CHAPTER II

GEOLOGY AND EARLIER WORK

The Mesozoic carbonatite-alkaline complexes taken up for this study include Amba Dongar, Mundwara and Sarnu-Dandali of Deccan flood basalt province, western India and Sung Valley, Samchampi, and Swangkre of Assam-Meghalaya plateau, eastern India (Fig. 1.4). In this chapter, the geology of these regions is described and the earlier work is reviewed.

2.1. GENERAL FEATURES OF MESOZOIC INDIAN CARBONATITE -ALKALINE COMPLEXES

A brief review of the geology of the carbonatite-alkaline complexes mentioned above is available in Krishnamurthy (1988). The emplacement ages of these complexes were estimated to be falling in the range 65 Ma to 156 Ma (Basu et al., 1993; Deans et al., 1973; Chattopadhyay and Hashimi, 1984; Krishna et al., 1991) prior to the present work. The origin of Amba Dongar, Mundwara and Sarnu-Dandali complexes, which are present within the Deccan Flood Basalt Province, has been linked to the Reunion-Deccan plume which generated the massive flood basalts over Indian subcontinent (Basu et al., 1993; Sen, 1995). Eastern Indian carbonatite complexes (Sung Valley; Samchampi; Swangkre) are thought to be related to the Kerguelen plume activity, which caused the volcanism of Rajmahal Traps, Bengal basin basalts and Sylhet traps on the eastern margin of Indian subcontinent (Kent et al., 1992). All these Mesozoic complexes are associated with major fracture zones (Fig. 1.4).

Most of the complexes, discussed here, display oval or semicircular outlines in plan view. They usually intrude into Precambrian gneisses, granites, metasedimentary rocks and in Amba Dongar into Deccan basalts as well. Rocks of many complexes, eastern region carbonatites in particular, are poorly exposed because of thick soil/alluvium cover in these regions. The alkaline silicate rocks comprise the major part in all these complexes. These consist of dominantly alkali pyroxenites, ijolites, and syenites except in Amba Dongar, where tinguaites, nephelinites and phonolites are predominant. Carbonatites comprise only a minor part of these complexes, barring the Amba Dongar where they form ~20% of the whole complex. Calcite-carbonatites are the major carbonatites in all these complexes, whereas ferrocarbonatites and dolomite-carbonatites are minor in occurrence. Carbonatites show a variety of intrusive forms like ring dykes, dykes, sills, cone sheets and veins. Fenitization of country rocks is a common feature in all these complexes and both potassic and sodic fenites have been observed.

2.2. THE AMBA DONGAR COMPLEX

2.2.1. Regional Geology and Field Relations

The Amba Dongar carbonatite-alkaline complex is the first carbonatite complex to be identified in India (Sukheswala and Udas, 1963). This complex is located 2 km north of Narmada river in Baroda district of Gujarat state and is a part of a large carbonatite-alkaline province of Chhota Udaipur (Sukheswala and Viladkar, 1978). The rocks of this complex intrude into the 955 Ma old gneisses (Gopalan et al., 1979), Cretaceous Bagh sediments (sandstones and limestones) and some earlier flows of Deccan tholeiites. It was believed that this complex intruded late in the Deccan trap magmatism (Deans and Powell, 1968), however, there was no accurate age data available in support of this hypothesis.

This complex is present within the Narmada-Son rift zone (Fig. 1.4) and inside the complex the magmatic activity seems to have followed the local fault patterns as majority of dykes are aligned along these (Viladkar, 1984). The complex is characterized by concentric ring dykes of calcite-carbonatite (sovite of Viladkar, 1981) and carbonatite breccia with tholeiitic basalt in the central depression. The alkaline rocks are present as plugs and dykes in the low surrounding areas of the main carbonatite dome and are exposed at places inside the ring dyke (Fig. 2.1). Ferrocarbonatites (ankerite-carbonatites of Viladkar, 1981) occur as small plugs in the ring dyke in the southern part of the complex (Fig. 2.1). The carbonatites of this complex host a massive fluorite deposit. Extensive fenitization of the country rock sandstones is the most striking feature of this complex.

