CHAPTER-2
DECCAN TRAPS
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2.1 Introduction

Deccan traps of India represent one of the largest and best-exposed continental flood basalt (CFB) provinces of the world (Sheth 1999; Subbarao 1988). The term “Deccan Trap” was coined by Sykes (1833) derived from a Sanskrit word “Dakshin” meaning south or southern while a Swedish word “Trapp”/“Trappa” means stair or terrace has given to describe prominent terraced topography of this terrain (Fig. 2.1, a-b). This volcanic province either called as Deccan Volcanic Province” (DVP) or simply the "Deccan traps formed by the eruption of enormous volume of basaltic has been erupted lava in comparatively short period covers much larger than 50,000 km² and these lava piles formed the plateau topography of the province. Deccan traps are considered as most extensive geological formation subsequent to Igneous and Metamorphic complex, Archaean era in Peninsular India. These flood basalts attracted the attention of several authors from worldwide are of global significance mainly due to the enormous volume of the erupted lavas could have exceeded 2 million and timing of eruption duration that overlapped the K-Pg boundary and related their origin to global tectonics (Mahoney 1988; Duncan and Pyle 1988; Courtillot et al 1988). Among five continental flood basalt that witnessed Indian subcontinent from the Middle Proterozoic to the Late Cretaceous-Early Tertiary Period (Siberian Traps (Permo-Triassic), the Karoo volcanics (Triassic Jurassic), the Parana Basalts (Jurassic-Cretaceous), the Deccan traps (Late Cretaceous-Early Tertiary), the Ethiopian Traps (Oligocene-Miocene) and the Columbia River Basalt Group (Middle Miocene). The Deccan CFB event was youngest and believed to be nearly associated with the east-west extension and rifting along the west coast of India from that led finally into the breakup of the Seychelles microcontinent (~64Ma) (Hooper et al 2010 and references therein). Eruption of the Deccan volcanism lasted for ~5Ma, between 63 and 68Ma ago, with a maximum eruption rate around 66-65 Ma ago (Baksi 1994; Pande 2002; Hooper et al 2010 and references therein) which overlapped the Cretaceous/Tertiary Boundary mass extinction (65·96 ± 0·04Ma) which may together may have caused the most severe biotic changes (Courtillot et al 1986, 1988; Duncan and Pyle 1988; Alvarez 2003 and references therein). In addition, Deccan intertrappean deposits of Cretaceous age further evidencing its role in triggering K-Pg mass extinction (Keller et al
2009 and references therein). Deccan volcanism was believed to be occurred when India was located in the Indian Ocean where Reunion is presently situated (Mahoney 1988). However, some authors considered Reunion hotspot is to be responsible for the Deccan Trap flood basalt and the major activity occurred at the K-Pg boundary that has been fixed at 64.5 ± 0.3Ma (Baksi 1994). It has been reported that gases released during Deccan basalt volcanism (mainly volcanogenic CO$_2$, SO$_2$) may have changed the global climate and leads to the global greenhouse effect, this is reflected in accelerated chemical weathering (Dessert et al 2001 and references therein) possibly linked with sudden catastrophic K/Pg mass extinction (McLean 1985; Courtillot 1990; Ravizza et al 2003 and references therein). Recently, it has been postulated that enormous Deccan volcanic eruption might have been triggered by Chicxulub impact (Richards et al 2015). However, the exact cause, duration of eruptive pulses of this major volcanic event and its impact on the global climate is still controversial. Earlier the eruption of Deccan trap basalts were considered as a product of fissure eruption, later detailed field observations suggested that most of the lavas are the likely to be results from the central type of volcanic eruptions (Agashe and Gupta 1971).

Fig. 2.1 (a-b) Field photographs of Deccan trap at Western-Ghats-Matheran and Mahabaleshwar and, India showing well exposed multiple layers of flood basalt imparting stairs or terraced topography to this terrain. (Source: https://upload.wikimedia.org/wikipedia/commons/c/c8/Western-Ghats-Matheran.jpg, and http://www.worldaroundus.org.uk/images/zoom/?id=454 accessed on 07/04/2016).
2.2 Distribution

