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Ground Magnetic and Very Low Frequency Electromagnetic surveys to locate Probable Kimberlites in Panna Diamond Belt, Madhya Pradesh, India

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ABSTRACT

The Panna Diamond Belt of Madhya Pradesh is known for the occurrence of kimberlites that are host rocks to diamonds. Presently, one kimberlite pipe at Majhgawan-Panna is the only diamond mine in India. This is a very old mine producing diamonds for more than 60 years. In order to locate probable kimberlites in the Panna region for diamond mining for an economical growth of the diamond industry in India, ground Magnetic and Very Low Frequency Electromagnetic (VLF-EM) surveys were conducted on probable kimberlite zones. The ground magnetic and VLF-EM surveys were conducted over the Hatinitor Pahar and Kadwara areas which are probable kimberlite zones. Magnetic survey was conducted in grid pattern with profile and observation interval of 50 m in north-south direction. A total of 3,272 magnetic observations were measured along 5 grids and 4 profiles were conducted for the VLF-EM method in the study area.

From the magnetic observations in Hatinator Pahar reduce-to-pole map showed east-west near circular anomaly and over a known kimberlite pipe B125. The reduce-to-pole map of the Kadwara showed a near circular magnetic anomaly and was identified as a kimberlite zone. This anomaly was similar to the known kimberlite B125. From 2-D modeling of the magnetic anomaly a depth of about 100 m was obtained over the Kadwara kimberlite pipe.

The VLF-EM data also correlated with the magnetic observations and a low current density was observed over the Kadwara kimberlite. Thus, the magnetic and VLF-EM observations have clearly demarcated the kimberlite in the PDB.

Keywords: Diamond, Kimberlite, Panna Diamond Belt, Magnetic, Very Low frequency Electromagnetic,

INTRODUCTION

Kimberlites are ultramafic intrusive rocks that form as host rocks to precious diamonds. In the Indian subcontinent, Bundelkhand, Dharwar, Singhbhum cratons are the major kimberlite bearing rocks. The Vindhyan group of rocks overlay the Bundelkhand craton in the Panna Diamond Belt (PDB). Kimberlites are intruded through the Bundelkhand granite and Kimur group of Vindhyan basin (Krishnan and Swaminath, 1959).

The Majhgawan kimberlite pipe is one of the oldest mines producing diamonds in India. Geological Survey of India (GSI) located the Hinota pipe at Majhgawan (Kailasam, 1971) by geophysical methods during 1956-1959. The Saptarshi kimberlite field was identified by Rio Tinto (Masun, 2009). The Geological Survey of India (GSI) reported other probable kimberlite location from the aeromagnetic surveys (Raynes et al., 2018) in PDB. A few more kimberlite locations in the Panna Diamond Belt were reported from gravity and magnetic surveys (Kumar, et al., 2020). In addition to these a few more kimberlite locations were proposed by ground gravity and magnetic surveys in Baghain and Rampura-Motwa areas of Panna Diamond Belt (Mukherjee et al., 2021).

Geophysical response is dependent on the contrast of source with the surrounding environment as well as geometry of the source. Hence, a geophysical response can be observed over the kimberlites since they are hard compact rocks in comparison to the Vindhyan group of rocks. The magnetic method is a conventional method to locate kimberlite. The response for the kimberlite structure is bipolar in nature in magnetic surveys. A kimberlite Pipe-TK6 in Timmasamudram Cluster, Anantapur District, Andhra Pradesh was located as a bipolar anomaly using magnetic surveys (Srinivas, and Rao 2016). Magnetic anomalies that overlap due to poor resolution of the magnetic data can be resolved using second derivate maps (Cowan et. al., 2000). Weathering on the surface of a kimberlite shows a lower magnetic response and impacts the identification of the anomaly (Ruotsala 1975; Burley and Greenwood, 1972; Kamara, 1981; Macnae, 1995).

