Abstract

Deccan Traps (India) are one of the most important large igneous provinces in the world. This province is mainly constituted by tholeiitic lava flows, and it is characterised by the presence of alkaline and carbonatite bodies. I investigate the relationship between alkaline and tholeiitic magmatism and their mantle sources in the northern Deccan through Sr-Nd-Pb isotope and trace element contents.

Plotting \(^{143}\text{Nd}/^{144}\text{Nd}\) vs. \(^{87}\text{Sr}/^{86}\text{Sr}\) compositions, samples describe two trends, both departing from the most primitive composition: one trend points toward low \(^{143}\text{Nd}/^{144}\text{Nd}\) and \(^{87}\text{Sr}/^{86}\text{Sr}\), the other toward high \(^{87}\text{Sr}/^{86}\text{Sr}\) and low \(^{143}\text{Nd}/^{144}\text{Nd}\). This suggests, in agreement with what has already been observed for lava flows, that the mantle-derived magmas have been contaminated by two different crustal endmembers whose contribution will be determined through the assimilation-fractional crystallization modeling.

Introduction

Large Igneous Provinces (LIPs) form both on continents and oceans and are characterized by huge volumes of magma (>1 Mkm\(^3\)) and large eruption rates, with eruptive pulses of few hundred years. They are formed mainly by low viscosity basaltic lava flows, thus able to cover long distances. Tholeiitic basalts are the predominant magma type, but alkaline types and more evolved differentiates are also present. They have been recognized in several LIPs, such as Deccan Traps (India), Karroo (S Africa), Paranà-Etendeka (Brazil-Namibia).

One of the world’s most important LIPs, the Deccan Traps in India, is mainly constituted by tholeiitic lava flows, which presently cover 0.5 Mkm\(^2\) and reach the maximum thickness of almost 2000 m (Mahoney, 1988), and are therefore the most studied portion. They have been divided into 11 formations where four of them define end-member isotopic trends which are followed by the other formations. The Ambenali fm. is characterized by low Ba, Rb, Sr, TiO\(_2\) and K\(_2\)O contents and low Zr/Nb, Ba/Y ratios, low \(^{87}\text{Sr}/^{86}\text{Sr}\) and high \(\varepsilon_{\text{Nd}}\), and therefore it is thought to be the least contaminated formation. From its isotopic composition two trends depart toward low and relatively high \(^{87}\text{Sr}/^{86}\text{Sr}\), respectively. The first trend is defined by the Mahabaleshwar fm. which consists of basalts with higher Ba, Rb, Sr and K\(_2\)O with respect to the Ambenali formation, higher \(^{87}\text{Sr}/^{86}\text{Sr}\) and lower Zr/Nb and \(\varepsilon_{\text{Nd}}\). The second trend is described by the Poladpur and Bushe formations. The first one has high Ba, Rb, K\(_2\)O and SiO\(_2\) contents, high Zr/Nb and high \(^{87}\text{Sr}/^{86}\text{Sr}\), and low Sr, and \(\varepsilon_{\text{Nd}}\); whereas the Bushe fm. is considered the most contaminated one in that it has low Nb, Zr, Sr and TiO\(_2\), very high \(^{87}\text{Sr}/^{86}\text{Sr}\) (>0.710), Ba, Rb and K\(_2\)O.

The isotopic characteristics together with trace elements suggest that the Ambenali formation is substantially uncontaminated; the Ambenali-Poladpur-Bushe trend may be due to temperature-controlled assimilation Archean granites which explains the higher contamination of the most mafic compositions; and the Mahabaleswar trend suggests an involvement of a mantle enriched in large-ion lithophile elements (LILE), being the crustal contamination almost insignificant (Cox et al., 1984).

This study focuses on the northern Deccan where several alkaline bodies outcrop in close association with tholeiitic flows and dykes. The alkaline magmatism represents early and late phases of the Deccan magmatism (Basu et al., 1993), and its generation is associated with four main fault regions. The Cambay graben is a N-S extensional structure in the northern part of the province, and two complexes are associated with it: Samu-Dandali and Mundwara in Rajasthan state; in the Kutch peninsula the complexes (Mount Girnar and plugs of alkaline olivine basalt) are associated with the Kutch rift departing the Cambay basin and extending to the W; the Narmada valley is a W-E rift that extend from the Cambay basin to the eastern part of the province and along it many alkali-carbonatite bodies outcrop: Phenai Mata,
Amba Dongar, Netrang in Gujarat state, and Barwaha in Madya Pradesh; the Jawahar Nepheline Syenite (near Mumbai) is linked to the Western Gaths, on the western coast of India. The generation and evolution of the alkaline complexes will be constrained through a geochemical and geochronological study in order to define their relationship with the more abundant tholeiites and provide a model for the evolution of the whole province.

