Rb-Sr AGE AND Sr ISOTOPIC COMPOSITION OF ALKALINE DYKES NEAR MUMBAI: FURTHER EVIDENCE FOR THE DECCAN TRAP-RÉUNION PLUME CONNECTION

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We report a new Rb-Sr isochron age of 64.9±0.8 Ma for the West Coast lamprophyre at Murud, south of Mumbai and trace element and Sr isotopic composition (0.70384-0.70419) for alkaline, ultrapotassic and basic suites of dykes NE of Kalyan near Mumbai intruding the Deccan basaltic flows. The age of lamprophyre is synchronous with the bulk of the Deccan Trap activity and nearly coincides with the K/T boundary. Also, the initial Sr isotopic composition is similar to the Deccan and Réunion basalts suggesting a genetic connection to the Réunion plume.

Introduction

A number of basic and alkaline dykes is known to intrude the Deccan Trap lavas in the area around Mumbai (Fig.1). South of Mumbai (Bombay) City in Alibag-Murud area, the dykes (Dessai and Bodas, 1984; Dessai et al. 1990 and references therein) intrude the Poladpur Formation (Subbarao and Hooper, 1988), whereas north of Mumbai in Kalyan area they cut across flows belonging to Upper Ratangarh Formation (º Thakurvadi Formation; Godbole and Ray, 1996). While no reports of radiometric ages are available for dykes from the Kalyan area, Ar-Ar plateau ages ranging from 70.77±0.12 to 69.71±0.14 Ma have been reported for mica separates from the lamprophyres of Murud (Knight et al. 2000). These authors also reported biotite-whole rock Rb-Sr model ages of about 63-64 Ma, appreciably younger than their Ar-Ar ages.

While the Rb - Sr ages are consistent with their cross cutting relationship with the host flows (Poladpur Formation, about 67 Ma; Venkatesan et al. 1993), the Ar-Ar ages are at variance and are clearly older. To verify the Rb-Sr model ages of these lamprophyres, a Rb-Sr internal isochron (whole rock-biotite) approach was attempted. The present note reports the results of this exercise and comments on the petrogenetic aspects of the alkaline rocks from the Deccan Volcanic Province using Sr isotopic and selected trace element data.

Sr Isotopic Composition

Rb-Sr isotopic data of four biotite phenocrysts and their whole rock from the Murud lamprophyre together define a linear array with a good spread of the data points (Fig. 2). Interpreted as an isochron, this gives an age of 64.9±0.8 Ma (MSWD = 0.28) and an initial $^{87}Sr/^{86}Sr$ ratio of 0.70405±3. This age is not only stratigraphically consistent, but also indistinguishable from the peak eruptive stage of the Deccan magmatism (about 65 Ma). Of the other alkaline complexes in the Deccan Province, Phenai Mata, occurring to the north of Murud has an Ar-Ar age of 64.96±0.11 Ma (Basu et al. 1993) coeval with the Murud lamprophyre. Further north, those at Mundwara and Sarnu have Ar-Ar plateau ages of 68.53±0.16 Ma and 68.57 ± 0.08 Ma respectively (Fig. 3). The age of trachytes of Mumbai varies between 61.8 and 60.4 Ma (K-Ar age 61.5±3 Ma, original age reported by Rama, 1964 is recalculated by Vandamme et al. 1991 using new decay constants; Ar-Ar age 61.8-60.4 Ma, Sheth et al. 2001) (Fig. 3). These ages put together suggest progressive younging of alkaline magmatism from north to south, within the Deccan Province, consistent with rapid northward migration of the Indian plate over the Réunion plume during that time.

Initial $^{87}Sr/^{86}Sr$ isotopic compositions of alkaline, ultrapotassic and basic suites of dykes from Kalyan vary between 0.7038 and 0.7041 (Fig.1&3). These initial Sr compositions overlap with not only the isotopic composition of the Murud lamprophyre dyke (0.7040), but also the earlier reported alkaline intrusives from the Trombay Hill (Mumbai, Fig. 3) (0.7042, Mahoney et al. 1985) and Salsette Island (Mumbai, Fig.3) (~0.704, Lightfoot et al. 1987). Interestingly, the initial Sr compositions of all these dykes in and around Mumbai are similar to the flows of Ambenali Formation (about 0.7039-0.7041, Mahoney et al. 1982; Cox and Hawkesworth, 1985) which are considered to be the least contaminated of all the Deccan flows, and also the Réunion island basalts (about 0.7040, Fisk et al. 1989).