The Very Low Frequency electromagnetic (VLF-EM) method has been used to identify kimberlite / lamproite in various different geological setting (Kumar, et. al., 2020; Ravi et. al., 2024). The response of the VLF-EM method depends on the nature of the source rocks and weathering of the kimberlite / lamproite. In case of compact rocks, a low current density is observed in the VLF-EM method especially in a sedimentary environment (Kamara, 1981; Kumar et al., 2020). When surficial exposures of kimberlite / lamproite are observed, then there is a possibility of weathering, which would impact the low current density in the VLF-EM response.

Airborne magnetic and radiometric data was analyzed in the PDB and probable kimberlite zones were identified in Hatinitor Pahar, Kadwara, Kishangar and Moharkuwa at the Satya and Kishangar Revenue divisions of Chhatarpur and Panna districts of Madhya Paresh (Lingaswamy and Mathur, 2024). The present work deals with the ground magnetic surveys and VLF-EM response of kimberlite zones in the Satya Kishangar Revenue divisions of the Chhatarpur and Panna Districts of Madhya Pradesh.

GEOLOGY OF THE STUDY AREA

The present study area lies in the Panna Diamond Belt, where the surface rock exposures belong to the Baghin sandstones of Kimur group of rocks and is south west to the known Majhgawan pipe. The kimberlite (974 –1170 Ma) in this area are younger than Proterozoic Vindhyan sub groups of Semri (1599±8 Ma; Rasmussen et al., 2002; Paul et al., 1975). Stratigraphically, the oldest underlined Bundelkhand granite (2.4 –2.5 Ga, Singh and Slabunov, 2016) is the basement of the Vindhyan Group of rocks and the granite mineral composition varies spatially from plagioclase to orthoclase feldspar with or without ferro-magnesian minerals. Semri is an older sub-group of Vindhyan rocks that overlie the

Bundelkhand granite. The Kimur Group of rocks (910 ±39Ma; Vinogradav et al, 1964) overlie the Semri formations. The Rewa Group of rocks are the youngest formations in the Vindhyan Group of rocks (710 Ma±120Ma; Srivastava and Rajgopalan, 1988). Kimberlites intruded through Semri and Kimur and buried under Rewa group of rocks. These kimberlites have been classified as 'transitional kimberlite–orangeite–lamproite' rock type (Chalapathi Rao, 2006).

There have been significant advances in understanding the geological formations and their mineral inclusions and relationships between the occurrence of diamonds, this has been a topic of importance for developing the diamond mines in this area (Sarkar et al. 1984; Smith et al.2017; Singh and Slabunov 2016). The present area of the study lies between north latitude 24º 27'24.04" to 24º 37' 49.64" and meridians of east longitude 79º 40' 14.59" to 79º 51'43.78" to explore the occurrence of kimberlites. The thickness of the Vindhyan group of formations in this area is about 600m (Bhattacharya et al. 1995). B125 and B108 are the known kimberlites the study area. Shale, limestone andsandstone are the major rock types in the area and Geological Survey of India (https://bhukosh.gsi.gov.in.) inferred a fault which is in NW-SE direction in the study area and formations dip in SE direction and trend is in NE-SW direction.