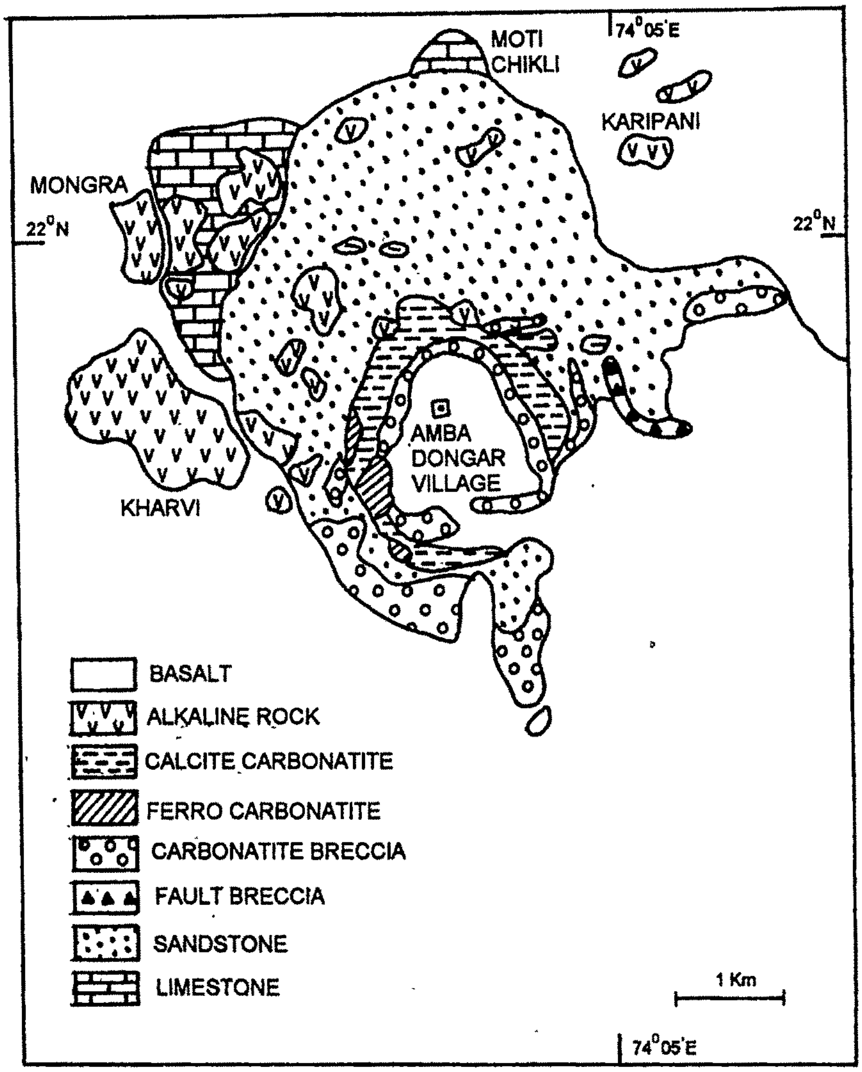

Fig. 2.1. *Geological map of Amba Dongar carbonatite-alkaline complex modified from Viladkar, 1981.*

2.2.2. Alkaline Silicate Rocks

Alkaline silicate rocks of Amba Dongar have been identified as tinguaite, phonolite/phono-nephelinite and syenite/nepheline-syenite (Viladkar, 1984; Srivastava, 1994). These rocks occupy most of the hill tops surrounding the carbonatite ring dyke. Mineralogically, these rocks have nepheline, aegirine-augite and melanite-garnet as phenocrysts while ground mass contains analcite and calcite (Srivastava, 1994). Phonolitic nephelinities have, apart from above minerals, alkali feldspars as phenocrysts (Viladkar, 1984). Chemically, most of these rocks have been classified as foidites and basanites (Srivastava, 1994). From trace and rare earth elemental studies it was found that Sr and REE content in alkaline rocks are smaller compared to the associated carbonatites (Viladkar, 1984; Viladkar and Dulski, 1986). By studying trace elements in growth zones of pyroxenes from these rocks, Rock et al. (1994) found that the pyroxenes reflect disequilibrium effect, which according to them, is due to rapid growth or fast cooling of these minerals. There is no report of isotopic data on these rocks.

2.2.3. Carbonatites

Carbonatites of this complex are mainly of two types, calcite-carbonatites and ferrocarbonatites. As mentioned earlier, calcite-carbonatites form a large ring dyke into which ferrocarbonatites intrude as small plugs (Fig. 2.1). The carbonatite breccia, which forms the innermost ring of the dyke, contains xenoliths of older rocks (gneisses; basalts; sandstones). Apart from dykes and plugs, numerous calcite carbonatite and ferrocarbonatite veins are present within the massive calcite carbonatites all over the complex. Calcite carbonatites of Amba Dongar are coarse to fine grained rocks, in which the most common minerals are calcites (>70%), magnetites and apatites. Accessory minerals include fluorites, barites, pyrochlores and zircons. Sometimes they also contain phlogopites, particularly the carbonatite veins. It has been observed that there are two generations of calcite-carbonatites, an early coarse grained variety and a late medium to fine grained variety which usually carries the earlier phase as xenoliths (Viladkar and Wimmenauer, 1992). Ferrocarbonatites are fine grained dark red coloured carbonatites in which ankerite is the major carbonate mineral. In many instances, ankerites were found to have been oxidized giving rise to iron oxides. Calcite in ferrocarbonatites is present up to 40%. Other minerals include apatite, barite, magnetite, pyrochlore, bastenite, cerite, monazite and some sulphides. These rocks are invariably altered and have lots of microcrystalline silica and in many instances, are affected by fluorite mineralization.

Major elemental analyses of these rocks by Viladkar and Wimmenauer (1992) show that the calcite carbonatites have ~50% CaO and ~2% MgO on an average, whereas ferrocarbonatites have ~35% CaO, >10% Fe_2O_3, ~8% MgO, and ~2% MnO. Among the trace elements Sr and Ba are the most abundant elements in both the types of carbonatite. In calcite-carbonatites Sr concentration is generally more than the Ba concentration while in ferrocarbonatites it is just the reverse (Viladkar and Wimmenauer, 1992). These carbonatites are highly enriched in REE and it has been observed that the REE content increases from coarse grained calcite carbonatites to ferrocarbonatites through medium to fine grained calcite carbonatites suggesting extreme differentiation of the parent carbonate magma (Viladkar and Dulski, 1986).