Of the alkaline complexes north of this region, the Phenai

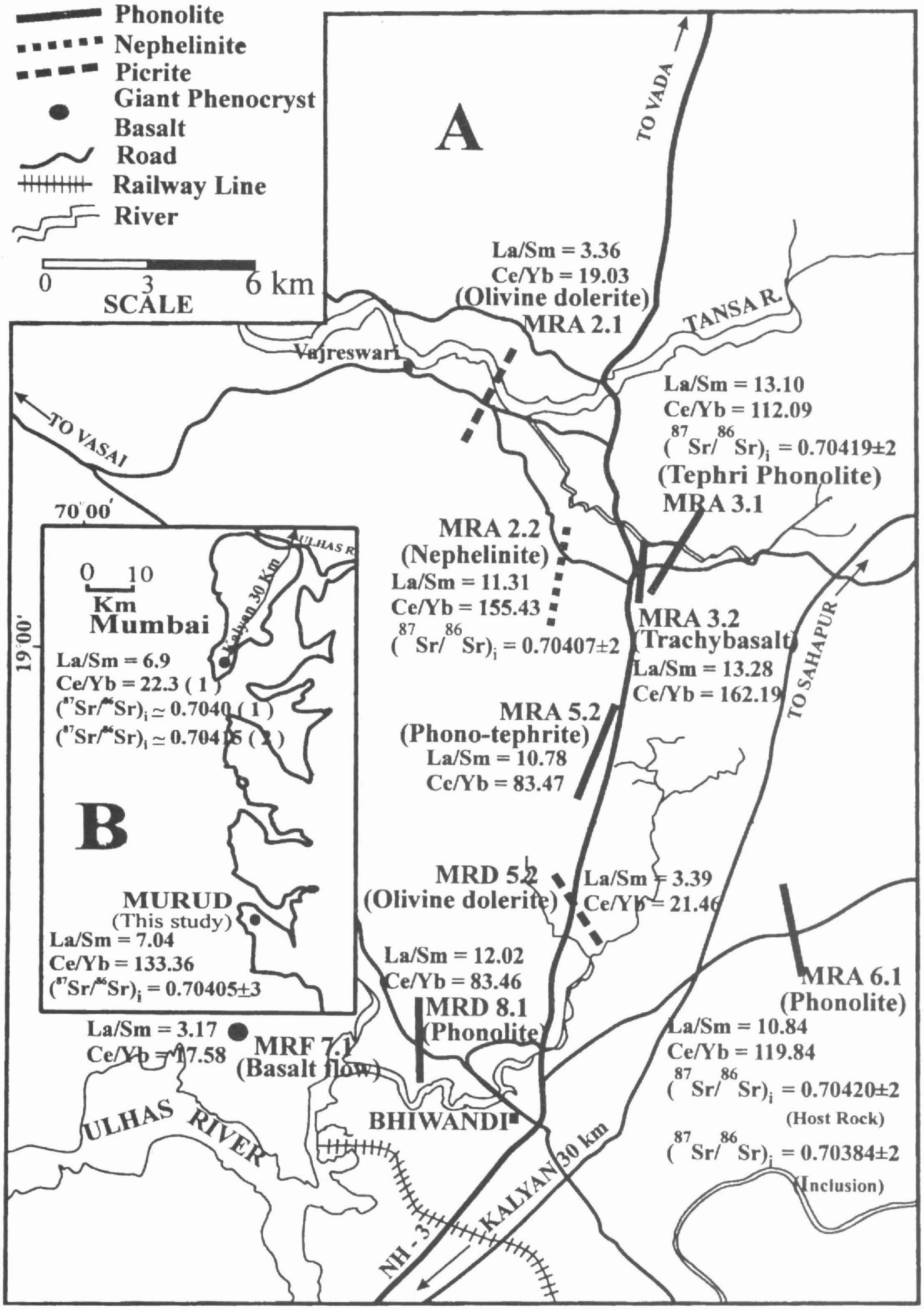

Fig.1. Location of dykes in and around Mumbai. **A.** Dykes of varied composition from Kalyan region are shown with selected REE ratios and initial Sr isotopic composition (This study). Note one of the phonolite dykes (sample # MRA 6.1) and its associated basic inclusions show narrow range of initial Sr isotopic composition (0.70420- 0.70384). Dykes (straight line) and flows (filled circle) are not shown to scale. **B.** Alkaline dykes occur in parts of Mumbai City and south of Mumbai City around Murud. Selected REE ratios and initial Sr isotopic composition are shown in the figure. Reference for Mumbai trachyte (1): Lightfoot et al. (1987); Mumbai (Trombay) lamprophyre (2): Mahoney et al. (1985); Murud lamprophyre (this study). Elemental concentrations are obtained on ICP-MS at Royal Holloway, University of London (Thompson and Walsh, 1989).