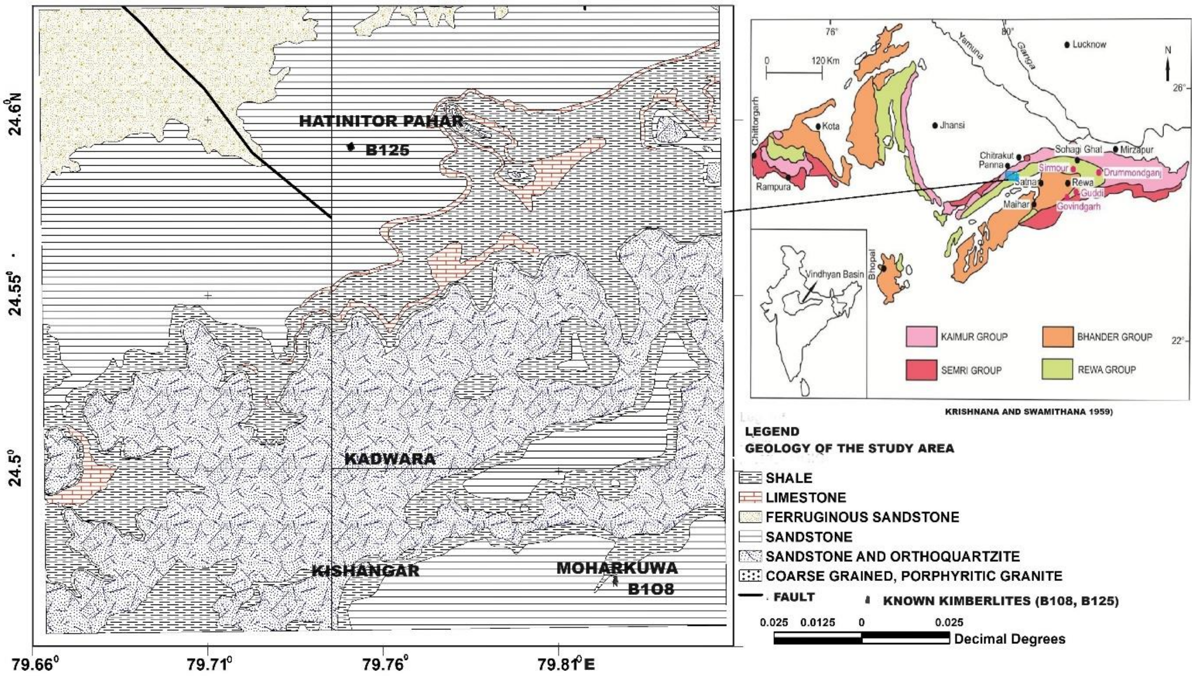

Figure 1. Geological map of the study area (https://bhukosh.gsi.gov.in)

GROUND MAGNETIC SURVEY

The total magnetic field was measured in a grid pattern in Hatinitor Pahar and Kadwara regions of the Panna Diamond Belt where probable locations of kimberlite exits. For this purpose, a Proton Precession Magnetometer (PPM-600T) of GEM systems make with a resolution of 0.1 nT was used. The magnetic inclination and declination of the study area is 38.2° and 0.4° respectively. The magnetic anomaly over the kimberlite pipe generates a circular or near circular anomaly that becomes easier to identify the structures. In case of weathering in the kimberlite the magnetic anomaly may be asymmetric.

The survey was planned along north- south profiles in a grid pattern in the survey area. These grids were prepared based on Remote sensing, geological stream sediments (Guha et al, 2018), aeromagnetic and airborne radiometric data (Lingaswamy and Mathur, 2024). A total of 3272 magnetic observations were measured with a profile and observation interval of 50m. For the purpose of diurnal correction, a similar PPM was placed outside the survey area at a fixed point during the period of recording the magnetic data with the rover. The total magnetic field was recorded at the base station with a 10-minute time interval. The magnetic data was subjected to diurnal correction and of International Geomagnetic Reference Field (IGRF) correction using the 13th generation IGRF field with the survey year as 2019.

The magnetic survey was conducted on a known kimberlite B125 (**Figure 1**) which is located in Hatinitor Pahar area. The magnetic anomaly map of the B125 (**Figure 2**) shows a near circular anomaly in the centre of the grid and trending in north-south direction, controlled by declination and inclination of the ambient field, The maximum and minimum contour levels are 394nT and 368nT with a contour interval of 2nT. The elongated anomaly on the western side of this circular anomaly can be observed. It might be an intrusive (**Figure 2**).

