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Geomagnetic Investigation in the Seismoactive area of Narmada-Son Lineament, Central India

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ABSTRACT
Activation of Narmada south fault caused the devastating Jabalpur earthquake (6.0 M) on May 22, 1997. To understand the secular variation of the total geomagnetic field in the vicinity of Narmada south fault, particularly comprising the seismoactive zone of Jabalpur and its adjoining areas in the Narmada-Son Lineament, Central India, tectonomagnetic studies were undertaken by carrying repeat surveys since 2003. The repeat survey area covers a total of 70 observation stations falling in areas of Jabalpur, Mandla, Seoni, Lakhnadon and Narsimhapur in Deccan Trap provinces. Using the Proton Precession Magnetometer of sensitivity 0.1nT, simultaneous measurements of total geomagnetic field were made at all stations and at base station and the process was repeated at yearly intervals. In this study, Seismic Observatory, Jabalpur was used as reference base station. For data interpretation purpose, five magnetic profiles were drawn i.e. the Katangi-Mandla (AA'), Mandla-Lakhnadon (BB'), Lakhnadon-Narsimhapur (CC'), Narsimhapur-Jabalpur (DD') and Jabalpur-Seoni (EE'). Repeated yearly surveys of 2003, 2004, 2005, 2006 and 2007 bring out secular changes in total geomagnetic fields that seem to be concentrating locally. Results of these observations have shown the anomalous geomagnetic field secular variations in a range of $\pm$ 0.06 to $\pm$ 9.54 nT at separate stations over the distinct profiles. The anomalies in secular variation of the total geomagnetic field may be related to anomalous accumulation of tectonic stresses and tensions on the fault zones and crustal blocks due to recent geodynamic processes and tectonic setting of the Narmada-Son Lineament.

INTRODUCTION

The ENE-WSW trending Narmada-Son Lineament (NSL) in Central India is a spectacular lineament zone about 1600 km long and 150-200 km wide, which is traceable across the Indian Peninsula between latitudes 21.5^{o} and 24^{o} N and longitudes 70^{o} and 88^{o} E and may further extend in either direction (Ravi Sankar 1990). The lineament has a Precambrian ancestry and may possibly be limited to development of the Vindhyan basin to its north and the Gondwana belt to its south (West 1962). It has been considered as an ancient rift or active fault zone and is a zone of crustal upwarping through which lava intruded (Auden 1949). A large number of experiments have been carried out to study the evolution of the region and to understand the tectonic processes that might have taken place in the region since geological time. Deep Seismic Sounding (DSS) studies along several profiles across the NSL have indicated the presence of deep seated Narmada North Fault (NNF) and Narmada South Fault (NSF) extending down to the Moho, along the Narmada and Tapti lineaments, which have divided the crustal section into blocks (Kaila et al., 1985). The vertical movements of these blocks not only appears to have played a key role in shaping the crustal configuration into a horst and graben structure, but also have controlled the nature of sedimentation by limiting the Vindhyan basin to the north and the upper Gondwanas to the south (Kaila et al., 1987). The deeper crustal section, in addition to well-marked reflectors corresponding to the Moho and Conrad discontinuities, also shows a large number of reflector segments which are not contiguous. On the heat flow map compiled by Ravi Shankar (1988), the region of lineament is characterized by symmetrically disposed heat flow zone, with the highest values lying over the Satpura ranges. The region of the NSL on the residual gravity anomaly is shown by a broad gravity high with a narrow low (coinciding with the Narmada valley) embedded in the centre (Qureshy 1982). Geomagnetic Depth Sounding (GDS) experiments provided strong evidence for the existence of an elongated high electrical conductivity zone south of Jabalpur beneath the Satpura ranges, due to the fluids in the crust (Satpura Conductivity Anomaly-SCA). The lateral extent of the SCA is bounded between Jabalpur and Paraswada and its centre is located beneath Kalpi