Deccan traps considered among one of the Large igneous province (LIP) (Coffin and Eldholm 1994, 2005 and references therein) with a present day areal extent of 500,000 km² assuming original lava volume \((1-3) \times 10^6 \text{ km}^3\) (Wadia 1975; Sen 2001; Jay et al 2009) which marks the first surfacial expression of the Reunion hotspot on the on the Indian subcontinent (Vandamme et al 1991) north-western, central, and southern Indian Peninsula. However, an original extent of the lava pile prior to erosion and possible down-throw on the western side into the Arabian sea are estimated to be the order of 1 to 1.5 million sq.km (Krishnan 1953). Eruption of such enormous volume of basaltic has been erupted lava that covered hundreds of square km forms the plateau topography of Deccan traps. Based on lava occurrence the (DVP) geographically, divided into various subprovinces- the main Deccan Province covers the state of Maharashtra, Karnataka, A.P., the Malwa Traps occurring in Malwa region of M.P, the Mandla Traps occupies Mandla region of M.P. and the Saurashtra and Kutch Traps covers the Saurashtra region of Gujarat. Deccan traps consists of thick sequence of flat lying basalt currently spread nearly an area of over 5,00,000km² of west central India (Beane et al 1986) including continuation beyond Arabian sea (Krishnan 1953). In Western and Central India, DVP distributed mainly in the states of Maharashtra, Madhya Pradesh, Karnataka, Gujarat, and Andhra Pradesh and also has its nominal presence in southern parts of Uttar Pradesh and eastern parts of Rajasthan shown in the Fig. 2.2. The classification of Deccan lavas has been done based on the area of occurrence into four classes: Malwa Trap: exposed in Malwa region of Madhya Pradesh, Mandla Traps: occurring in Mandla region of Madhya Pradesh, Saurashtra Trap: occurring in Saurashtra region of Gujarat and Main Deccan plateau: occurring in States of Maharashtra, Karnataka and Andhra Pradesh (Fig. 2.2) (Bodas et al 1984; Beane et al 1986; Subbarao 1994 and references therein).
Fig. 2.2 Map showing areal extent of Deccan traps showing Malwa Trap: exposed in Malwa region of Madhya Pradesh, Mandla Traps: occurring in Mandla region of Madhya Pradesh, Saurashtra Trap: occurring in Saurashtra region of Gujarat and Main Deccan plateau: occurring in States of Maharashtra, Karnataka and Andhra Pradesh and additional exposures in Kachchh and Rajasthan and under the Arabian Sea offshore western India, as well as Rajahmundry on the southeastern Indian coast and also subsurface exposures Deccan rocks. Note the major geographic divisions and geological features of the Deccan province are shown, and all localities mentioned in the text and some others are marked (Map modified after Seth 2016).
2.3 Age

Deccan volcanism were likely to be occurred in two phases with a maximum eruption rate at around 66-65Ma ago (Courtillot et al. 1988; Duncan and Pyle 1988; Venkatesan et al. 1996; Sheth 2000; Pande 2002) which overlapped the K-Pg boundary (65.96 ± 0.04Ma; Kuiper et al. 2008) and lasted for ~5Ma, between 63 and 68Ma ago. However, the exact cause and age of Deccan basalt eruption is still under discussion. Some authors considered Reunion hotspot is to be responsible for the Deccan Trap flood basalt and the major activity occurred at the K-Pg boundary at around 64.5±0.3Ma (Baksi 1994) while K-Ar ages show a spectrum between 80-30 Ma, 87Sr/86Sr ratios of the basalts showed corrected age to 66 Ma( Peng et al 1994) and 40Ar-39Ar ages give a mean age of 65 40Ar-39Ar and recent Re-Os geochronology coupled with palaeomagnetic and palaeontological studies suggest that the Deccan Traps were erupted around the K-Pg boundary 65.5 Myr ago with quite short on a geological time scale, spanning less than 1 Myr (Haggerty 1996; Courtillot et al. 2000 and references therein) when the Indian plate was moving northwards i.e. during early Paleocene 29R-N magnetic reversal (Vandamme et al. 1991; Jay et al. 2009). In addition, Chenet et al. (2007) recognized three main phases of Deccan volcanism based on 40K-40Ar radiometric dating with major eruption occurred during phase1 near about 2 Ma which is closer to the K-Pg boundary, while second phase occurred just before and ended at the K-Pg boundary (Keller et al. 2012) and Phase 3 was believed to be erupted ~2-300ka and therefore post-dates the K-Pg boundary. Recently it has been postulated that enormous Deccan volcanic eruption might have been triggered by Chicxulub impact (Richards et al. 2015).

