Crustal structure of Narmada-Son Lineament: An aeromagnetic perspective

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Aeromagnetic data analysis over the Narmada-Son Lineament (NSL) shows that prominent anomalies are located over dyke swarms and trap flows and the major formations present have distinct magnetic signatures. A major extensive ENE fault is identified which coincides with the course of the Narmada river and which appears, as earlier suggested, to control Gondwana sedimentation to the south and Vindhyan sedimentation to the north. By isolating the sources, it is found that the signatures of the Deccan traps have a distribution that is possibly related to their time of eruption and subsequent evolution. The region between Hoshangabad (HBD) and Narsimapura (NSR) are made up of two structural units: a shallow ENE structure superposed on a deeper NW-SE feature which is possibly related to the continuation of the Godavari Gondwana Graben towards the northwest. The region north and south of the deep-seated fault F1 has undergone different evolutionary history. The thickness of the magnetic crust in the Narmada-Son region lies between 25 to 31 km, implying a lithological change below this depth. This is borne out by the high velocity layer (7.2 km/s) within the lower crust identified by DSS studies.

Key words: Magnetic anomalies, transformations, rifting, continental crust.

1. Introduction

The Narmada-Son Lineament (NSL), the most conspicuous feature in the Indian subcontinent with a total strike length of 1,200 km, extending from 72.5 to 82.5°E longitude and 21.5 to 24°N latitudes, is believed to mark the boundary between two regimes of contrasting geological history: the Bundelkhand protocontinent to the north and Dharwar protocontinent to the south. Widely differing views have been put forward regarding the tectonic setting of this belt (West, 1962; Ahmed, 1964; Choubey, 1971; Qureshy, 1982). Ahmed (1964) considered NSL as a swell in the crust, while Qureshy (1982) described this feature as a horst, delimited by the Son-Narmada fault on the north side and Tapti fault to the south. Jain *et al.* (1984) and Kale (1985) interpreted this as being due to the collision of the Indian plate with the Eurasian plate and as a suture zone of collision of the Bundelkhand protocontinent to the north and the Dharwar protocontinent in the south, respectively. To have a better understanding of the deep structure and tectonics of this belt, the Geological Survey of India, in 1978, initiated multidisciplinary studies under the name CRUMANSONATA, crust-mantle-studies along the Son-Narmada-Tapti lineament, (GSI, 1995). Integrated geophysical studies have thrown much light on the crustal structure of NSL although some controversies still remain regarding the “rift” nature of the Narmada-Son lineament (Kaila, 1986; Ravi Sankar, 1991; Mahadevan, 1994). Of all the geophysical surveys conducted over the NSL, only the gravity and aeromagnetic surveys have two-dimensional data coverage. The ground gravity surveys are heavily dependent on access to roads resulting in large data gaps. The advantage of aeromagnetic data is that the data coverage is independent of road access and surface topography and therefore has a fairly uniform 2D coverage. In the present paper, aeromagnetic data over the NSL is analyzed using analytical techniques to have another look into the structure and tectonics of the region integrating available geological and geophysical evidence.

2. Geology

Major geological formations observed in the area under investigation include Archean metamorphics, the Bijawars, Vindhyan and Gondwana formations, Deccan traps and recent alluvium. Figure 1 depicts the general geology and tectonic elements of the region (GSI, 2000, 2001). The Narmada valley can be divided into two parts along its strike, the divide being around Barwaha (Gosh, 1976). West of Barwaha, the Narmada river flows through Deccan traps, while in the east Gondwana, Vindhyan, Bijawar and Archean rocks are exposed on either side of the Narmada valley. It is noteworthy that north of NSL, no Gondwana rocks are exposed and to the south, no Vindhyan rocks are known (West, 1962). In the central part, near Hoshangabad (HBD), the Vindhyan rocks and Deccan traps are present to the north of the Narmada river and to the south, Archean rocks are exposed and overlain by the Gondwana formations. Towards the west, the Narmada valley is covered by an almost horizontal lava pile, which varies in thickness from 100 to 800 m. Discontinuous EW trending basaltic dykes are reported in the area south of the river. The Bijawar, the oldest formation of the area, comprises limestones, pelites, quartzites, breccia and contemporaneous lava flows. The Vindhyan formation overlying the Bijawars consists essentially of shale, limestone and sandstone. The Son-Mahanadi and Satpura basins host known

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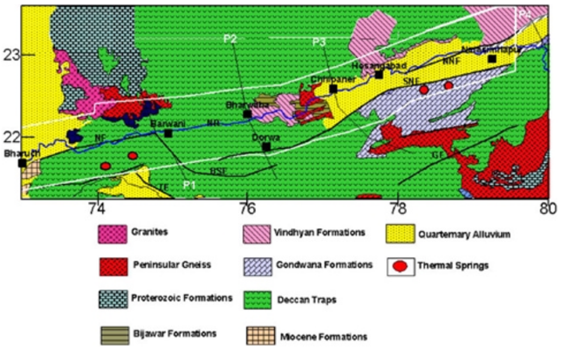