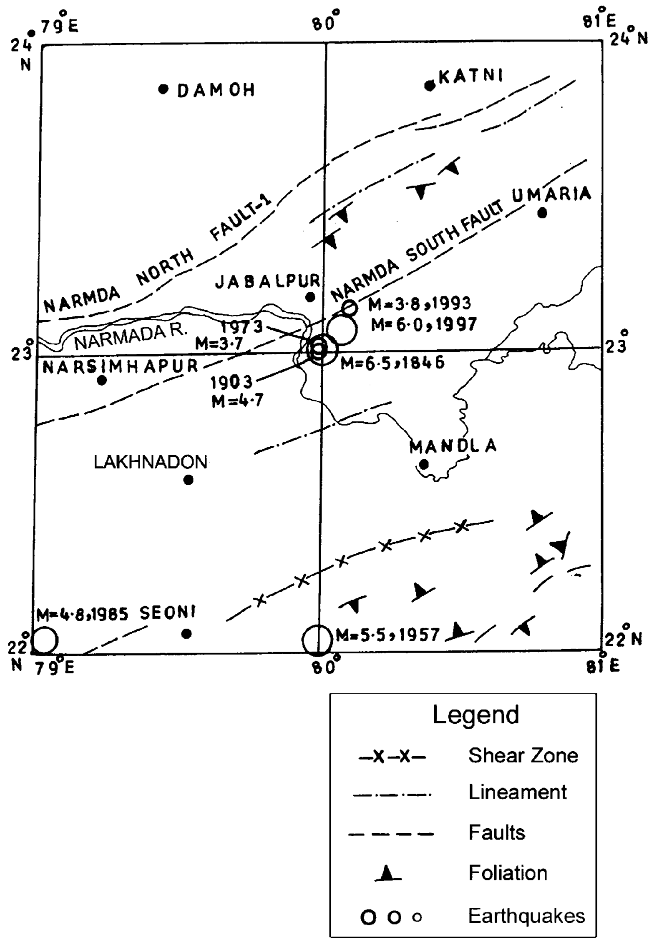

Figure 1. Map showing a number of earthquakes of various magnitudes (M) occurred in recent past with their epicenters located near Jabalpur. (Figure is redrawn from a consolidated document on Jabalpur earthquake of May 22, 1997, India Meteorological Department, New Delhi, 1998).

(Arora, Waghmare & Mahashabde 1995).

More than 30 earthquakes in the magnitude range 3.0 and 6.5 are reported for the seismically active NSL (Gupta et al., 1997). A devastating earthquake of magnitude 6.0 on the Richter scale occurred on May 22, 1997 and struck the Jabalpur area killing about 50 people and causing extensive damage to property. The main shock and after shock studies of this earthquake revealed the depth of hypocenter section at a range of 35-40 km (Acharyya et al., 1998). Waghmare (2003) has shown a good correlation between the Jabalpur earthquake of May 22, 1997 and SCA. Jabalpur and adjoining areas fall within the NSL zone with exposed litho tectonic units ranging in age from Achaean to recent. Fig. 1 shows a number of earthquakes of various magnitude (M) that have occurred in the past with epicenters in and around Jabalpur, these are 1846 (6.5 M), 1903 (4.7 M), 1973 (3.7 M), 1993 (3.8 M), 1997 (6.0 M) as reported by India Meteorological Department (1998). Keeping in mind the seismicity history in Jabalpur area, a project "Tectonomagnetic study as repeated measurements of the total geomagnetic field over Jabalpur and adjoining areas in Central India" was launched by Indian Institute of Geomagnetism, Navi Mumbai, in 2003. Total 70 field stations on the natural ground and far from man-made structures and with inter-distances of less than 10 km were selected through geomagnetic measurements to ensure that stations are located in low-gradient areas. Sandstone pillars have been installed as stable benchmarks over which magnetometer sensor is placed for total geomagnetic field measurements. The locations of the stations comprise areas of Jabalpur, Katangi, Mandla, Seoni, Lakhnadon and Narsimhapur in Madhya Pradesh. A reference base station was established in the study area at Seismic Observatory, Bargi hill, Jabalpur. Fig. 2 shows a layout of repeat survey stations along with

