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Combined gravity and magnetic modeling over Pavagadh and Phenaimata igneous complexes, Gujarat, India: Inference on emplacement history of Deccan volcanism

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ABSTRACT

A large number of igneous intrusions related to the Deccan magmatism are exposed in the western and central part of the Indian shield. Gravity and magnetic (G–M) surveys over some of these igneous intrusive bodies depict gravity high and bipolar magnetic anomalies as the most characteristic signatures. The present G–M survey was carried out over the Pavagadh and Phenaimata igneous intrusives. Associated with the Phenaimata complex, Bouguer gravity anomaly shows an elliptical shaped relative gravity high of about 40 mGal and bipolar magnetic anomaly varies from South to North between −800 nT and 1200 nT. The joint G–M modeling reveals the presence of a dense mafic body (2.86 g/cm^3). This body is characterized by a remanant magnetization; the related inclination (I) = ∼44° and declination (D) = ∼160° may correspond with the 29R polarity chron of Deccan magnetostratigraphy. Remanant magnetization together with age data suggest that the Phenaimata igneous intrusive emplaced during the end of the main magmatism phase of Deccan. Over the Pavagadh, a circular gravity and magnetic lows of about −15 mGal and −500 nT respectively is reported for the first time which is surrounded by a gravity and magnetic high of about 30 mGal and 350 nT, respectively. The joint G–M modeling over the Pavagadh intrusive reveals the presence of a deep-seated cone shaped high-density (⩾3.0 g/cm^3) gabbroic body which might extend up to a great depth. Its top surface reaches up to a depth of about 10.0 km. Overlying this body is a low-density (2.40 g/cm^3) rhyolite, which extends up to the surface and is the source for low gravity anomaly. It is surrounded by another high-density (2.89 and 3.02 g/cm^3) mafic bodies with reverse remanant magnetization direction (I = ∼38° and D = ∼152°). The modeled direction of remanant magnetization for the rhyolite (I = −32° and D = 336°) and deeper gabbroic (I = −32° and D = 340°) bodies show normal polarity. Measured magnetization direction for the mafic body surrounding the rhyolite relates to the middle reverse polarity (29R) chron. Inferred declination and inclination may then correspond to upper normal (29N), middle reverse (29R) and lower normal (30N) polarity chrons. Therefore, the magma forming the Pavagadh igneous complex was emplaced covering the major span of Deccan eruption. G–M model suggests that the magma chambers developed within the higher crustal levels and rhyolite originated from the underlying mafic magma through assimilation and fractional crystallization (AFC).

1. Introduction

The Deccan basalt exposed in the northwestern (NW) and central India (Fig. 1) is one of the largest continental flood basalt (CFB) provinces (500,000 km^2) of the world. The Deccan basalt erupted due to a large thermal anomaly, generated by Réunion mantle plume during the continental break up in late Cretaceous (Courtillot et al., 1986; Duncan and Pyle, 1988; White and Mckenzie, 1989). Deccan basalt predominantly occurs in the form of lava flows. However, a large number of volcanic intrusives of limited areal extent are also present in the NW and central India (Sen, 1995). Flows of the Deccan basalt are predominantly tholeiitic in composition (Ghose, 1976) while the volcanic intrusives show considerable variation in their composition from mafic/ultramafic to acidic (Ghose, 1976; Bose, 1980; Sen, 1995). Vandame et al. (1991) suggested an age of 65 ± 2.5 Ma based on $^{40}Ar/^{39}Ar$ dating for the tholeiitic basalt representing the main pulse of Deccan volcanism. $^{40}Ar/^{39}Ar$ dating of biotite grains taken from alkali olivine gabbro and alkali pyroxenite of the Mundwara and Sarmu-Dandali igneous complex located in Rajasthan has yielded an average age of 68.53 ± 0.16 Ma and 68.53 ± 0.12 Ma respectively (Basu et al.,