Fig. 1. Geology and Tectonic map of Narmada redrawn from the geological map (GSI, 2001) and Seismo-tectonic Atlas (GSI, 2000). NF-Narmada Fault, BSF—Barwani Sukta Fault, TF-Tapti Fault, NR—Narmada River, SNF—South Narmada Fault, NNF—North Narmada Fault, GF- Gavilgarh Fault. P1, P2, P3, P4 are part of the DSS profiles in the study region. HBD—Hoshangabad, NSR-Narsingpur, BRH- Baruch, BWN-Barwani, BHR-Bharwaha, CPR-Chhipaner, DRW-Dorwa. The study region is outlined in white.

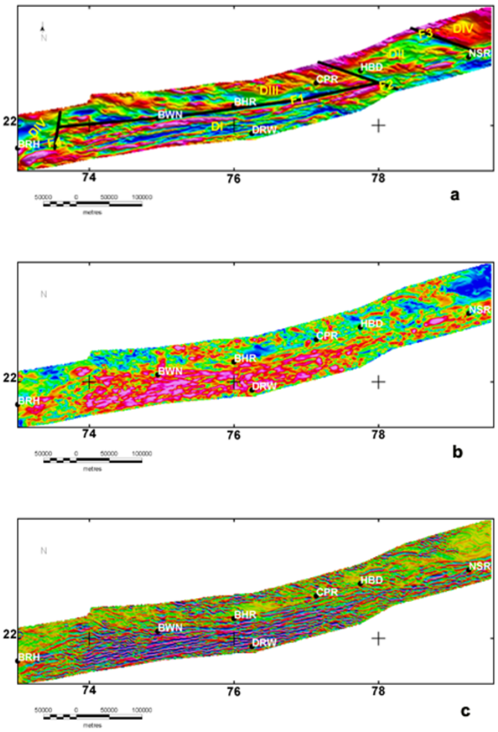

Fig. 2. Total field anomaly map and its transformations. Red depicts highs and blue lows. (a) Total field aeromagnetic anomalies with superposed interpreted major faults and domains. (b) Analytic signal map, maxima (highs) are located over the magnetic source. (c) Second vertical derivative of total field.

Gondwana deposits along the NSL. The Deccan traps, occurring to the south and north of the lineament, have been dated from 66 to about 64 Ma (Alexander, 1981). The rectilinear course of the Narmada, the apparently mutually exclusive distribution of certain formations immediately to the north and south of this line, igneous activity, seismicity and mineralization along this line suggest this to be a major dislocation zone.

3. Aeromagnetic Data Analysis

An aeromagnetic survey covering an area of 58,000 km^2, from west of Jabalpur to almost the west coast of India, was carried out during 1978–79 by the National Geophysical Research Institute for the Geological Survey of India (GSI). Considering the topography of the region, the survey was conducted in two blocks. Block I, the Baroda-Indore block (73 to 76°N) had a survey altitude of 5000 ft above mean sea level and line spacing 4 km; Block II, the Indore-Jabalpur block (76 to 79.5°N) had a survey altitude 3500 ft above msl on lines spaced at 2 km. Aeromagnetic contour maps, purchased from the GSI, were machine digitized along the contours, corrected for the main field using the International Geomagnetic Reference Field (IGRF) corresponding to the epoch and altitude of survey, re-gridded at 1 km interval, reduced to a common datum level of 3500 ft and merged (Geosoft, 1999) to form the aeromagnetic map of the region (Fig. 2(a)). To isolate the sources responsible for the mixture of short and long wavelength anomalies with varying amplitudes, vis-à-vis the depth, the data was subjected to various transformations (Blakely, 1995). The analytic signal (Roest *et al.*, 1992) of the total intensity data (Fig. 2(b)) is computed to understand the distribution of magnetic sources in the study region. Application of this technique to the aeromagnetic data of Central India revealed that charnockites, intrusives, iron ore bodies and trap flows are the main sources of high magnetic anomalies (Rajaram and Anand, 2003). Mathematical operations like the second vertical derivative (Fig. 2(c)) and upward continuation (Fig. 3(a)) were performed to isolate shallow and deep sources. The data was subjected to high-pass filtering at different wavelengths (Rajaram *et al.*, 2003) and it was found that the filtered map, to retain wavelengths of less than 125 km (Fig. 3(b)), was able to reproduce the observed map (Fig. 2(a)), excluding the edges. Based on the rule of thumb that the depth to the sources do not go below one-fifth to one-fourth of the filtered wavelength (Dobrin, 1976), the bottom of the magnetic sources was estimated to be confined within 25 and 31 km.