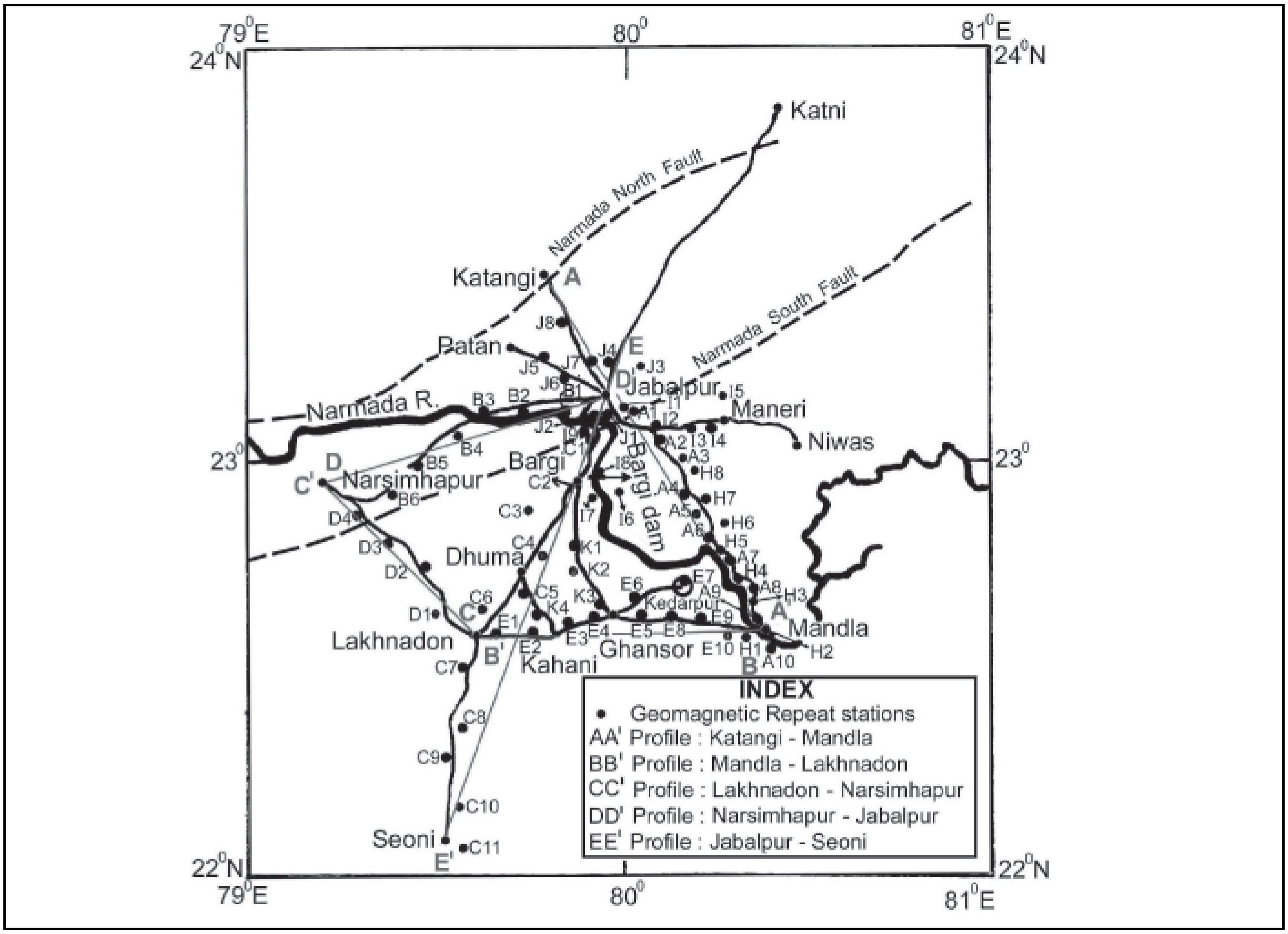

Figure 2. Map showing layout of geomagnetic repeat stations in Narmada-Son Lineament, Central India. Five geomagnetic profiles are also shown in map.

station codes covering five geomagnetic profiles. For the measurements of total geomagnetic field intensity T, two drift-free and absolute measurable Proton Precession Magnetometers (PPMs) having a sensitivity of 0.1 nT were used. One was deployed at base station and other was used at field stations. Before an observation, PPMs were calibrated at exactly the same time by portable GPS receiver and sample scanning intervals were set for 15 seconds. Both the PPMs were operated simultaneously at the base and field station for half an hour and a total of 120 values of total geomagnetic field intensity T were recorded on auto mode and saved in PPMs memory, later downloaded to the Personal Computer at the field. This procedure was adopted for covering all survey points and entire survey was completed within 30-40 days during each campaign. Five phases of surveys were completed starting from March-April 2003, which were repeated in February-March 2004, February-March 2005, January-February 2006 and January-February 2007.

DATA ANALYSIS

The geomagnetic field is subjected to various kinds of variations with its origin in ionosphere and magnetosphere as well as within the Earth. However, these variations can approximately be treated as being spatially over areas of local extent. On the basis of this approximation, it is possible to detect changes associated with stress changes or other processes in the Earth by taking difference between fields simultaneously observed at two or more stations (Honkura 1981). While studying electromagnetic induction within the Earth by natural external variation of magnetic field, Gough (1973) indicated that external fields incident on most of the Earth's surface are those of distant currents of ionosphere/ magnetosphere and have wavelengths of thousands of kilometres. The external source field can be contaminated in the auroral and equatorial zones due to electrojets prevailing in these zones. Thus, external magnetic source fields may be considered as uniform to certain extent in the low and middle latitudes of the Earth. Moreover, Nishida et al., (2004) have indicated that the contributions from Earth's core or ionospheric origin are ruled out as source mechanisms because of local distribution of the anomalous stations. Also, Honkura & Koyama (1976) pointed out that distances between survey sites and reference base station should be less than 100 km to avoid apparent changes of the secular variations exceeding 1 nT/yr. If we consider the external source field uniformity, according to Gough (1973) indications, our tectonomagnetic study area in the NSL is in the low latitudes between 22º N and 24º N and necessarily the external magnetic source field is uniform without any contamination due to the influence of electrojets. Also our reference base station is located in the study area about < 100 km aerial distance from the field stations covering the external source fields to have similar contributions at the base and field stations. Hence, simple difference method can be applied to data analysis for eliminating the ionospheric/ magnetospheric contributions.

However, the most disturbing factor is the presence of lateral inhomogeneities that exist in crust, which cause electrical conductivity anomalies by electromagnetic induction from external varying geomagnetic field. The electromagnetic induction within the Earth is the frequency (period) dependent phenomenon, which follows the skin depth relationship $Ds = 0.5\sqrt{\rho t}$ km, where ρ is resistivity in Ω.m and t is in seconds (Gough 1992). There is a working rule that longer the time of external variation field deeper is the penetration of induced current within the Earth. But we are interested in probing crustal depth, so short period variation of the field can be used. For short-period variations of micro-pulsation type, total magnetic field data for 10 minute averaging procedure is satisfactory, and the 'noise' component due to electrical conductivity inhomogeneities in the surrounding rocks does not contribute significantly to the variations of ΔT (Skovorodkin et al. 1978). They also suggested that when high sensitivity (0.1nT) absolute proton precession magnetometers are used, the mean square error of a single observation of ΔT for 10 minutes is $\leq \pm$ 0.2 nT, when data samples taken number between 20 and 30. As per Skovorodkin, Bezuglaya & Guseva (1978) indications, for the area under investigation, tectonomagnetic variation may be judged as significant when the change in ΔT exceeds 0.6 nT. It is not possible to determine the actual error of calculation in geomagnetic field secular variations at each site. In this study, the proper data selection is necessary for the analysis i.e. the precision measuring, and associated noise level that may be severely limited during detection of tectonomagnetic effect, which on theoretical considerations is not expected to exceed 10 nT (Rikitake 1976; Zlotnicki & Cornet 1986). In present case a difference method for data analysis is followed (Skovorodkin, Bezuglaya & Guseva 1978; Kuznetsova & Klymkovych 2001).