The first ever isotopic work in this complex were reported by Deans and Powell (1968). This study showed that the carbonatites have an average $^{87}Sr/^{86}Sr$ of 0.706, which is higher than the observed ratio in most of the carbonatites of the world. The authors also ruled out any possible genetic relationship between the carbonatites and country rock limestones owing to their widely different $^{87}Sr/^{86}Sr$. In a recent isotopic study Simonetti et al. (1995) have observed that the Nd and Sr isotopic results from this complex indicate derivation from a Rb/Sr and Nd/Sm enriched mantle source region, which is very different from many carbonatite complexes of the world. They also suggested that, the carbonatites do not show any kind of contamination/assimilation of the country rock sandstones. A few (numbers of) $\delta^{13}C$ and $\delta^{18}O$ values of carbonatites, reported by Simonetti et al. (1995), have been interpreted as primary or results of low temperature meteoric water alteration.

2.2.4. Metasomatic Rocks

Metasomatic features (fenitization) are inherent to carbonatite complexes and these are generally produced during the emplacement of the carbonatites. At Amba Dongar fenitization is widespread in the host rocks, in sandstones particularly. These fenites have been extensively studied, both from mineralogical and chemical point of view by Shukeswala and Viladkar (1981) and Viladkar (1996). The chemistry of fenites revealed two trends of fenitization, an earlier and deeper sodic fenitization and a later predominantly potassic fenitization confined to shallower levels (Viladkar, 1996). Some alkaline rocks are also thought to have been fenitized by the carbonatite related metasomatic activity (Viladkar, 1996). In this variety of rocks, we also include the rocks which show fluorite mineralization. The carbonate content of these rocks vary from 0 to 10%. The fluorite mineralized rocks also contain large amounts of micro crystalline silica.

2.2.5. The Fluorite Deposit

The Amba Dongar fluorite deposit, the largest in India, is believed to be a hydrothermal deposit, formed much later to the carbonatite emplacement (Deans and Powell, 1968; Simonetti and Bell, 1995). Chemical and isotopic studies of fluorites do not indicate any direct genetic relationship of the mineralization with the carbonatite magmatism (Simonetti and Bell, 1995). Fluid inclusion studies revealed that these fluorite deposits were formed from a low-salinity, CO_2- bearing aqueous fluid at low temperatures (100-150°C) [Roedder (1973); Sharma (1991)].

2.2.6. The Geologic Evolution of the Complex

The general belief is that the Amba Dongar alkaline complex, like Phenai Mata of the same alkalic province (Chhota Udaipur), represents one of the late magmatic pulses of the Deccan Flood Basalts (Basu et al., 1993). However there is no unambiguous age data in support of this hypothesis. Very early attempts by Deans et al. (1973) to date the pyroxenes from nephelinites and two feldspars from potassic fenites, using K-Ar method of dating, yielded varying ages of 37.5±2.5 Ma, 61±2 Ma and 76±2 Ma, respectively. Basu et al. (1993) reported an ^{40}Ar-^{39}Ar age of 65 Ma for the Phenai Mata alkaline-carbonatite complex, which is geographically close to Amba Dongar complex, and hypothesized it to be contemporaneous with Amba Dongar. However, it is so far not clearly established whether Phenai Mata and Amba Dongar are temporally related.

Viladkar (1981, 1984) suggested, on basis of major and trace elemental chemistry, that this complex is not genetically related to the Deccan tholeiites. He also suggested that the alkaline silicate rocks and carbonatites of this complex were derived as a result of liquid immiscibility of a parent melanephelinitic magma. The only combined isotopic study on this complex based on Nd, Sr and Pb isotopes, by Simonetti et al. (1995), suggested an LREE enriched mantle source for the carbonatites (possibly an EM-II type of mantle) and indicated a possible relationship with the Reunion-Deccan plume activity. In a recent experimental phase equilibria study, Sen (1995) suggested that the tholeiites, carbonatites and alkaline silicate rocks, all are generated from the Deccan-Reunion plume. According to him carbonatites and alkaline lavas were generated by very low degree of melting (~1%) from the cooler, volatile rich apron of the plume head.

2.3. THE MUNDWARA COMPLEX

2.3.1. Regional Geology and Field Relations

The Mundwara alkaline-carbonatite complex is present 400 km northwest of Amba Dongar complex (Fig. 1.4) in the Sirohi District of Rajasthan. The complex occurs as ring shaped and plug like intrusions within the Precambrian Erinpura granites. This complex is composed of three plutons namely, Musala, Mer and Toa, which are laccolith type of bodies fringed by basalts (Fig. 2.2). Mer is the largest plug, which is composed mostly of alkaline mafic rocks. Carbonatites form a very minor part of the complex and are also present as dykes and veins in the basement rocks, east of Mer plug. Ultramafic and mafic rocks are dominant in Toa complex, whereas in Musala some minor felsic rocks are present along with the major mafic rocks. The Mundwara complex is present within the northward extension of Cambay Graben (Fig. 1.4) and is believed to be an early alkalic pulse of the Deccan Flood Basalt volcanism (Basu et al., 1993).