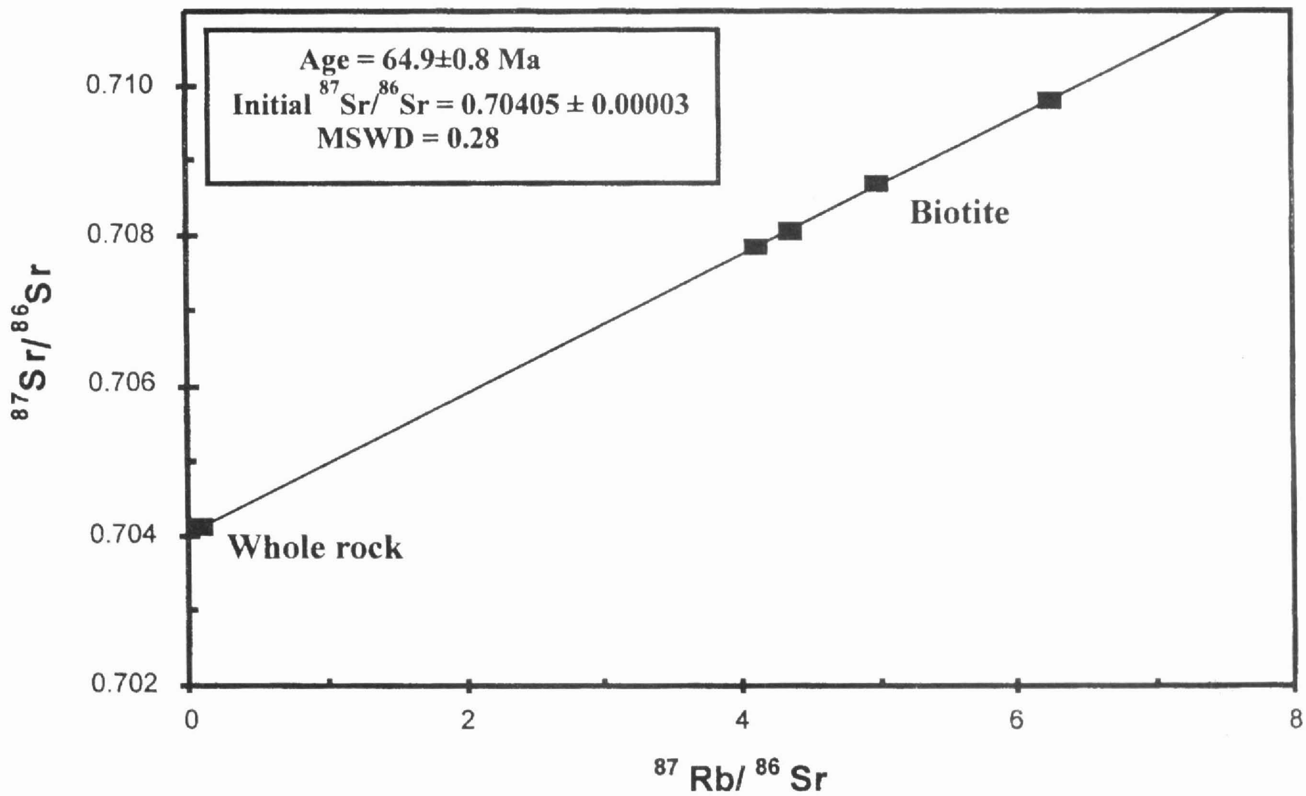

Fig.2. Rb-Sr isochron for biotites and whole rock for Murud lamprophyre (*see* Fig. 1B and 3 for location). Rb-Sr dating was carried out using VG354E Thermal Ionization Mass Spectrometer in a single collector mode at the National Geophysical Research Institute, Hyderabad (*see* Kumar et al. 1998 for details of analytical procedure).

Mata complex, though coeval with the Murud lamprophyre, bears a considerably more enriched Sr (0.7069) and Nd (ε_{Nd}-15 to -5) isotopic composition (Basu et al. 1993). This has been explained as due to crustal contamination. The older complexes at Mundwara and Sarnu also show enriched Sr isotopic compositions of 0.7045 and 0.7050 respectively (Basu et al. 1993). But, with their $^3He/^4He$ ratio of 12.8 (Sarnu) and 13.9 (Mundwara) times that of the air ratio and typical mantle like $\delta^{18}O_{SMOW}$ value of + 6.1 per mil, the enriched Sr isotopic compositions of these complexes are believed to reflect the compositions of their mantle source (Basu et al. 1993).

The dissimilar isotopic compositions of alkaline complexes from the two regions might suggest their derivation from different sources. Alternately, the difference in isotopic composition perhaps reflects the heterogeneous nature of the Réunion plume, or simply the temporal variation of these alkaline lavas