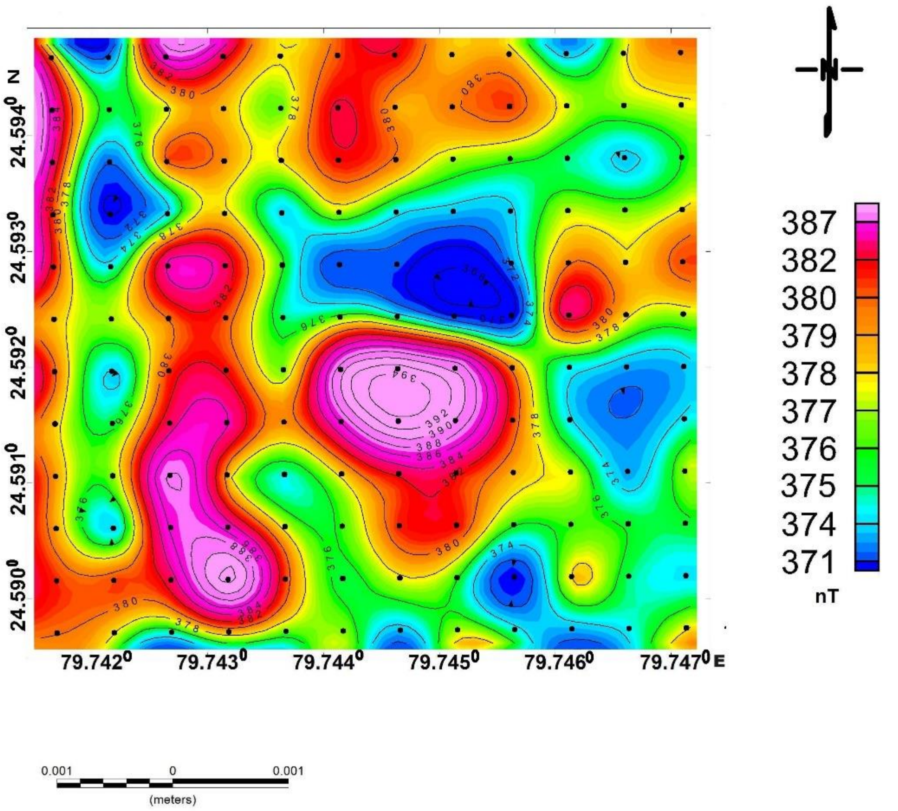

Figure 2. Magnetic Anomaly map of Hatinitor Pahar Grid of known kimberlite (B125)

The anomaly map of the Hatinitor Pahar grid-1(**Figure 3**) defines parallel fractures in north-south direction and strong low and high circular anomalies can be observed along these fractures which are generated by cress cross fractures. The magnetic contours of anomaly map are from 300nT to 395nT with contour interval of 5nT.

The Hatinitor Pahar grid-2 anomaly map (**Figure 4**) delineates a high in the south east and a low in the central region of the area. The variation from high to low is representative of a fracture zone dissecting the high and low. The magnetic contours in this region range from 430nT to 530nT.