Daytime data in terms of micro-pulsation (Pc5) type were used in present study, which is ranging 150-600 seconds (Samson 1991). Continuous string of 20 values i.e. 300 seconds simultaneous data for the base and field station were selected for averaging and calculation of standard deviations. The difference was obtained by subtracting averaged value of base station from the average value of field station. Finally, a single value for particular station is determined as the residual field, which can be interpreted as tectonomagnetic signal with respect to reference base station. Thus, the residuals were calculated for all field stations with respect to the reference base station for all repeated data sets. The theoretical interpretation is given as follows:

On the basis of a long series of repeat total geomagnetic field surveys, anomalies of temporal geomagnetic field changes $\Delta T = \Delta\Delta F$, i.e. tectonomagnetic anomalies are detected within a given time interval of observations. Within the profile and spatial observations of repeat surveys following quantities were followed: F_i and F_o-total geomagnetic field intensity in the i-th point and basic point (for all points of network), respectively. If F_i^* and F_o^* are values for the first cycle of the observations, then $\Delta F^* = F_i^* - F_o^*$. If F_i^{**} and F_o^{**} are values with a repeat cycle of the observation (within a chosen time interval, e.g. day, month, year, etc.), then $\Delta F^{**} = F_i^{**} - F_o^{**}$. The tectonomagnetic anomaly is characterized by $\Delta\Delta F = \Delta F^* - \Delta F^{**}$. If no local changes of the field of tectonomagnetic origin occurs, then $\Delta\Delta F \to 0$ (within the measurement errors and outer field identity). The values $\Delta\Delta F \neq 0$ indicate the availability of recent tectonic processes, which seem to be revealed due to repeat surveys (Kuznetsova & Klymkovych 2001).

RESULT AND DISCUSSION

The statistical results of the observational data show that the mean standard deviation associated with residual field ΔT, values range between 0.3-2 nT. Much of the interpretation to follow is based on the pattern resulting from statistical significant ΔT values and /or on the patterns emerging from group of stations. A technique is followed here as Shapiro et al. (1978) for the presentation of the results as in figures 3-7. The differences in secular changes in the total magnetic field were obtained by subtracting the second year residual field from first year and third year from second year and so on.

Secular changes along AA´ profile

AA' profile covers 29 stations between Katangi and Mandla with inter-station distance of about 5 km. Fig.3 shows the change of geomagnetic field along the AA' profile. There are four plots, in which year to year changes of the geomagnetic field between 2003 to 2007 i.e. the ΔT difference (2003-2004), (2004-2005), (2005-2006) and (2006-2007) are plotted on same scale. The amplitudes of the ΔT differences are seen in the range of fraction to ± 8.5 nT at different stations. It is speculated that distinctive pattern of ΔT differences observed in Fig. 3 may be because of some manifestation of stress and tension variations due to geodynamic processes and anomalous movements of crustal blocks and intrusion with Mahakoshal belt, Satpura horst and graben like structures of the Narmada fault systems. Coincident deep reflector/ refractor studies in Central India have shown presence of upper and lower crustal low-velocity layers. These layers, high heat flow, hot springs, significant reflectivity character north and south of Central Indian suture and mild seismic activity in the Central India strongly suggest neo-tectonic activity in the region, including, the horst structure between Katangi and Jabalpur (Reddy, Sain & Murty 1997).

Secular changes along BB´ Profile

BB' profile covers 13 stations between Mandla to Lakhnadon with inter-station distance of about 10 km. Fig. 4 shows changes in geomagnetic field along the BB' profile. In fig.4, yearly ΔT difference have been taken for (2003-2004), (2004-2005), (2005-2006) and (2006-2007).The amplitude of the geomagnetic anomalies falls in the range of fraction to ± 9.54 nT. The initial few stations of the profile show pronounced anomalies whereas the middle of the profile has smooth anomaly followed again by pronounced changes between station numbers 7 to 13 with reduced amplitude in geomagnetic anomalies. The area between Mandla and Lakhnadon is covered by Deccan Traps. The interface between Deccan Traps and underlying Archaean (basement) is interpreted to be at a depth of 900 m near Lakhnadon (Naskar et al. 2003). Another fault is inferred at 13 km south of Lakhnadon called Gavilgarh fault (Jain, Nair & Yedekar 1995), which may be influencing the geomagnetic anomalies in the region.