resulting from an evolving plume source. The higher Sr ratios at Sarnu and Phenai Mata could also be produced from melting of incompatible element-enriched, veined or plum-pudding type mantle source as suggested by Niu et al. (2002), Halliday et al. (1995) and Sun and Hanson (1975). However, Murud and Kalyan dykes have isotopic compositions similar to the pristine plume compositions (Deccan-Ambenali flows and Réunion basalts) and hence suggest their positive genetic connection.

Trace Element Geochemistry

La/Sm ratio varies between 3.17 and 3.39 in the tholeiitic rocks, while the alkaline suite displays higher ratios (7.04-13.32) (Fig. 1A & 1B). Mantle-normalized elemental spider plots are subparallel with two distinct populations (Fig.4) marked particularly by high Ba, Th, Nb, and REE for the alkaline suite. Alkaline dykes also show high Nb/La (> than 2) suggesting least contamination.

Two of the high magnesian olivine dolerites (Kalyan) (~14% MgO) have low Nb/La (< 1.0) with large negative Eu anomalies (15-17 %). The negative Eu anomaly could be either due to strong alteration or involvement of crustal component in the magma generation/differentiation. These low alkali picrites are strongly Al depleted and have strong HREE depletion, suggesting a large amount of garnet in the residue, and at the same time have low abundance in REE