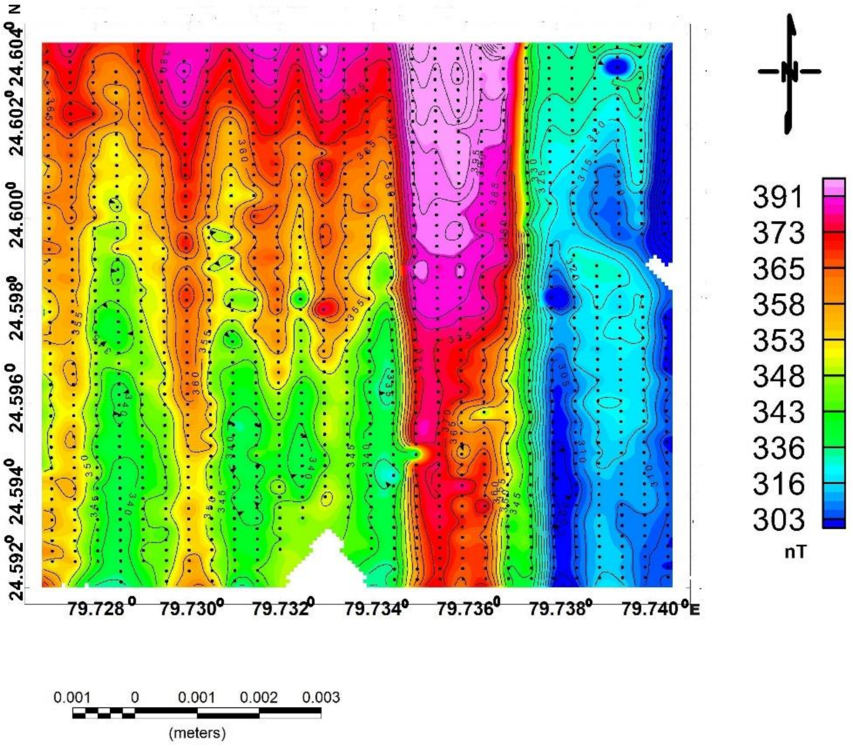

Figure 3. Magnetic anomaly map of Hatinitor Pahar grid-1

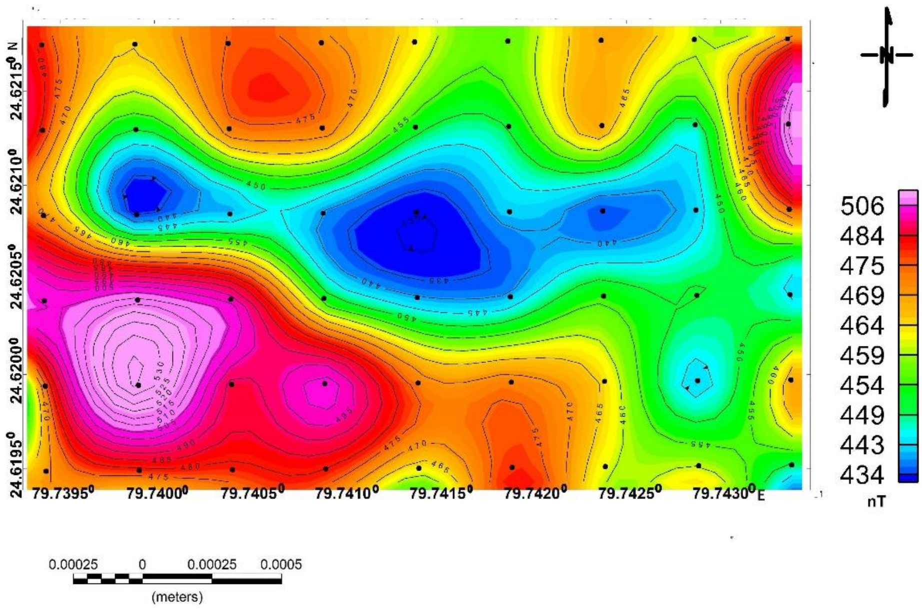

Figure 4. Magnetic anomaly map of Hatinitor Pahar Grid-2

The Kadwara gird-1 (**Figure 5**) with a contour interval of 5 nT shows a circular bipolar anomaly in the central region displaced slightly towards the west. The trend of the Kadwara anomaly is similar to the known kimberlite (B125) of the Hatintor Pahar (**Figure 2**).

In Kadwara grid-2, the magnetic anomaly is plotted with a contour interval of 5 nT. The east-west direction anomaly observed (**Figure 6**), which could be an intrusive bipolar anomaly with a linear pattern in the north-south direction, which could be because of the presence of lineaments or fractures, or may be attributed to local magnetic heterogeneity.