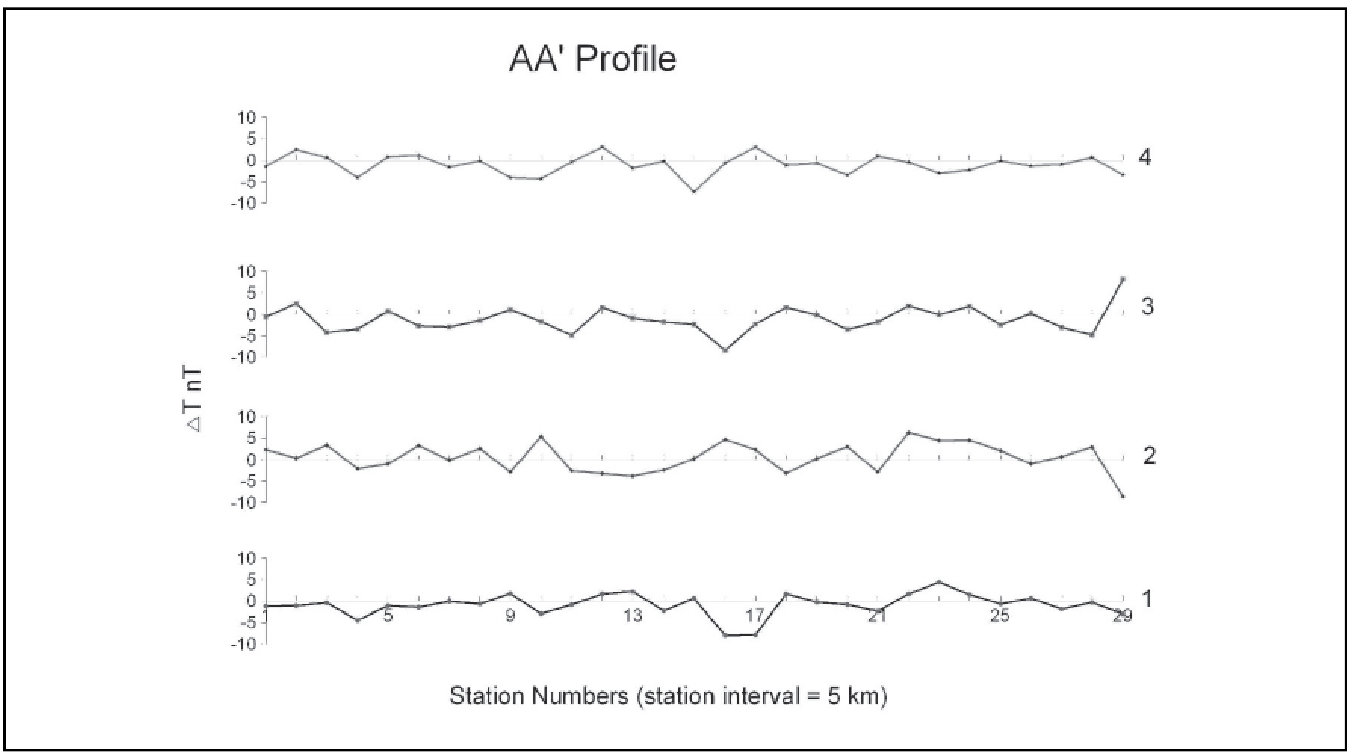

Figure 3. Secular change of the geomagnetic field T along the Katangi-Mandla (AA') profile.1, ΔT difference (2003-2004); 2, ΔT difference (2004-2005); 3, ΔT difference (2005-2006); 4, ΔT difference (2006-2007).

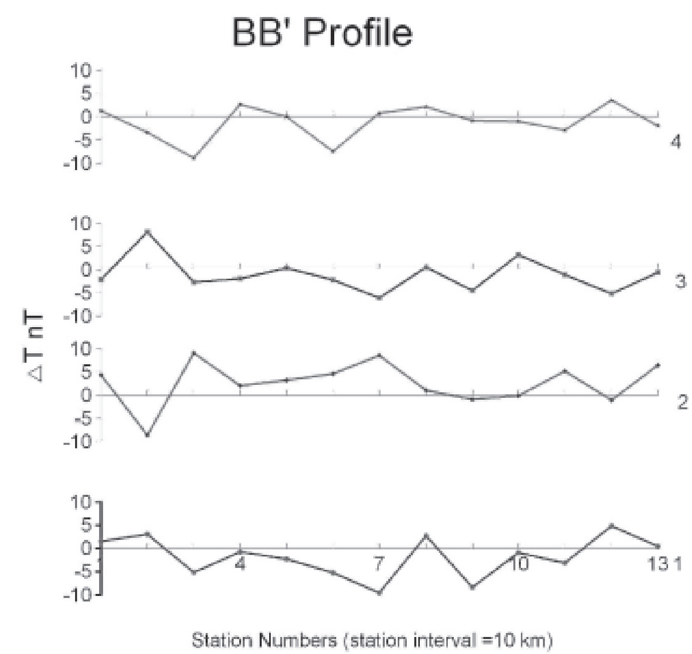

Figure 4. Secular change of the geomagnetic field T along the Mandla-Lakhnadon (BB') profile. 1, ΔT difference (2003-2004); 2, ΔT difference (2004-2005); 3, ΔT difference (2005-2006); 4, ΔT difference (2006-2007).

Secular changes along CC´ Profile

This profile covers only 5 stations between Lakhnadon and Narsimhapur with inter-station spacing of about 10 km. Fig. 5 gives changes of the geomagnetic field along CC' profile with an amplitude in the range of ±0.6 to ± 9.06 nT. The year-to-year changes in ΔT may be related to the stresses building in the vicinity of the Narmada south fault and adjoining areas of the Narmada rift system.