The magnetic effects of the major geological formations in the area are distinctive and the magnetic trends show remarkable conformity to the structural trends. Vindhyan rocks as well as Mesozoic sediments are characterized by low magnetic gradients with very few anomaly closures. Basic and ultra-basic intrusives are represented by short wavelength and high amplitude anomalies. Low amplitude, moderate frequency with circular or elliptical anomaly features of small aerial extent, represent Archean rocks. Gondwana rocks are characterized by low amplitude anomalies with isolated negative closures. High amplitude, high gradient and short wavelength anomalies are the signature of Deccan traps. The boundaries of various geological formations can be identified based on these criteria. On the basis of the anomaly intensity, amplitude, wavelength and trend, the anomaly map can be categorized into four major domains: Domain-I (DI) is characterized by elongated elliptical high amplitude, medium to short wavelength two-dimensional anomalies trending ENE and fall over the region covered by trap flows in the west and alluvium in the east. These 2D anomalies have been modeled by Verma and Dutta (1994) suggesting dyke-like bodies at an average depth of 0.5 km. Domain-II (DII) extending over the region covered by al-

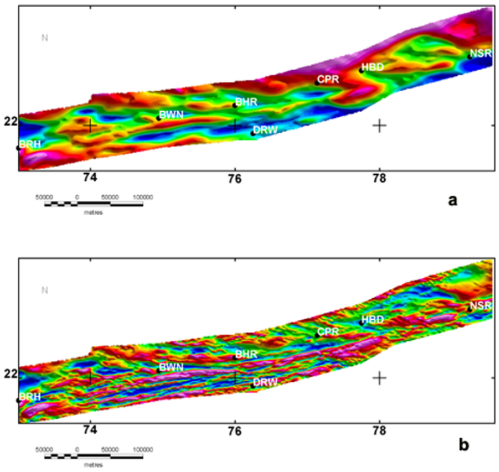

Fig. 3. (a) Total field anomaly upward continued to 5 km above msl. (b) High pass filtered map with a cut-off wavelength of 125 km, reflecting the magnetic sources between 25 and 31 km.

luvium in the center with Gondwana and Vindhyan formations to the south and north, respectively, is characterized by ENE and NW-SE trending anomalies. Domain-III (DIII) is characterized by broad/subdued, long wavelength anomalies and overlies the region covered entirely by trap flows. Domain-IV (DIV), overlying alluvium, shale, limestone and sandstone of the Vindhyan and Baruch basins, show broad wavelength anomalies reflecting the basement. The nature and pattern of anomalies in different domains shows considerable contrast, suggesting that the contacts between these zones are faulted. The ENE trending mega-fault F1 separating the high amplitude two-dimensional structures of DI from DIII closely follows the Narmada river. Faults F2 and F3 separate DII from DI/DIII and DIV respectively. Fault F4 separates DI from DIV. The major interpreted faults and domains are marked in Fig. 2(a).

The analytic signal map, Fig. 2(b), clearly brings out the magnetic sources associated with traps and suggests the eastward continuation of the traps in DI underneath the alluvial cover. A striking feature in the analytic signal map is the absence of major magnetic sources in the trap-covered region of DIII. The second vertical derivative map (Fig. 2(c)) shows ENE trends, implying the sources responsible for these trends are shallow. The ENE orienting fault/fractures within DI are clearly brought out in this map and are found to extend into DII. The total field anomaly map continued upward to 5 km above mean sea level, shows ENE trends west of Hoshangabad (i.e., in DI and DIII), while the region east of Hoshangabad (HBD), DII, is characterized by NW-SE trends. From this it can be inferred that there is no change in the crustal structure, in deeper levels, in DI and DIII, while in DII the trends change from ENE at shallow level to NW-SE in the deeper levels. In DI, the upward continued map (Fig. 3(a)) shows large elliptical negative anomaly closures in the trap-covered region, suggesting the presence of Gondwana rocks underneath trap cover.

4. Discussion

An examination of the total magnetic field and its transformations shows that in the Narmada valley there are two main lines of faulting of the basement rocks which are almost at right-angles to each other with NW-SE trend representing deeper features and the ENE-WSW shallow features. The observed linearity of many magnetic features suggests that they formed from brittle fracturing of the crust. The NW-SE faults (F2 and F3) and features between Hoshangabad and Narsingpur are deeper, as evidenced from the upward continued map (Fig. 3(a)). The Bouguer anomaly map (Verma and Banerjee, 1992) also shows NW-SE trends in this region. The change in the nature of the anomalies of the potential field data suggests that this region has undergone intense deformation associated with major tectonic activity. In the regional gravity picture, this NW-SE trend is found to extend further north and abuts against the Delhi-Aravalli system. When extended southwards, the trend joins with the Gondwana Godavari graben (Atchuta Rao *et al*., 1992) implying that the NW-SE trending Permian-Jurassic Gondwana rift valley runs from central India to the east coast, till the ocean continent boundary (Rajaram *et al*., 2000).