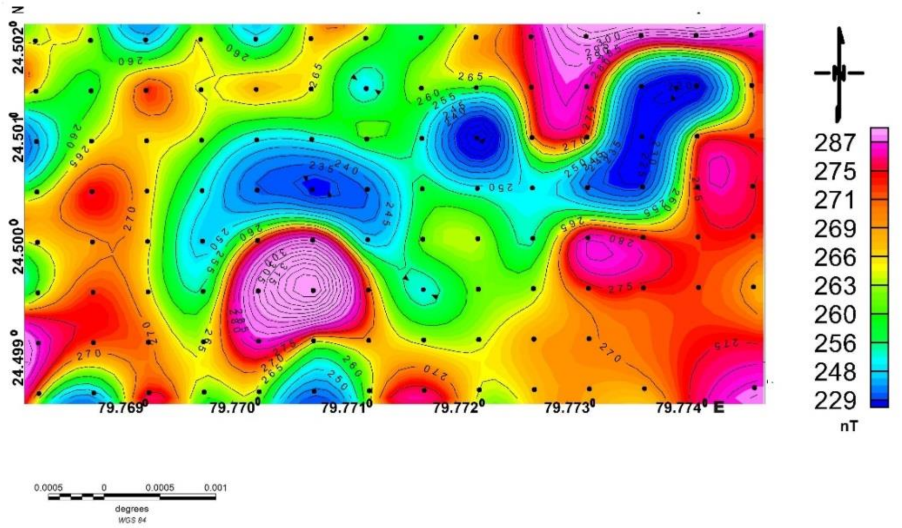

Figure 5. Magnetic anomaly map of Kadwara grid-1

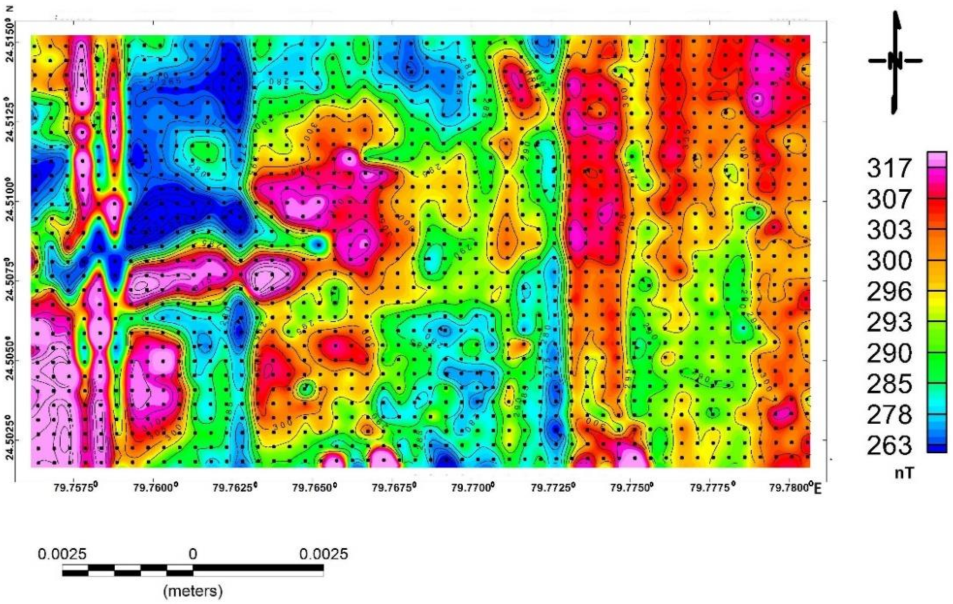

Figure 6. magnetic anomaly map of Kadwara grid-2

For a detail understating of the magnetic anomalies in the Hatinitor Pahar and Kadwara regions reduce-to-pole (RTP) technique was applied to the total magnetic field anomalies as this removes the asymmetry which is generated by the magnetic inclination at low latitudes (Baranov, 1957; Baranov and Naudy, 1964; Telford et al., 1990; Hansen and Pawlowski, 1989; Mendonca and Silva 1993; Silva, 1986). A circular anomaly with a magnetic high is observed over B125 Kimberlite in the RTP map (**Figure 7**). The north-south directed linear high magnetic anomaly to west of the circular anomaly could be due to the presence of an intrusive body. This implies that the area could be impacted by fractures which could have originated from the kimberlite intrusion.