Secular changes along DD´ profile

This is another small profile covering stations between Narsimhapur and Jabalpur. Fig.6 gives four plots each with amplitude ranging from ± 0.06 to ± 7.68 nT. In this figure ΔT shows negative values for initial 4 stations but sudden positive jump is observed at 5th station of about 7-8 nT which is gradually suppressed further to about zero at the end of profile particularly in the 4th plot. The region is more or less in the Mahakoshal group with alluvial deposits between Narsimhapur and Jabalpur (Jain, Nair & Yedekar 1995). Also the area is located in the vicinity of the Narmada south fault. The secular variation anomalies may be manifestation of the joints of adjacent tectonic crustal blocks.

Secular changes along EE´ Profile

This profile covers 19 stations between Jabalpur and Seoni and inter-station spacing is about 10 km. Fig.7 gives ΔT difference with the amplitude ranging from ± 0.06 to ±9.06 nT. In fig.7, year-to-year differences for the five surveys are taken from 2003 to 2007. Jabalpur to Seoni area is mostly covered by Lameta sediments, Deccan basalt and intrusives (Jain, Nair & Yedekar 1995). The Archaeans include the older metamorphites, some ultramafic/basic intrusives and unclassified granite gneisses intruded at places by quartz, pegmatite and aplite veins in south of Seoni area (Naskar et al. 2003). The swarm type seismic activities were experienced around Bamhori, Seoni district in April-May 2000. The hidden basement fault beneath the Deccan Traps may have existed there, causing swarm type seismic activity around Bamhori village (Pimprikar & Devarajan 2003).

No major seismic activity as well as volcanic activity was recorded during the repeat survey period for March-April 2003 to January-February 2007. Hence, significant correlations have not been observed between seismic events and the investigated secular variation of geomagnetic field in the survey area. However, sometime these secular variation anomalies could be correlated with seismic activities (for example,

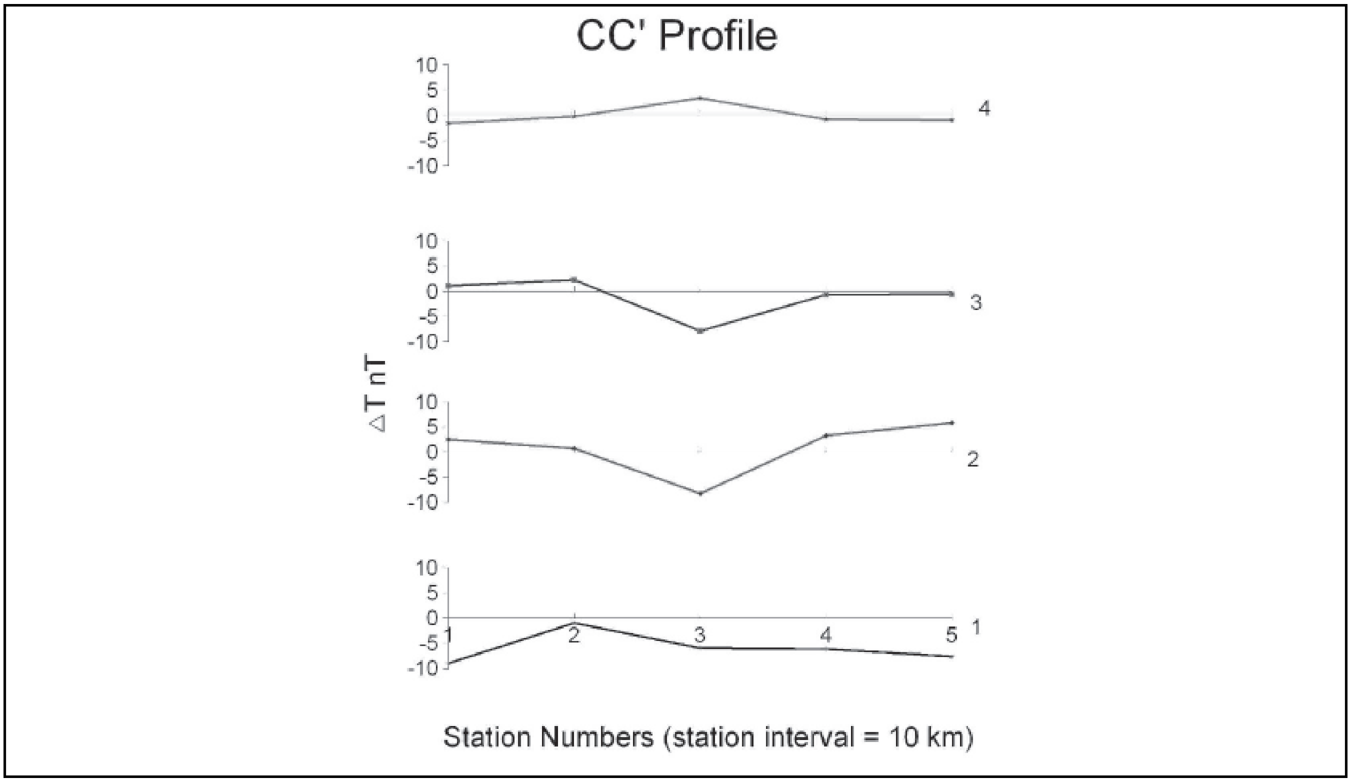

Figure 5. Secular change of the geomagnetic field T along the Lakhnadon-Narsimhapur (CC') profile. 1, ΔT difference (2003-2004); 2, ΔT difference (2004-2005); 3, ΔT difference (2005-2006); 4, ΔT difference (2006-2007).