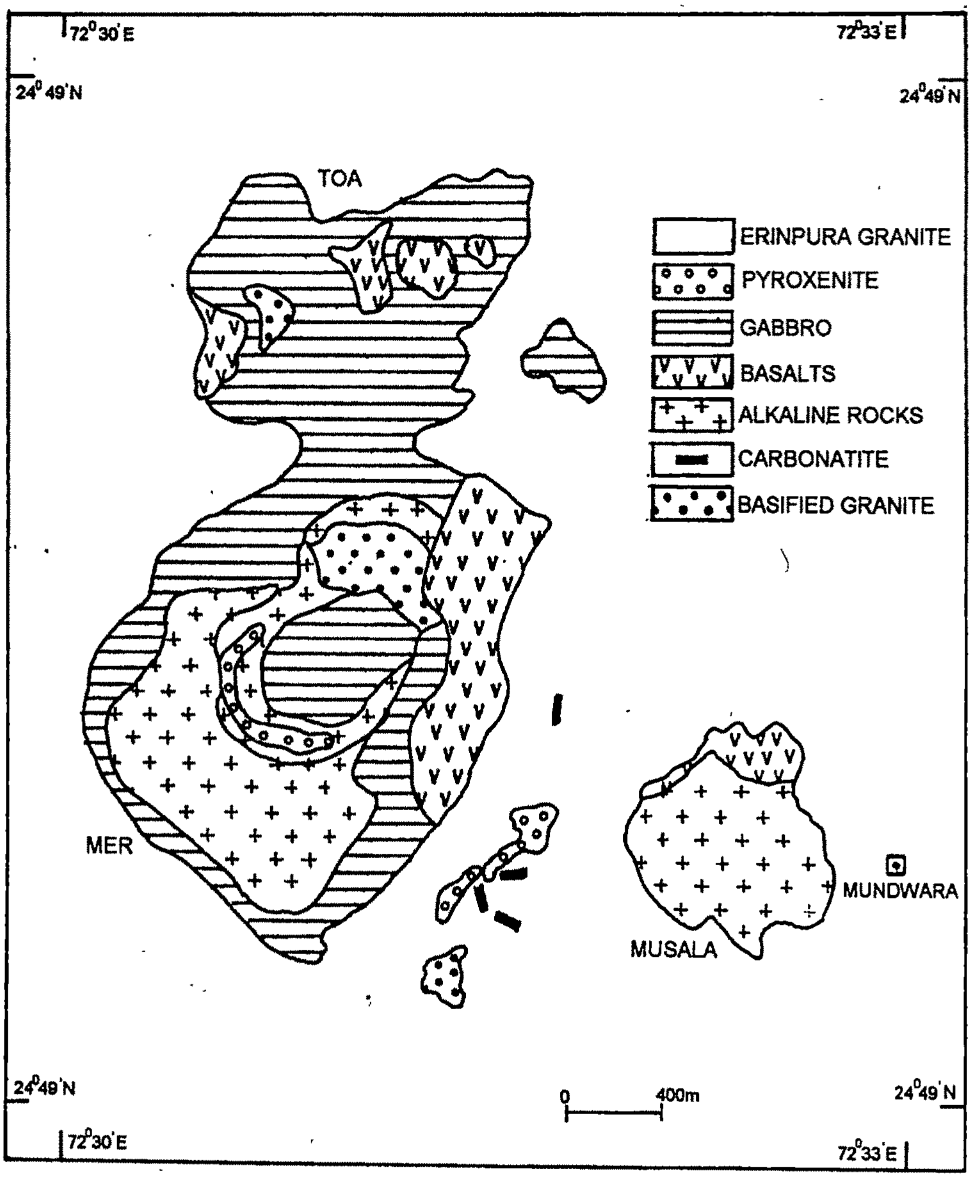

***Fig. 2.2.** Geological map of Mundwara carbonatite-alkaline complex modified from Rathore et al.(1995).*

2.3.2. Alkaline Silicate Rocks

The alkaline end members of this complex include alkali pyroxenites, alkali gabbros, theralites, essexites, melteigites, and syenites (Subrahmanyam and Leelanandam, 1989). Extensive studies on petrology and geochemistry of these rocks and other silicate rocks of this complex have been carried out by various workers viz. Sharma (1967); Bose and Das Gupta (1973); Das Gupta (1974, 1975); Chakraborty and Bose (1978); LeBas and Srivastava (1989); and Subrahmanyam and Leelanandam (1989, 1991). These authors suggested that the alkali olivine basalt (which occurs as flows in Toa) was the parent magma for this complex, which generated the whole sequence of rocks through fractional crystallization. Sr and He isotopic study by Basu et al. (1993) favours a lower mantle source (possibly plume related) for these rocks.

2.3.3. Carbonatites

Mundwara carbonatites occur as dykes and veins. They intrude into the Erinpura granite (Fig. 2.2) and comprise <1% of the complex. Compositionally all these carbonatites are calcite carbonatites (LeBas and Srivastava, 1989). Calcite is the only carbonate mineral present in all these. Other minerals include amphiboles, magnetites, apatites, phlogopites and some times minor pyroxenes. Some calcite carbonatites show considerable secondary alteration. Chemically, CaO content of Mundwara calcite carbonatites is ~50%, MgO content is ~0.5% and SrO content is 1.5%. These also show very high enrichment of rare earth elements (LeBas and Srivastava, 1989).