2.4 Origin

Origin of Deccan volcanic province has been still under discussion for concerns whether the magmas formed by melting a giant mantle plume, normal plate tectonic processes, or impact of a large extraterrestrial bolide (Mahoney 1988; Richards et al. 1989; Chandrasekharan and Parthasarathy 1978; Chatterjee and Rudra 1992; Sen 1995; Sheth 2005a, b). There are several opinions regarding the origin of Deccan flood basalt province. Morgan (1972, 1981) for the first time proposed deep mantle plume model flood basalt volcanism. Some authors proposed have
long been considered to be a product of Reunion plume-Indian lithosphere interaction, about 65Ma ago. Mantle plume initiation model for the origin of Deccan Traps of India, one of the largest and best examples of CFBs in the world has been widely accepted (Sheth 2005 and references therein). This model suggests that mantle plumes initiates intraplate, “hotspot” volcanism - abnormally hot upwellings that originate at the core-mantle boundary and has been largely based on fluid dynamical experiments, which show that plume head produces voluminous flood basalts whereas a plume tail produces hot picritic melts. Sheth (2005) suggested that the mantle source of the such voluminous Deccan lavas was not only peridotite but also included a basaltic component (predominantly eclogite) while some have suggested that Deccan volcanism results from mantle plume activity formed by melting a giant “plume head” that rose from the core–mantle boundary (Richards et al 1989; Duncan and Richards 1991). However, this model has been objected due to various reasons. While Chandrasekharam and Parthasarathy (1978) proposed a model of shallow mantle melting in which the preexisting rift zones were reactivated and magma simply poured out of fissures. Most of the field evidences showed that the eruption of Deccan basalts occurred largely through fissures in the crust while Seth (2005) has been suggested that the Deccan Traps were erupted along rift zones and a new continental margin that had developed along ancient suture zones traversing the subcontinent. Subsequently, non-plume, plate tectonic model has been proposed for Icelandic hotspot volcanism suggested melting of a shallowly recycled eclogitized Iapetus oceanic crust formerly trapped along the Caledonian suture (Foulger 2002; Foulger et al 2005). The model enlightens the geochemical-petrological characteristics of Icelandic basalts, and is consistent with passive upper mantle upwelling under Iceland inferred from recent seismic tomography. Eruption of the Deccan volcanism lasted for ~5Ma, between 63 and 68 Ma ago, with a maximum eruption rate around 66-65Ma ago (Pande 2002). Earlier proposed models suggested that lava erupted at extremely rapid rates while recently models showed that at least some of the flows are emplaced at gradual rates, lasting months to years.

2.5 Geology

Deccan volcanic Province (DVP) overlie the Precambrian basement of cratons and mobile belts of the Indian Shield consists of several lava flows of varying thickness variable due to
undulating nature of the emplaced surface ranging from few meters (7m) to as much as 40m maximum and can be mapped out nearly up to distance of 20km with a partial intrusions and recent black soil at some places (Karmarkar 1974 and references therein). The Deccan basalt sequence is thin (~500m) along its margins, and it apparently thickens towards its centre. In particular, it is ~4km thick along the Narmada-Son region that forms a part of the Central Indian Tectonic Zone. The detailed account on the geology of DVP has been discussed by Subbarao (1999). DVP is predominantly composed of nearly flat tholeiitic basalts in the south and southeast (Chatterjee and Rudra 1992 and references therein), while variable volumes of alkaline and tholeiitic in the west and northwest with minor amounts of alkaline and picritic basalts (Krishnamurthy and Cox 1977; Bose 1980; Vandamme et al 1991; Subbarao 1999). However, some authors have suggested Western Ghats sequence is almost exclusively tholeiitic (subalkalic), with a stratigraphic thickness of ~3,000m, and on the basis of geochemical characteristics and field markers, has been divided into three subgroups and eleven formations. Field observations showed two types of lava flow such as “simple” and “compound” (pahoehoe or ropy lava and the aa or block lava) (Nicholas 1969; Walkar 1993) at some places has been attributed to fissure eruptions from apparent feeder dikes in a broad area around Igatpuri (Hooper 1990). Simple lava flows are uniform over a large area and composed of single unit while compound lava flow shows characteristics of pahoehoe or ropy lava. These flows are separated by several inter-flow bole beds, amygdales and Giant Plagioclase Basalt (GPB) horizons. The inter-flow bole beds are commonly red, but also green, brown, or black are also seen up to 2 m thick composed of friable earthy or clayey material possibly represent weathered basaltic flow layers or altered ash layers (Wilkins et al 1994; Widdowson et al 1997). The DVP was divided into three parts based on presence or absence of sedimentary horizons within the lava flows (inter-trappean beds) into upper, middle and lower. In general, compact massive basalt flows are thick and relatively free from vesicles except at the small portion of top and bottom of each flow while undulated basalt flows are vesicular (Doke and Kulkarni 2015). At various locations DVP shows spectacular basaltic and doleritic dykes and dyke swarms mainly north-south-trending west coast swarm, the east-west-trending Narmada-Tapi swarm in the north-central Deccan and the Nasik-Pune swarm in the central western Deccan (Auden 1949; Deshmukh 1988; Misra 2008 and references therein). In addition, several ‘giant plagioclase
basalt’ (GPB) with abundant of plagioclase phenocrysts (upto 5cm in length) in the form lava flows and dikes are also seen (Karmarkar 1974; Sheth 2016).