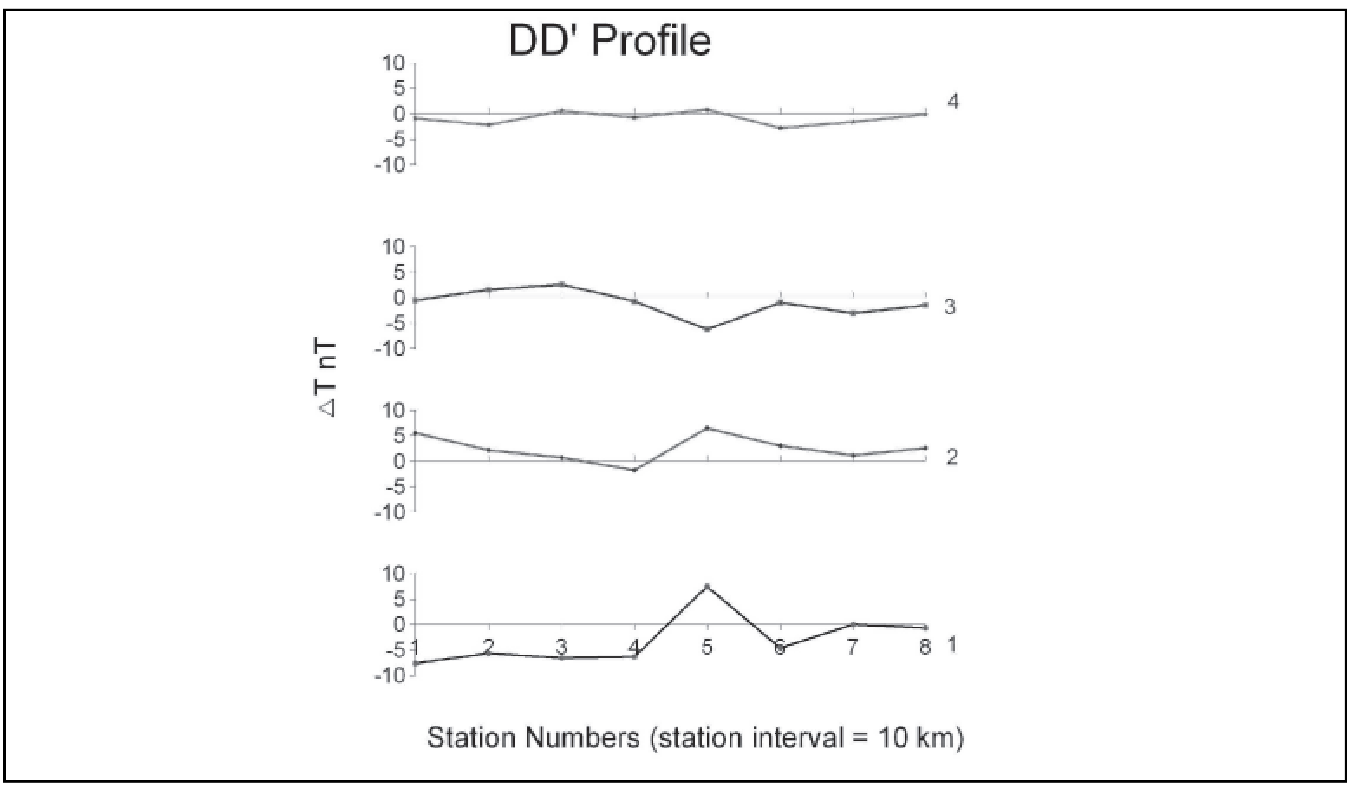

Figure 6. Secular change of the geomagnetic field along Narsimhapur-Jabalpur (DD') profile.1, ΔT difference (2003-2004); 2, ΔT difference (2004-2005); 3, ΔT difference (2005-2006); 4, ΔT difference (2006-2007).