Radioisotopic measurements in carbonatites is lacking. Based on only three analyses of $\delta^{13}C$ and $\delta^{18}O$ of these carbonatites LeBas and Srivastava (1989) suggested that these indeed show mantle values, which proves their magmatic nature.

2.3.4. Fenitization

Fenitization in this complex is observed only on a small scale. Contact granites are fenitized from a few millimeters up to 3 cm (Subrahmanyam and Rao, 1977). Both potassic and sodic fenitization effects have been observed by LeBas and Srivastava (1989).

2.3.5. The Geologic Evolution of the Complex

The Mundwara alkaline magmatism, like Amba Dongar, is also believed to be a variation of the Deccan flood basalt volcanism. In a recent work, Basu et al. (1993) showed that this complex is 68.53±0.16 Ma old and high $^{3}He/^{4}He$ ratio in olivine gabbro and olivine pyroxenite (~13.9 times atmospheric) suggested a lower mantle origin. Using He isotopes and Sr isotopes, they suggested a plume origin of this complex. Being present north of the Deccan Traps and older in age (by 3.5 Ma), Mundwara alkaline magmatism fits well into the plume model of Reunion-Deccan, which generated the traps and represents an early alkalic pulse.

As mentioned earlier, it is now believed the wide variety of alkaline rocks may have formed, from a parental alkali olivine basaltic magma by fractional crystallization. However, the evolution of carbonatites of this complex is not understood clearly. Subrahmanyam and Rao (1977) suggested that the fractional crystallization of primary carbonated-silicate magma was probably responsible for the formation of carbonatites of this complex.

2.4. THE SARNU-DANDALI COMPLEX

2.4.1. Regional Geology and Field Relations

The Sarnu-Dandali alkaline-carbonatite complex is located 150 km northwest of Mundwara in the Barmer district of Rajasthan and falls within the Malani Igneous Province which forms a part of the Thar desert. Although the complex was recognized earlier by Udas et al. (1974), the work of Chandrasekaran (1987) revealed the alkaline silicate rocks and carbonatite association in it. It comprises a variety of acidic, intermediate, and alkalic rocks, including plugs of ijolites, foidal syenites, and dykes of carbonatites and is intrusive into the Malani rhyolites and Cretaceous sediments (sandstones and siltstones). Fenitization here is predominantly sodic in nature. Fig.2.3 gives the distribution of different rock types in the complex.

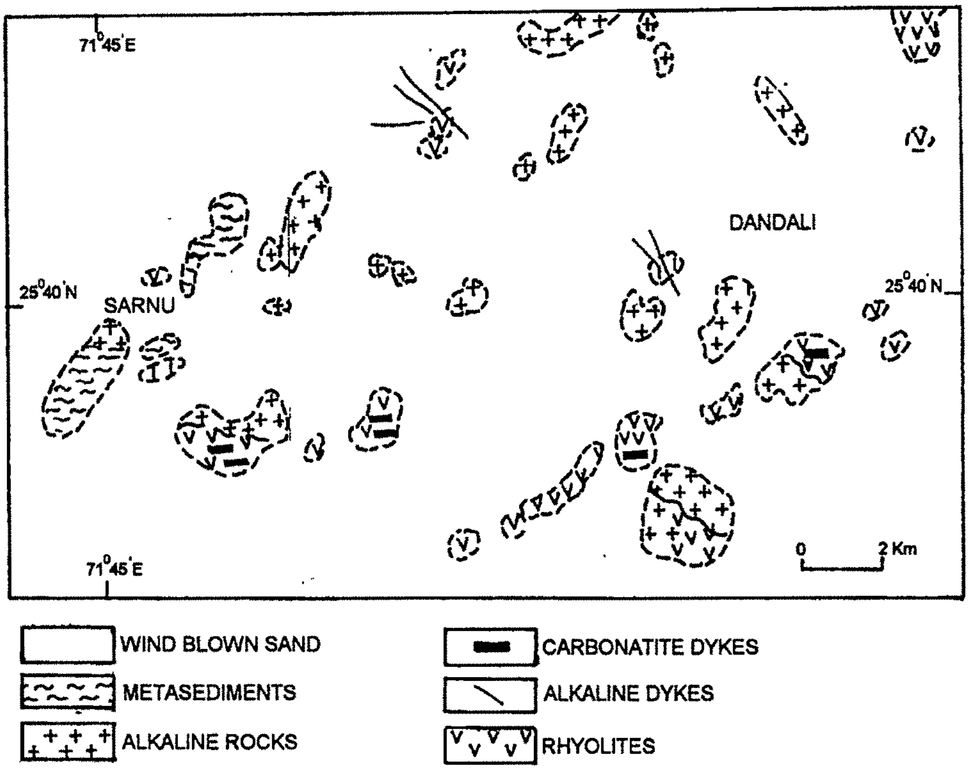

***Fig. 2.3.** Geological map of Sarnu-Dandali carbonatite-alkaline complex modified from Chandrasekaran et al.(1990).*

2.4.2. Alkaline Silicate Rocks

The alkaline suite ranges in composition from alkali pyroxenites to foidal syenites through melteigite and ijolite, besides nephelinite and phonolite (Chandrasekaran et al., 1990). The mineral constituents of these rocks, in general, are titano-augite and nepheline in various proportions besides orthoclase, aegirine augite, aegirine, biotite, melanite, camcrinite etc.(Chandrasekaran et al., 1990). The whole suite of alkaline rocks here have been interpreted as the product of extreme differentiation of a primary alkali pyroxenite or a carbonated alkali peridotite magma (Chandrasekaran et al., 1990). Like the Mundwara complex, $^{3}He/^{4}He$ ratio and $^{87}Sr/^{86}Sr$ ratio of these rocks indicate a plume origin for the complex (Basu et al., 1993).