63 sample were collected in a region of alkaline bodies, 400km north of Mumbai. The Amba Dongar sector is a carbonatite-ring complex intruded by ferrocarbonatite plugs and dykes and cored by basalt (Simonetti et al., 1995); 2) the Siriwasan-Dugdha sector contains trachytic rocks and phonolites; 3) the Phenai-Mata sector shows an association between alkaline rocks and a layered tholeiitic intrusion constituted by a layered gabbro associated with anorthosite, granophyre, nepheline syenite and dolerite (Sukheswala et al., 1973); 4) the Panwad-Kanwant sector is mainly characterized by syenites, phonolites and lamprophyres which form plugs and EN or WNW striking dykes; 5) the Bakhatgarh-Phulmahal sector contains basic and ultrabasic dykes (dolerites and picrites) mostly with EN trend.

50km east of the Amba Dongar area, the Rajpipla area shows a similar succession with early tholeiites (lava flows) overlain by K-rich alkaline flows, in turn cut by late tholeiitic dykes (Krishnamurty et al., 1980). Mount Pavagadh is the northernmost sampled area (50km NE of Phenai Mata) and consists of a 550m thick sequence of basaltic lavas overlain at the top by rhyolitic lavas with a thin layer of pitchstone. XRF whole-rock analyses have revealed a high variability in the composition of the sampled rocks. SiO$_2$ contents vary from 43wt% to 79wt%, whereas MgO varies 17wt% to near-zero. Samples are mainly potassic (Na$_2$O-K$_2$O<2.0wt%). On the basis of the total alkali content, and according to Gwalani et al. (1993), samples have been divided into three series: alkaline, tholeiitic and transitional series. SiO$_2$ and Na$_2$O vs. MgO show a negative correlation, the tholeiitic samples are enriched in SiO$_2$, and the alkaline ones in Na$_2$O. Alkaline samples are also enriched in Ba and Sr with respect to the tholeiitic samples.

**Second year activity**

In the second year of my Ph.D. I carried out several analyses on both whole rocks and mineral phases.

Mineral phase compositions were measured by means of electron microprobe. Given the huge variety of collected lithologies, also a large variety of compositions can be observed in mineral phases. Crystals of olivine, clinopyroxene, plagioclase, amphibole, biotite were analysed.

Plagioclases show a wide range in An content, varying from the most albitic terms (Ab$_{60}$), to the most anorthitic ones (An$_{90}$), but a common characteristic in most samples is a reversed zoning indicative of crystal growth reflecting magma mixing, with late arrival of little evolved magmas in particular.

Clinopyroxenes (cpx) also show compositional evolution starting from the most primitive sample with Mg# (Mg# = 100*Mg/(Mg+Fe$^{2+}$)) up to 98, typical of mantle peridotite diopsides, to the most evolved crystals with Mg# of 65. Starting from cpx compositions, and comparing them with the whole rock ones, temperature and pressure were calculated by means of the geothermobarometer of Putirka (2003). Many of the samples don’t show equilibrium compositions between cpx and whole rock, and thus they don’t provide reliable values of these parameters. Only three samples yielded reliable pressure estimates from 7 to 13kbar and temperatures from 1100 to 1270°C.

The compositional range in olivines varies from Fo$_{87}$ to Fo$_{62}$.