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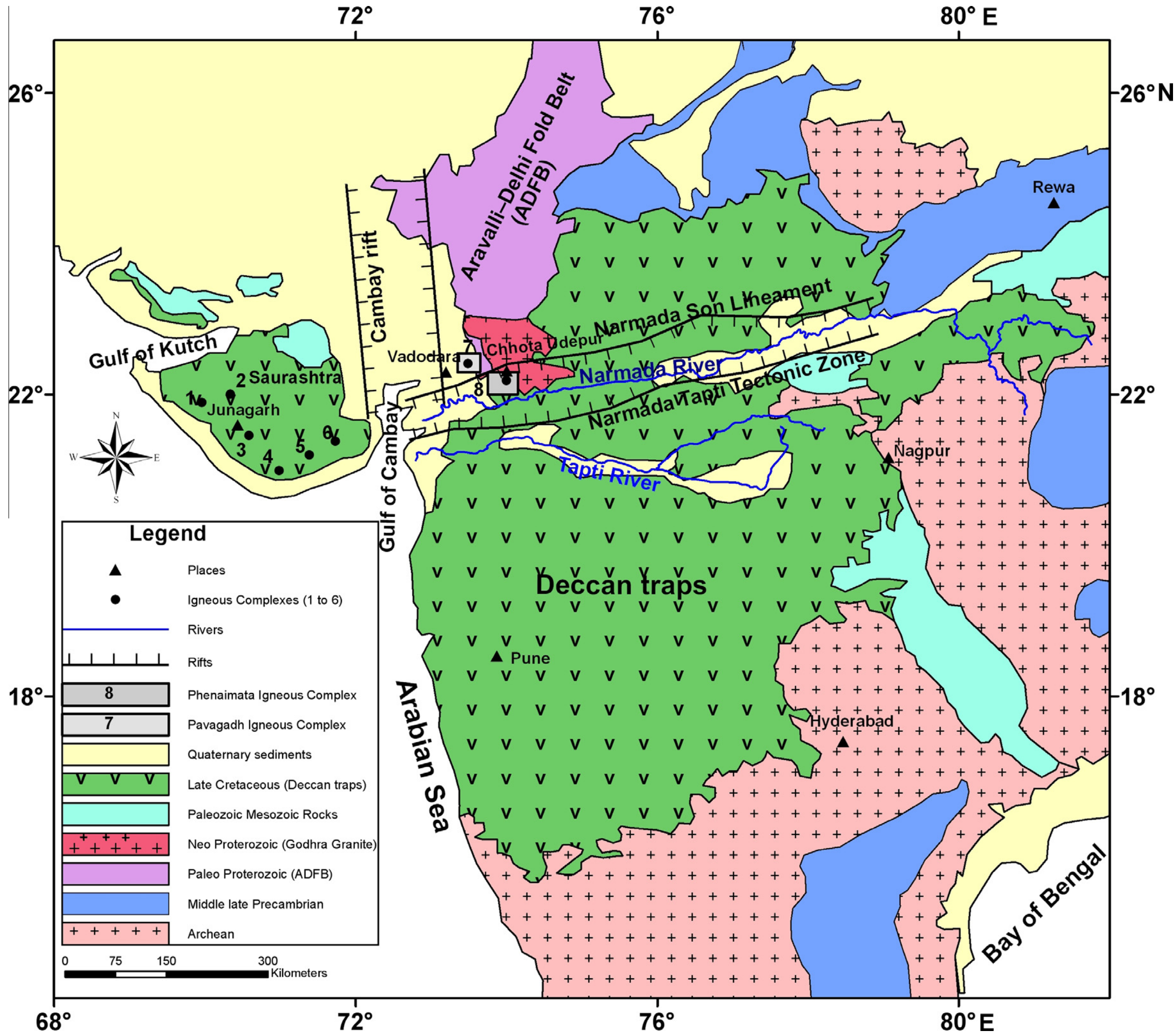

Fig. 1. Simplified geological and tectonic map of the Deccan traps (green) and adjacent area showing locations of some important igneous complexes in the NW and central India. Grey color rectangles indicate present study area covering Pavagadh (7) and Phenaimata (8) igneous complex. Other complexes are; 1. Barda, 2. Alech, 3. Girnar, 4. Rajula, 5. Palitana, 6. Vallabhipur (modified after Krishnamurthy et al., 2000). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

1993) which indicates that the alkali magmatism began about 3.5 million years before the main pulse of Deccan volcanism. Whereas, $^{40}Ar/^{39}Ar$ dating of biotite grains from olivine gabbro of Phenaimata alkalic complex located in central India yielded lower age of 64.96 ± 0.11 Ma (Basu et al., 1993) while the rhyolitic lava/intrusion near Bombay gave the youngest age of ~61 Ma (Lightfoot et al., 1987). Palaeomagnetic measurements on tholeiitic lava flows of the Deccan basalts indicate normal–reverse–normal (29N–29R–30N) polarity sequence with predomination of middle reverse (29R) and upper (29N) polarity (Vandame et al., 1991). Pande (2002) reviewed the available radiometric and paleomagnetic data from the Deccan flood basalt and suggested that volcanism was episodic in nature, and probably continued from ~69 Ma to ~63 Ma between 31R and 28N magnetic chron. The palaeomagnetic studies of alkaline igneous intrusions associated with the Deccan basalts has revealed normal and reversed magnetic directions (Chandrasekhar et al., 2002; Poornachandra Rao et al., 2004). In general, the direction of magnetization with reverse and normal polarity varies over a wide range. For example, inclination (I) and declination (D) of the reverse polarity shows $I = 50° \pm 20°$ and $D = 152° \pm 25°$ where as normal polarity shows $I = -45° \pm 20°$ and $D = 335° \pm 25°$ (Verma and Mittal, 1974a). The palaeomagnetic measurement of rock samples from the Girnar igneous complex near Junagadh in Saurashtra shows both reverse ($I = \sim 52°$ and $D = \sim 137°$) and normal polarity ($I = \sim -38°$ and $D = \sim 336°$) at lower and higher levels respectively (Bhalla et al., 1974; Chandrasekhar et al., 2002). Average density of exposed volcanic plugs of Saurashtra varies from ~2.65 to ~3.20 g/cm^3 with an average of about 2.92 g/cm^3 while susceptibility varies between ~0.001 and ~0.006 CGS units. The intensity of remanant magnetization also shows a wide range from ~0.002 to ~0.027 emu/cm^3 (Chandrasekhar et al., 2002). The geophysical field response particularly G–M anomalies over igneous complexes show distinct gravity high and associated bipolar magnetic anomalies which was successfully used to delineate them (Bott and Tantrigoda, 1987; Chandrasekhar et al., 2002; Bauer et al., 2003). The detailed G–M measurements over a number of igneous intrusives of Saurashtra, western India such as Alech, Barda, Girnar and Palitana (Fig. 1) imaged large amplitude gravity high and associated bipolar magnetic anomalies. This G–M anomaly signature is attributable to the presence of a high-density mafic (basic-ultrabasic) bodies extending to large depth related to the Deccan volcanism (Mishra et al., 2001; Chandrasekhar et al., 2002; Sethna, 2003). One of the most conspicuous features in the studied region is the absence of negative gravity anomaly over the acidic rocks of the volcanic plugs of Saurashtra. This suggests either poor sampling of G–M data or