2.4.3. Carbonatites

Like Mundwara, carbonatites here too comprise a very minor part of the complex. They occur as dykes and veins scattered all over the complex. These dykes and veins vary in length from a few cm to ~12 m and in width from a few mm to ~30 cm. They cut across the mafic alkaline members and contain angular xenoliths of various country rocks. Chemically two types of carbonatites, calcite carbonatites and ferrocarbonatites, are observed in this complex (Chandrasekaran and Srivastava, 1992). Calcite carbonatites are medium to fine grained rocks containing more than 50% of calcite (the only carbonate mineral). The accessory minerals include magnetite, biotite, barite and apatite. Ferrocarbonatite is yellow to yellowish-brown in colour and rich in iron-oxide. Some of the calcite carbonatites and ferrocarbonatites are highly altered and show the presence of microcrystalline silica in them. Radioisotopic studies in carbonatites do not exist. Very preliminary studies of carbon and oxygen isotopes revealed the magmatic nature of these carbonatites (Sarkar and Bhattacharya, 1992; Chandrasekaran and Srivastava, 1992).

2.4.4. Metasomatic Rocks

Most of the suspected calcite bearing carbonatites of Barmer town proper are actually metasomatic rocks as they contain <50% carbonates in them. These rocks are highly altered. Apart from calcites they also contain siderite, orthoclase and microcrystalline silica. Fenitization is confined only to the associated alkaline rocks and is predominantly sodic in nature (Chandrasekaran and Srivastava, 1992).

2.4.5. The Geologic Evolution of the Complex

Basu et al. (1993) reported an ^{40}Ar-^{39}Ar age of 68.57±0.08 Ma for the biotites from alkali pyroxenite, which has been interpreted as the emplacement age of the complex. Based on this age data, $^{3}He/^{4}He$ ratio of 12.8 times atmospheric value and initial $^{87}Sr/^{86}Sr$ ratio of 0.70499, Basu et al. (1993) suggested a lower mantle source these rocks and linked their origin to the Deccan-Reunion plume activity. They also suggested that this complex is probably the earliest manifestation of the Deccan volcanism on the Indian subcontinent.

The genesis of wide variety of alkaline silicate rocks have been explained by extreme differentiation of a parent alkaline pyroxenitic magma. However, so far no attempts have been made to link the alkaline rocks to the carbonatites of this complex, except that they are thought to be genetically related.

2.5. THE SUNG VALLEY COMPLEX

2.5.1. Regional Geology and Field Relations

The Sung Valley carbonatite-alkaline complex is the largest of all eastern Indian carbonatite complexes. It is located 49 km south of Shillong, in the state of Meghalaya. The complex intrudes into the Precambrian Shillong series metasedimentary rocks (quartzites, phyllites and quartz-sericite schists). The Assam-Meghalaya plateau in which Sung Valley is located, is considered to be an uplifted horst bordered by Dauki fault to the south and the Brahmaputra trough zone to the north (Fig. 1.4) (Krishnamurthy, 1985). The Sung Valley complex is an oval shaped pluton with the core occupied by serpentinized peridotite and rimmed by pyroxenite (Fig. 2.4). It is composed of a variety of alkaline silicate rocks like uncompahgrite, ijolite and syenite, which occur as small bodies within the pyroxenite. The carbonatites occur as small stocks, lenses, dykes and veins within the pyroxenites and are confined to the southern part of the complex (Fig. 2.4). Preliminary studies indicate the presence of both sodic and potassic fenites in this complex (Krishnamurthy, 1985).