2.6 Stratigraphy

Deccan traps are thickest and best exposed on western ghat Deccan Volcanic Province (DVP) near Mumbai (Cox and Hawkesworth 1985; Beane et al 1986; Subbarao 1988; Lightfoot et al 1990; Peng et al 1994) with total stratigraphic thickness varies from 2500m to 3,000m (or in fault-bounded grabens in west-central India, but become thinner (less than 100m) close to the margin of the trap province. Approximately ~3.4km thick Deccan basalt sequence (Mahoney et al 2000) on the basis of geochemical characteristics and field markers Stratigraphic sequence of Western Ghats of DVP has been divided into three subgroups: Wai, Lonavala, Kalsubai and eleven flow formations: Panhala, Mahabaleshwar Ambenali, Poladpur, Bushe, Khandala, Bhimashankar, Thakurvadi, Neral, Igatpuri, Jawhar among them the basalts of Ambenali formation are largely exposed on the southern part of the Deccan province (Sheth et al 2004 and references therein).

2.7 Geochemistry

The Deccan lava basalts are predominantly tholeiitic (48-50 wt.% SiO₂) showing normative hypersthene and quartz. However, alkali lavas and intrusions, carbonatite intrusive complexes, and silicic lavas and intrusives also occur (Le Bas et al 1986; Sen 2001 and references therein). While Carbonatites and alkalic lavas, with mantle xenoliths, are commonle restricted to the rift zones located near the peripheries of the Deccan traps. Nearly all Western Ghats lavas are subalkalic basalts to basaltic andesites However, intercalated basalt and picritic basalt flows are also reported from boreholes in the northwestern Deccan (around Botad) suggestive of possibly high-temperature, high-melt fraction picritic liquids derived from the axis of their conjectured plume (Beane and Hooper 1988; Campbell and Griffiths 1990). In general, Deccan basalts showing wide range of compositions not only isotopic ratios but also major and trace elemental content (Mahoney 1988). Detailed geochemical investigations of Deccan basalts from Bijasan Ghat section, Satpura range are relatively evolved, with MgO contents ranging from 3.79 to 7.09 wt.% and Mg numbers (Mg#) ranging from 42.8 to 52.5 which indicates widespread
magma source (Sheth et al. 2004) while that of ambenali and Mahabaleshwar formations showing compositional similarity (Najafi et al. 1981). Likewise, wide range has been reflected in the isotopic as well as major and trace element compositions suggesting various differentiation processes such as fractional crystallization, crustal contamination and accumulation of phenocryst phases (Mahoney 1984; Sen 2001 and references therein). In addition, Sano et al. (2001) classified the Deccan Trap basalts based on their derivatives and/or amount of contamination and also suggested that range of the compositions could also be generated due to addition of magmas derived from shallow level fractionation of continental lithospheric mantle (Sano et al. 2001 and references therein). It has been reported that at some places alteration has possibly caused redistribution of the some mobile elements in some of the samples as K, Rb and often U can be affected at rather modest levels of alteration while Ba and Na can be affected at higher levels (Sheth 2004 and references therein). However, with higher level of subaerial alteration several elements, including Si, Ca, P, Ni, Sr, Y and the lanthanide rare earths elements are also tends to affected, while some such as Al, Nb, Zr, Fe, Cr and Ti are relatively resistant (Mahoney et al. 2000 and references therein).

2.8 Petrology

Megascopically, Deccan trap basalts are compact massive, dark grayish colored partly weathered and some places vesicular/amygdaloidal nature in the field. While petrographically, Deccan trap basalts show characteristic porphyritic to microporphyritic textures with abundance of plagioclase phenocrysts and minor clinopyroxene set in a fine grained groundmass consist of plagioclase, clinopyroxene, glass, often olivine and Fe-Ti oxides (ilmenite, magnetite) with secondary minerals such as zeolites, chlorite, chlorophlaite. Thin section shows sub-ophitic, intergranular and intersertal textures with well twinned mega to microphenocrysts of plagioclase. However, microphenocrysts are usually smaller than 0.25 mm of plagioclase, clinopyroxene and completely altered olivine are seen in small but variable amounts in most of the Deccan trap samples. At places glass has been palagonitized. Fresh and altered grains of olivine are seen in groundmass, altered nature of olivine in the form of iddingsite, antigorite and chlorite are dominating over fresh olivine. The composition of dominant mineral plagioclase varies from An50 to An62, pyroxene of augite and olivine varies from Fo90 to Fo10. Picritic
basalts of the Western Ghats are enriched in cumulus olivine with wide range of compositions, Fo84-43 and clinopyroxene while tholeiites have an average olivine composition Fo77 (Sen 2001 and references therein).