The major ENE fault F1, running close and parallel to the Narmada river appears to have controlled the sedimentation pattern along the NSL. Vindhyan sediments are not found to the south of F1 and Gondwana sediments are not found to the north of it (West, 1962). During the period of Vindhyan sedimentation, DIII may have been down-faulted with respect to DI to receive Vindhyan sediments, while DIII was uplifted during the Gondwana period restricting Gondwana sedimentation to the south. Thus, it appears that F1 was episodically active right from the Proterozoic. The trap flows to the north of F1 are devoid of any magnetic signatures, while the traps to the south are associated with distinct magnetic signatures (Fig. 2(b)), possibly due to the difference in the thickness of the flows (Kaila, 1986) or the change in flow-polarity pattern, as evidenced from the paleomagnetic studies, suggesting different periods of eruption (Pal and Bhimasankaram, 1974).

The dense network of minor fault/fractures, dyke-like intrusive bodies in the basement of DI, is not present in DIII, thus suggesting that DI was under extensional strain in the geological past and seems to be an important element in shaping the present structural trends of the Narmada region. As portrayed in the DSS profiles (Tewari and Prakash Kumar, 2003), the region between the Narmada and Tapti rivers is characterized by basement uplift. The analysis of gravity data (Verma and Banerjee, 1992) also shows a higher density crust in the south in comparison to areas north of F1. It may be possible that the fault F1, is a deep-seated fault involving the Moho, along which DIII have been downthrown with respect to DI. The advective heat flow values in DI are 70–100 mW/m^2, higher than the global average of 60 mW/m^2 (Ravi Sankar, 1991), while in DIII it is 40–70 mW/m^2. Several thermal springs are also reported in DI. Hence, it appears that DI and DIII have undergone a different evolutionary history.

The Moho in NSL region is at an average depth of 38 km, as evidenced from the DSS profiles (Kaila, 1986). From the filtered map (Fig. 3(b)), the magnetic crust in the Narmada-Son region has a thickness lying between 25 and 31 km, implying that there are no magnetic sources below this depth. This would mean that there is either a lithological change at around this depth or the Curie isotherm is elevated. A high velocity (7.2 km/s) layer, below an average depth of 27 km, has been identified within the lower crust by Tewari and Prakash Kumar (2003) from the reinterpretation of the DSS profiles (Kaila, 1986) in the NSL, using the ray-tracing method, and would support a lithological change. Further, integrated geophysical studies (Rao *et al.*, 1995; Reddy and Rao, 2003; Gokarn, 2003; Arora *et al.*, 1993) suggest the presence of an anomalous zone of a hot upper mantle with temperatures higher than the solidus of basalt (1200°C) (Ravi Sankar, 1991) within the lower crust. Reddy and Rao (2003) suggests that the lower crust is underplated by the addition of asthenospheric materials or mantle derivatives through fractures ascending through deep crustal faults. Several kimberlite pipes, igneous complex, basaltic dyke swarms and carbonatites are reported south of F1 (GSI, 1995). The dense network of fractures in DI, coupled with deep-seated faults (Kaila, 1986), the reported occurrence of alkaline rock suites and the presence of basic/ultrabasic dyke swarms and magmatic underplating, support the interaction of the southern part of NSL with the mantle plume (Raval, 2003). Many hotspot tracks appear to become the locus of later rifting, as the heat of the hotspot weakens the lithosphere and causes the continents to split along these weakened lines. All this evidence confirms that the Narmada Son Lineament is a rifted feature.

5. Conclusion

The main conclusions drawn from the analysis of aeromagnetic data is as follows:

(1) Gondwana rocks are present underneath the traps in the region between Baruch and Bharwaha and are controlled by the fault F1 to the north.

(2) The magnetic signatures to the north and south of F1 are different, implying that the evolutionary history of the continental crust north and south of fault F1 is different and the trap flows on either side are not coeval or they have different thicknesses.

(3) In the region between Hoshangabad and Narasimapura, the crust is made up of two units: an EW shallow unit superposed on a deeper NW-SE unit possibly associated with the extension of the Gondwana Godavari Graben towards the northwest.

(4) The thickness of the magnetic crust in the Narmada-Son region lies between 25–31 km, suggesting a lithological change at around this depth. This is borne out by the DSS result that shows a high velocity zone below 27 km.

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