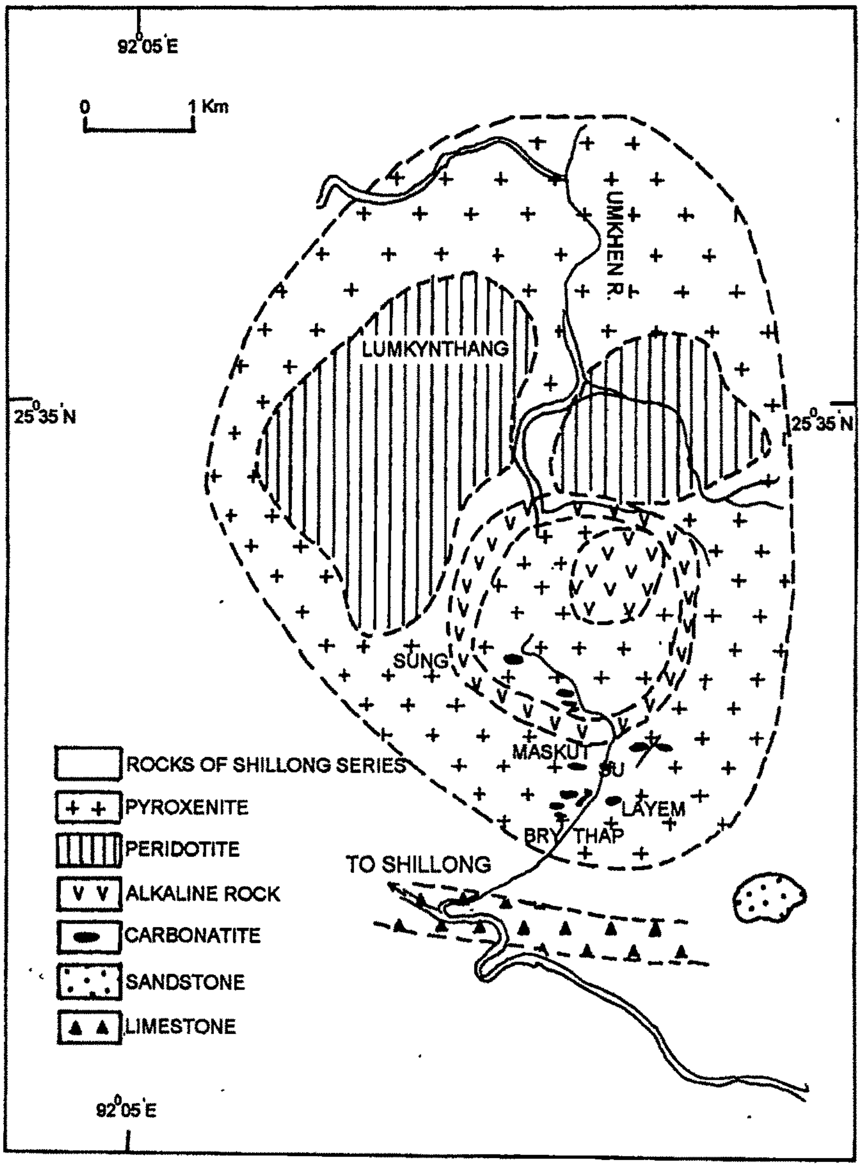

Fig. 2.4. *Geological map of Sung valley carbonatite-alkaline complex modified from Krishnamurthy et al. (1985).*

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2.5.2. Alkaline Silicate Rocks

Alkaline silicate rocks of Sung Valley complex include alkali pyroxenites, uncompahgrites, ijolites and syenites. Pyroxenites appear to be the earliest member and constitute the bulk of the complex. Two types of pyroxenites, coarse grained and medium to fine grained, have been reported (Krishnamurthy, 1985). Diopsidic augite is the major mineral of these rocks with minor phlogopite. Ijolite occurs as a ring dyke and a central plug, whereas syenite occurs as minor dykes. At places all the silicate rocks have been affected by fenitization due to carbonatite activity.

2.5.3. Carbonatites

Carbonatites comprise a minor part of the complex and are present as small stocks, dykes and veins in the pyroxenite. Calcite carbonatite is the major carbonatite variety, however, magnesiocarbonatite is also present (Krishnamurthy, 1985). Apart from calcite and dolomite, these rocks also contain a substantial amount of magnetite and apatite. Other accessory minerals include phlogopite, fluorite, pyrochlore, perovskite and olivine. Like other carbonatites of the world, Sung Valley carbonatites also show high enrichment of Sr, Ba, Nb and REE (Krishnamurthy, 1985).

A combined Pb, Sr and Nd isotopic study on these carbonatites (Krishna et al.; 1991) indicated a DUPAL mantle source for this complex and the isotopic ratios are found to be broadly similar to those of ninety degree east ridge basalts.

2.5.4. The Geologic Evolution of the Complex

The age of Sung Valley complex is not known unambiguously. The available age data show two widely different values; 90±10 Ma (Fission track age, Chattopadhay and Hashimi, 1984) and 150±26 Ma (Pb-Pb, whole rock isochron age, Krishna et al., 1991). In a recent development different workers have tried to link this carbonatite magmatism with the Rajmahal trap volcanism (Kent et al., 1992; Ghose et al., 1996 and references therein). The isotopic evidence for similar source regions for Ninety East Ridge Basalts and Sung Valley carbonatites (Krishna et al., 1991) indicates that probably the Kerguelen plume was responsible for this carbonatite magmatism. If so, then one would expect an age close to the 116 Ma (age of Rajmahal Traps, Baksi, 1986). However, accurate age data and detailed isotopic study are required to prove this hypothesis.

It is believed that both liquid immiscibility and fractional crystallization have played a major role in generating alkaline silicate rocks and carbonatites (Krishnamurthy, 1985). It is also suggested that a melanephelinitic parent magma was responsible for the generation of the whole complex (Krishnamurthy, 1985).

2.6. THE SAMCHAMPI COMPLEX

The Samchampi alkaline-carbonatite complex was first reported by Kumar et al. (1989). This complex is in Karbi Anglong district of Assam and located ~100 km to the east of Sung Valley complex (Fig. 1.4). It intrudes into the Precambrian Gneissic Complex of Karbi Hill Massif (Sengupta et al. 1997). Apart from carbonatites, this complex comprises of alkali pyroxenites, melteigites, ijolites, nephelinites and syenites. Carbonatites, which occur as dykes and veins, are mainly calcite-carbonatites. Only syenitic fenites have been reported from this complex (Sengupta et al. 1997). Detailed petrological or geochemical work in this complex is lacking.