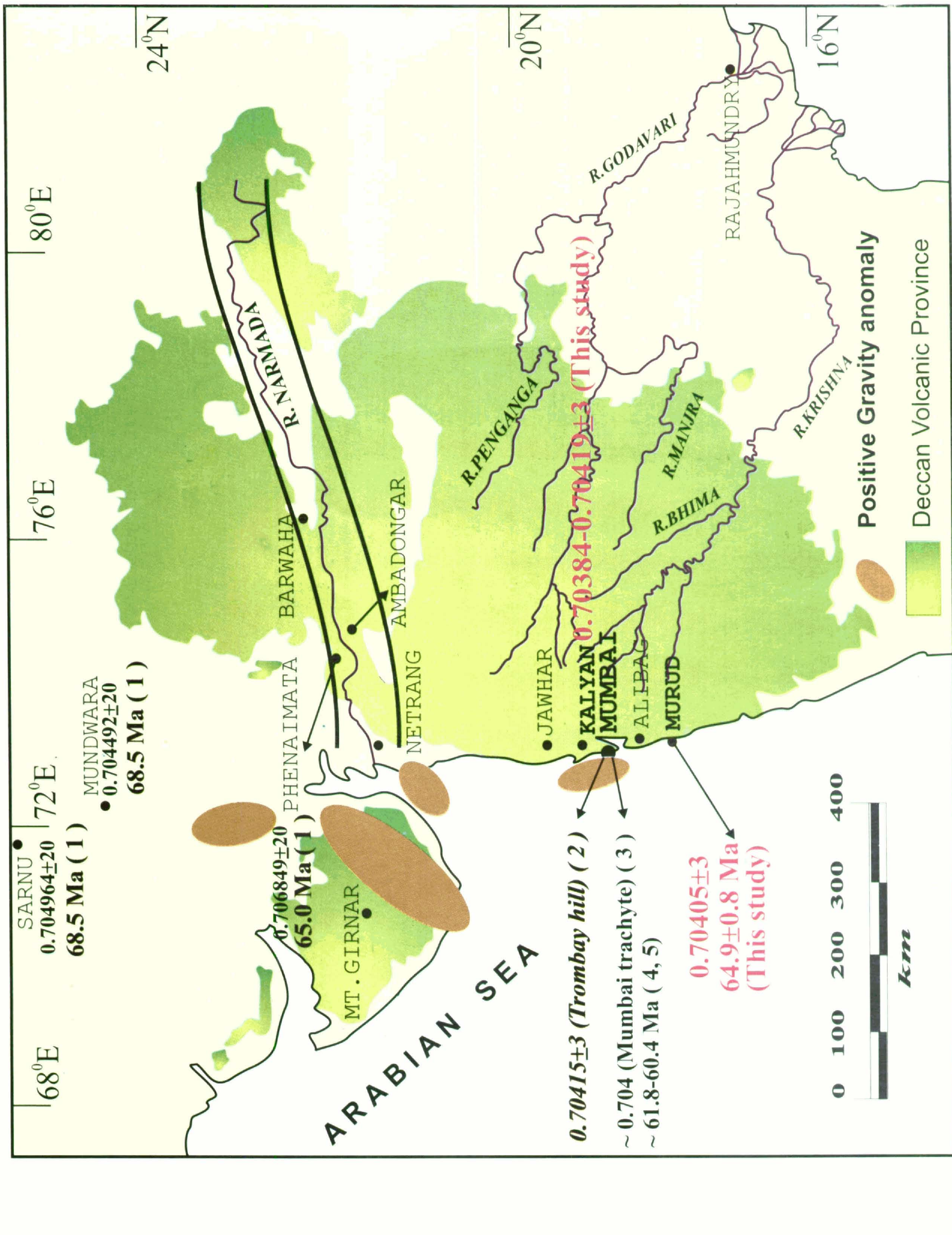

Fig.3. Location of selected alkaline complexes from the Deccan Basalt Province with their age and Sr isotopic composition $(^{87}Sr/^{86}Sr)_i$. References (1): Basu et al. 1993; (2): Mahoney et al. 1985; (3): Lightfoot et al. 1987; (4): Rama. 1964; (5): Sheth et al. 2001.

