important aspects, which should be taken up for study to establish many of the hypotheses presented in this work and elsewhere:

1. To establish whether plume material carries recycled carbon or not, carbon and oxygen isotopic studies are required on carbonates found in mantle xenoliths from many present day hot spot rocks (e.g. Kerguelen hot spot, Schiano et al., 1994).
2. A combined Sr, Nd and Pb isotopic study is required in the carbonatite-alkaline complexes of Assam-Meghalaya plateau, in order to characterize their source regions and their relationship with Kerguelen plume activity during early Cretaceous.
3. To confirm the plume origin for Amba Dongar and carbonatite complexes of Assam-Meghalaya plateau, He-isotopic study is needed.
4. Stable oxygen isotopic studies in silicate fractions of the associated silicate rocks are required to understand clearly the processes such as liquid immiscibility and crustal contamination in the Indian complexes, particularly in Amba Dongar.

5. For a better understanding of stable isotope fractionation during fractional crystallization, a theoretical model should be developed, which should treat isotopic evolution of a multicomponent source from which multiple phases crystallize at different temperatures.