2.7. THE SWANGKRE COMPLEX

The Swangkre complex of West Khasi Hill of Meghalaya (Fig. 1.4) was first reported by Nambiar and Golani (1985). After its discovery, to our knowledge, no further work on this complex has been done. Carbonatites of this complex occur as small dykes which intrude into Precambrian gneisses and granites and are calcite-carbonatites. The carbonatites of this complex are associated with lamprophyres, ijolites and tinguaites (Nambiar and Golani, 1985).

2.8. RELATIVE EROSION LEVELS OF THESE COMPLEXES

The relative erosion levels of the carbonatite complexes are estimated based on rock association, nature of carbonatites, degree of fenitization and type of fenites. Fig. 2.5 shows an idealized vertical profile of an alkaline-carbonatite complex (LeBas, 1977) with the estimated relative erosion levels of the complexes studied here. Except Amba Dongar complex, all other complexes show plutonic to subvolcanic associations.

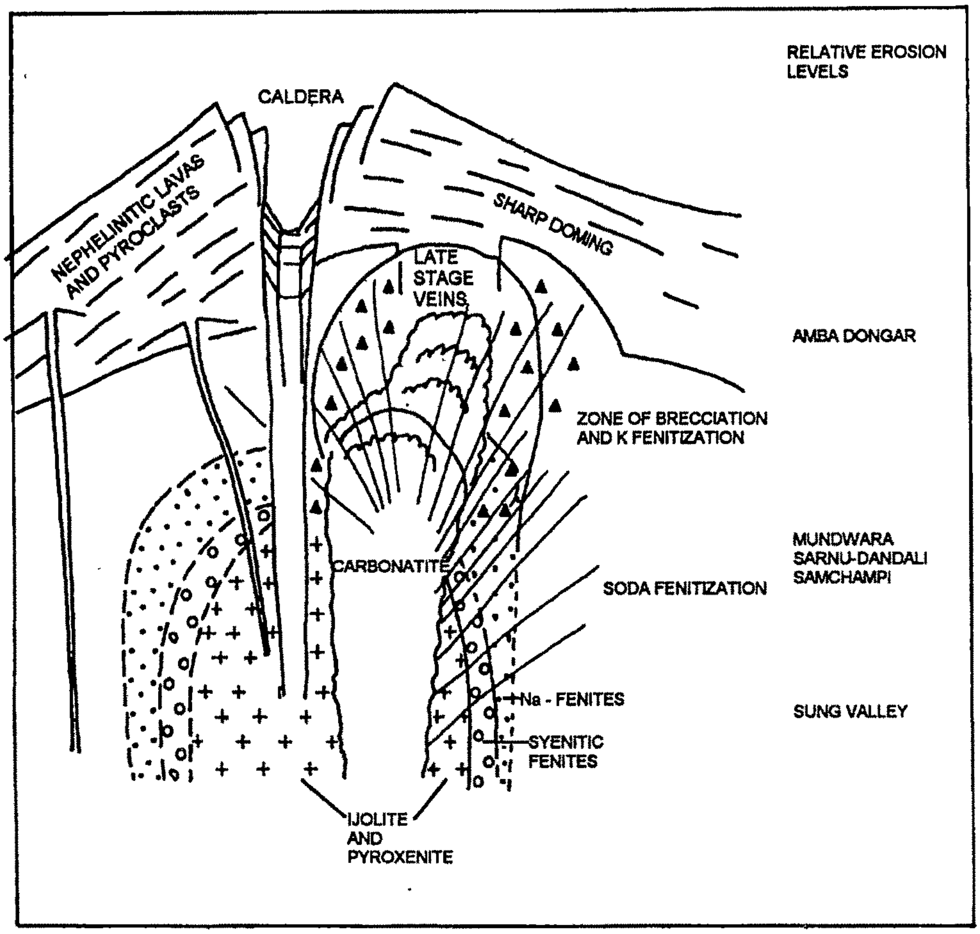

***Fig. 2.5.** Schematic cross-section of an idealized carbonatite-alkaline volcanic complex showing the normal structure, sequence of intrusion and zones of Na & K fenitization. It also shows the estimated erosion levels of the six complexes studied in the present work. Figure is modified from LeBas (1977).*

The subvolcanic to volcanic association, extensive brecciation, late stage carbonatite veining and predominant feldspathic fenitization, indicate a very shallow level of emplacement for Amba Dongar complex (Fig. 2.5). The plutonic association, the presence of sodic and syenitic fenites, and the very coarse grained nature of carbonatites put Sung Valley complex at the deepest emplacement level. The rock association and fenites of Mundwara, Samu Dandali and Samchampi indicate that the erosion level of these complexes is between those of Amba Dongar and Sung Valley complexes (Fig. 2.5). The emplacement/erosion levels estimated here are highly schematic, however, these probably have greater implications towards understanding the stable carbon and oxygen isotopic evolution of these complexes.

In summary, it was found that the following questions remained unanswered, which are addressed in the present work:

1. What is the exact relationship between the carbonatites and the associated alkaline rocks present in these complexes?
2. Where is the source region of carbonatite located, in the lower mantle or in the subcontinental mantle?
3. Is there any genetic relationship between the Cretaceous plume activities (Reunion-Deccan and Kerguelen-Rajmahal) with the above described contemporaneous carbonatite-alkaline magamtisms?
4. What is the nature of carbon in these carbonatites, juvenile or recycled?