ICP-MS analyses on 40 samples were performed at the Department of Earth Sciences of the University of Ferrara for the determination of trace element contents. The alkaline samples have the highest La/Yb ratio (13.76-71.64), the tholeiitic ones on average have intermediate values (3.27-41.81), whereas the transitional series show the least differentiated samples (La/Yb from 6.64 to 10.77, with an outlier at 38.70). Ba, Sr and Nb show similar behavior being more abundant in the alkaline series (up to 3500, 3800 and 725ppm, respectively), than in the transitional (ca. 600, 900 and 120ppm, respectively), and tholeiitic ones (192-1869, 25-755 and 12-183ppm, respectively). Considering Primitive Mantle (PM) normalized patterns, alkaline samples show negative K anomalies, and slightly negative Sr and Ti anomalies; tholeiites are characterized by negative HFSE (high field strength elements) anomalies (Zr, Hf, Nb, Ta), whereas transitional samples show a positive Ti anomaly.
After careful handpicking, 30 samples for isotope analyses were processed and analyzed at the University of Geneva by means of a Neptune Thermo Scientific multicollector ICP-MS. In agreement with what has already been observed for tholeiitic Deccan lava flows, age corrected (t=66Ma) isotopic compositions \(^{143}\text{Nd}/^{144}\text{Nd}\) vs. \(^{87}\text{Sr}/^{86}\text{Sr}\) describe two trends, both departing from the most primitive composition \((^{143}\text{Nd}/^{144}\text{Nd} = 0.51270 \text{ and } ^{87}\text{Sr}/^{86}\text{Sr} = 0.705238)\): one trend points toward low \(^{143}\text{Nd}/^{144}\text{Nd}\) at relatively low \(^{87}\text{Sr}/^{86}\text{Sr}\) (0.51189 and 0.710612, respectively), the other toward high \(^{87}\text{Sr}/^{86}\text{Sr}\) (0.727880) and low \(^{143}\text{Nd}/^{144}\text{Nd}\) (0.51191). Tholeiites belong to both trends and show the widest range of composition, \(^{87}\text{Sr}/^{86}\text{Sr}\) varying from 0.706248 to 0.727880, and \(^{143}\text{Nd}/^{144}\text{Nd}\) from 0.51260 to 0.51189; alkaline samples mostly belong to the first trend, and the transitional samples present almost constant \(^{87}\text{Sr}/^{86}\text{Sr}\) and variable \(^{143}\text{Nd}/^{144}\text{Nd}\) (from 0.51225 to 0.51272).

Pb isotopic compositions plot well above the North Hemisphere Reference Line (NHRL); tholeiitic samples have the most radiogenic compositions both in \(^{207}\text{Pb}/^{204}\text{Pb}\) and \(^{208}\text{Pb}/^{204}\text{Pb}\), whereas the transitional series presents the least radiogenic compositions. Among tholeiitic samples, two different groups can be recognized: the first points towards high \(^{206}\text{Pb}/^{204}\text{Pb}\), high \(^{87}\text{Sr}/^{86}\text{Sr}\) and low \(^{143}\text{Nd}/^{144}\text{Nd}\), whereas the second one points toward low \(^{206}\text{Pb}/^{204}\text{Pb}\) and high \(^{143}\text{Nd}/^{144}\text{Nd}\) and little lower \(^{87}\text{Sr}/^{86}\text{Sr}\) with respect to the first group. Alkaline and transitional series don’t show any particular trend. These features suggest that at least two different compositions, together with the most primitive one, have been involved in the evolution of the samples, one may be related tentatively to a crustal endmember, and the other to a continental lithosphere composition.

These processes will be investigated through the modeling of assimilation-fractional crystallization process taking into account the compositions the local crustal rocks.

**Next year activity**

In order to further constrain the mantle source of the rocks, Os isotope compositions will be determined at the Curtin University, Perth (Australia). The difference between the mantle \(^{187}\text{Os}/^{186}\text{Os}\) ratio and that of the crust is higher than those in Rb-Sr and Sm-Nd systems, and this makes Re-Os system an efficient tool in discerning crustal contamination processes, furthermore it allows the involvement of old lithospheric mantle to be distinguished.

\(^{40}\text{Ar}/^{39}\text{Ar}\) dating will be performed on 11 selected samples in order to provide the precise timing of emplacement of the Deccan Traps, to determine the geodynamical evolution of the province in terms of its motion over the Reunion hotspot, and to establish the correlation with it and the K/Pg mass extinction. Mineral separation has already been done, and the separates sent to the laboratory have been irradiated in a nuclear reactor.

**References**


**SUMMARY OF ACTIVITY IN THIS YEAR**

**Courses:**


R. J. ANGEL: “Scientific communication”, Dipartimento di Geoscienze, Università degli Studi di Padova.

**Lab activity:**

Hand picking of samples for Sr-Nd-Pb isotope analyses, Dipartimento di Geoscienze, Università degli Studi di Padova.

Preliminary preparation for Sr-Nd-Pb isotope analyses, Department of Mineralogy, University of Geneva (CH).

Hand picking of mineral separates (plagioclases, amphiboles and biotites) for ⁴⁰Ar/³⁹Ar dating, Dipartimento di Geoscienze, Università degli Studi di Padova.

Electron microprobe analyses.