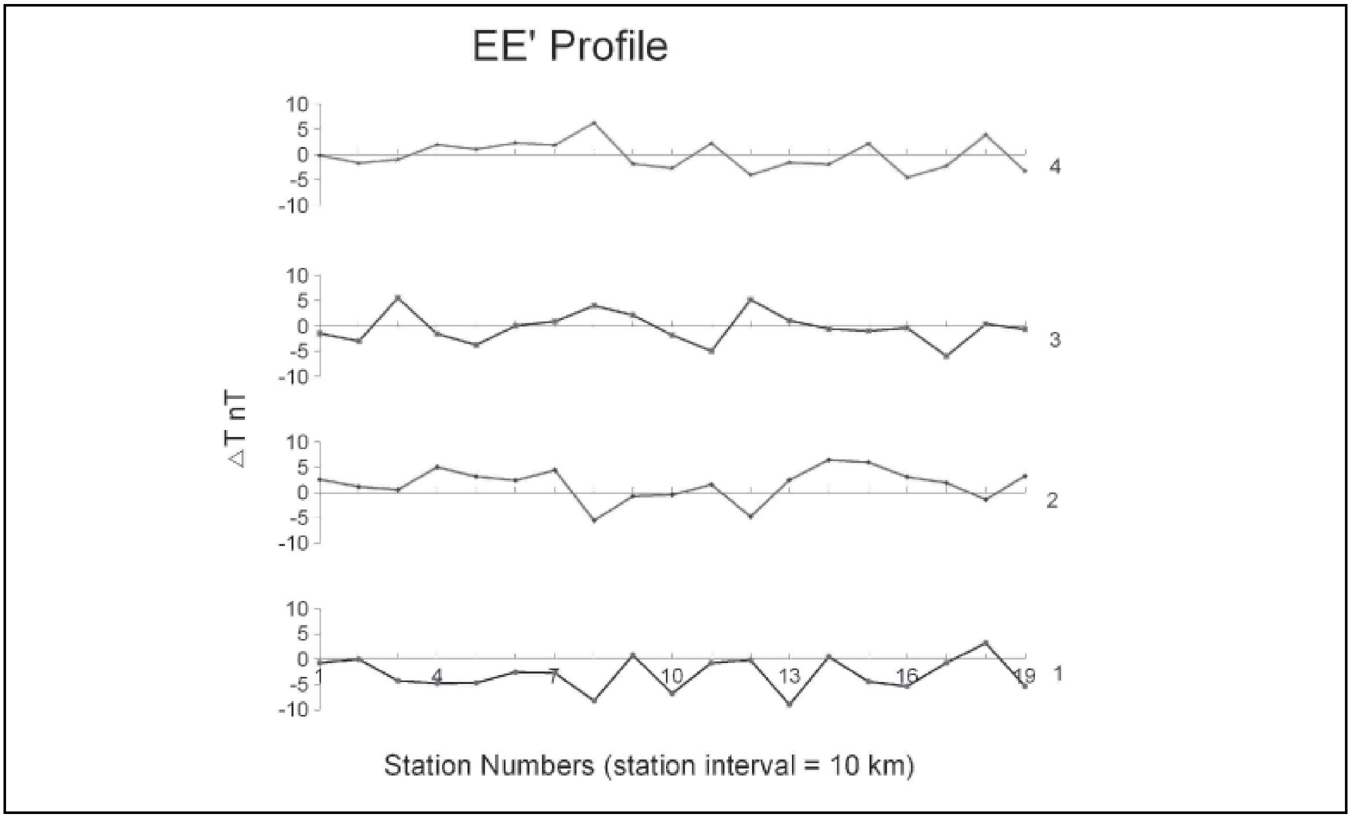

Figure 7. Secular change of the geomagnetic field along Jabalpur-Seoni (EE') profile. 1, ΔT difference (2003-2004); 2, ΔT difference (2004-2005); 3, ΔT difference (2005-2006); 4, ΔT difference (2006-2007).

Jabalpur earthquakes of 22.05.1997 and 17.10.2000). Figs. 3-7 have suggested that the changes of the geomagnetic field in the survey area are probably anomalous. However, it is suggested that the gradual crustal movement can cause stress and tension in the vicinity of faults and weaker zones resulting in the magnetization changes and the signatures can be seen on the magnetic anomaly (Sasai 1991, 1994). If the slower crustal movement develops the stress gradually, then the Central Indian crustal zone comprising NSL is most susceptible to stress development. Because, the region is situated on a seismically active NSL where stresses are continuously getting accumulated due to the movement of Indian plate in NE-SW direction (Gupta et al. 1997). Seismicity associated with NSL is due to the strike-slip or thrust mechanism, consistent with the compressive stresses transmitted from plate boundaries as well as internal fabric of crustal blocks. Besides, the influence of uplift processes such as horst like structures in the form of Satpura mountain ranges that possibly originate through lithosphere-mantle interaction, perhaps are not uniform in magnitude and direction as the plate tectonic stresses (Mall, Singh & Sarkar 2005). The gained data appears to be related to stress-strained state variations of the Earth's crust leading to temporal anomalous variations of the geomagnetic field.

CONCLUSIONS

Repeated measurements of the total geomagnetic field carried out over seismically active Jabalpur and adjoining areas bring out the static secular variation anomalies of the geomagnetic field of the crustal origin ranging from ± 0.06 nT/yr to ± 9.54 nT/yr. The small-scale secular variation anomalies may be a manifestation of tectonically and seismically active parts and joints of different tectonic crustal blocks of NSL. The secular variation anomalies of total geomagnetic field may have resulted in response to the gradual movement of Indian plate in NE-SW direction and collision with Eurasian plate building the stresses and tension on the weaker fault systems of the NSL zone. Data gathered in the present surveys can be of help in investigating the tectonomagnetic effect for the impending seismic activity.

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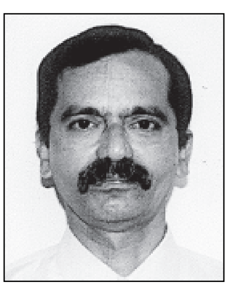

Mr. Arun Govind Patil was born in November 1955 at Mumbai. He got his B.Sc. degree from Mumbai University in 1973. He joined Indian Institute of Geomagnetism in 1980 in the Instrumentation section. He has worked on the development of proton magnetometer. He has published two papers on data processing techniques using proton magnetometer. Currently, he is working as a Technical Officer-II.