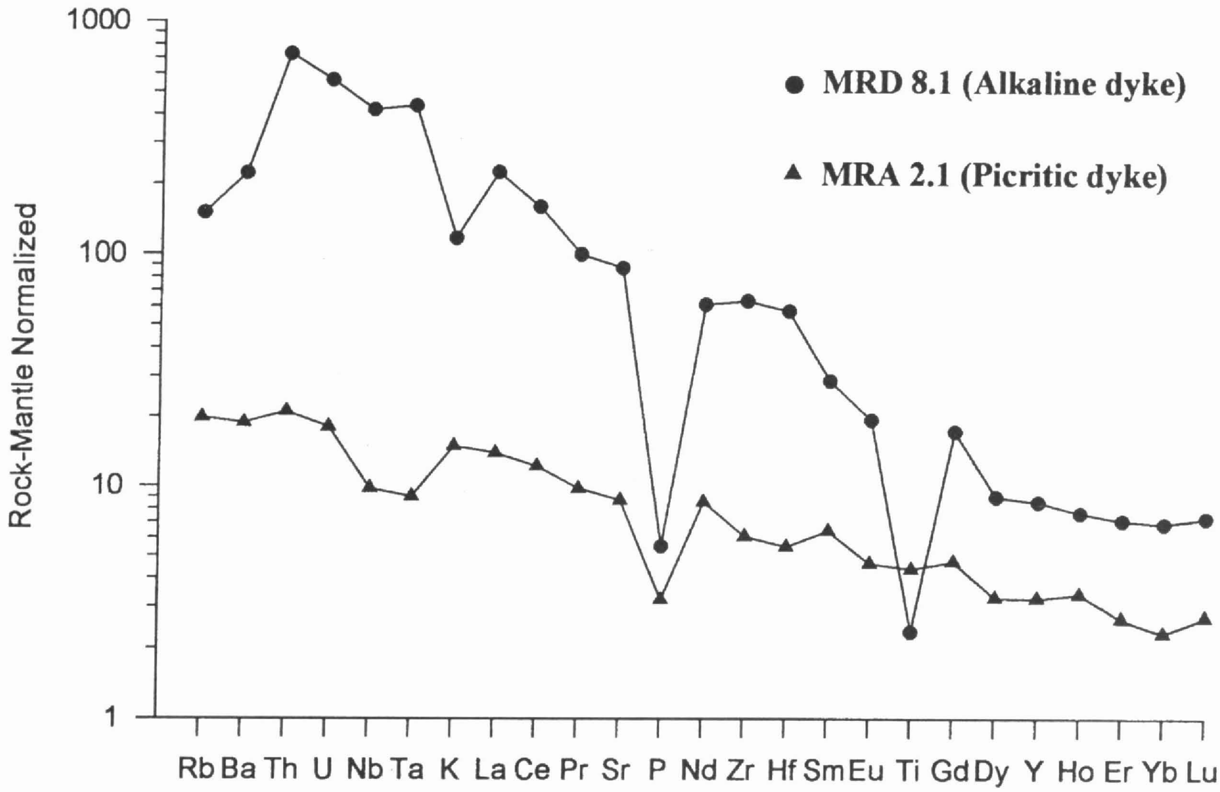

Fig.4. Mantle normalized (after Sun and McDonough, 1989) elemental patterns for representative picrite and alkaline rock from Kalyan area (this study). See Fig.1 for location of sample sites.

and Zr suggesting a large degree of mantle melting. In comparison with the NW Deccan borehole picrites (Peng and Mahoney 1995; Subbarao 2000; K.V. Subbarao and J.N. Walsh, unpublished data), these picritic dykes show lower abundance in REE and Zr concentration.

When the lithospheric lid becomes thinner and thus magma separation depths become shallower (say, 25 Kb), the final pooled degrees of melting become larger and normative olivine content (~25%) in the melt becomes less, and then we could have picrites produced from mantle plume. At 25 Kb depth, small degree of melting at lower temperature (~1300°C) in the normal asthenospheric mantle would produce nephelinite, which does not require to have plume connection. On the other hand, since plume head could have entrained a large amount of cooler upper mantle material, it is not impossible to generate some alkaline rocks, which have plume connection, under a thick lithospheric lid of about 100 km. It is quite possible that the picritic, alkalic and ultrapotassic dykes close to Mumbai having similar Sr isotopic compositions to Réunion and Deccan pose a connection to the Réunion plume. Further, the Sr isotopic data of the dyke rocks also seem to reflect mixing of Réunion plume with the asthenospheric mantle under the Indian continent as observed in samples of the Ambenali Formation (~ 0.7039-0.7041) (Peng and Mahoney, 1995). In the light of geophysical and petrological synthesis on mantle plume and flood basalts given in the benchmark contribution of White and McKenzie (1995), the genesis of the dykes under study and their implications to the evolution of the Deccan Volcanic Province including the Deccan-Réunion plume connection will be discussed in another paper.

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