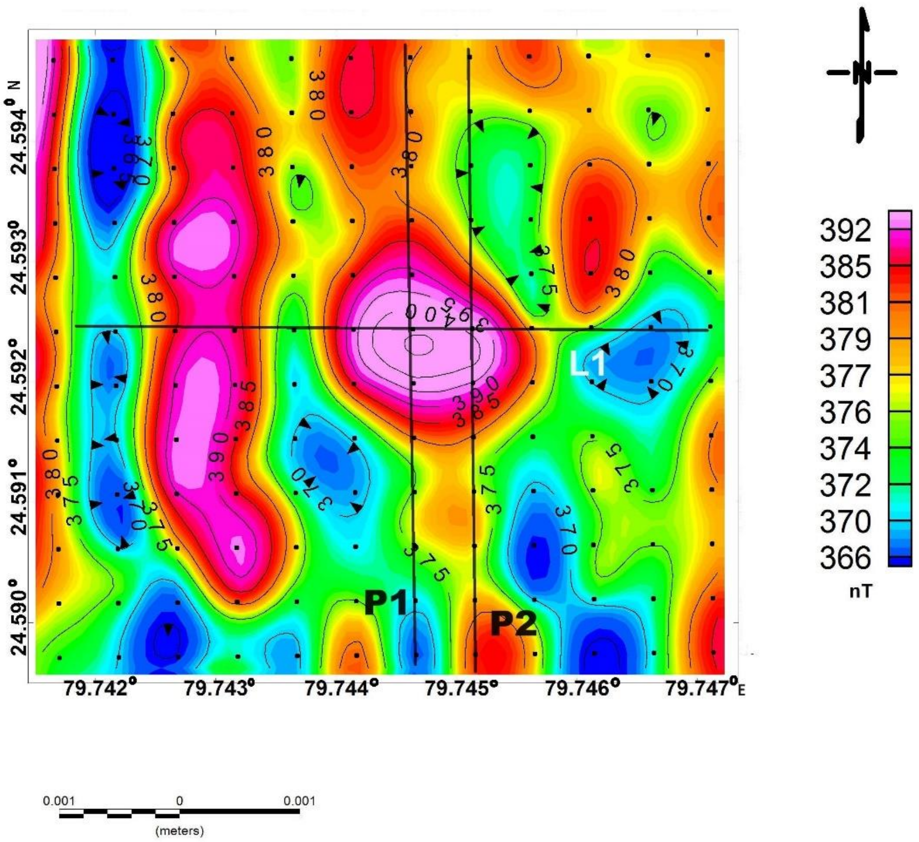

Figure 7. Reduce to pole Map of Hatinitor Pahar Grid(B125).

The RTP map of Hatinitor Pahar-1 shows north-south directed linear bipolar anomaly towards the western side of the map (**Figure 8**). This could be attributed to the response of deep parallel fractures.

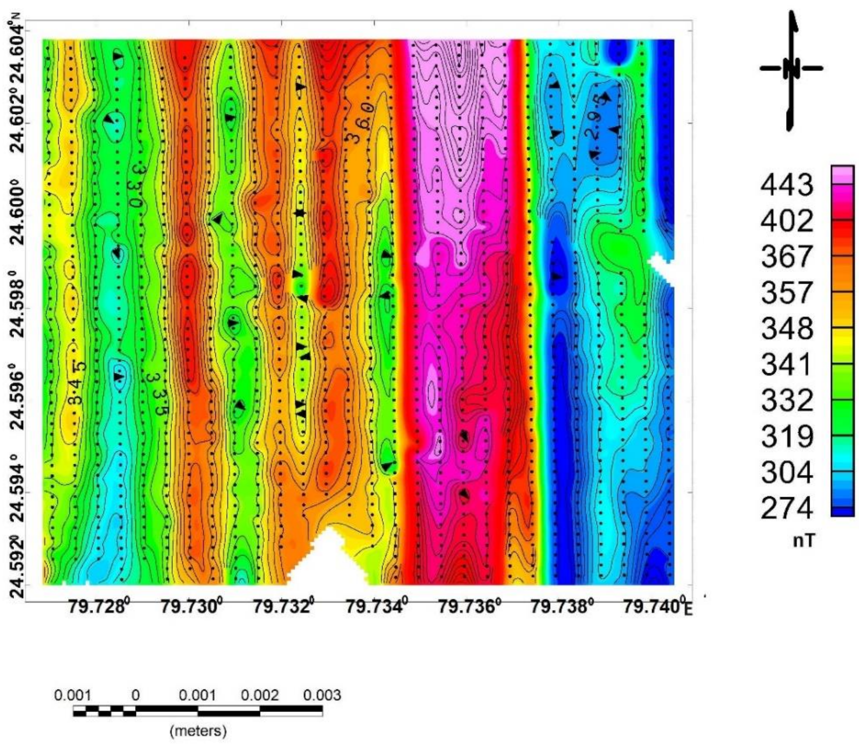

Figure 8. Reduce to Pole Map of hatinator Pahar-1

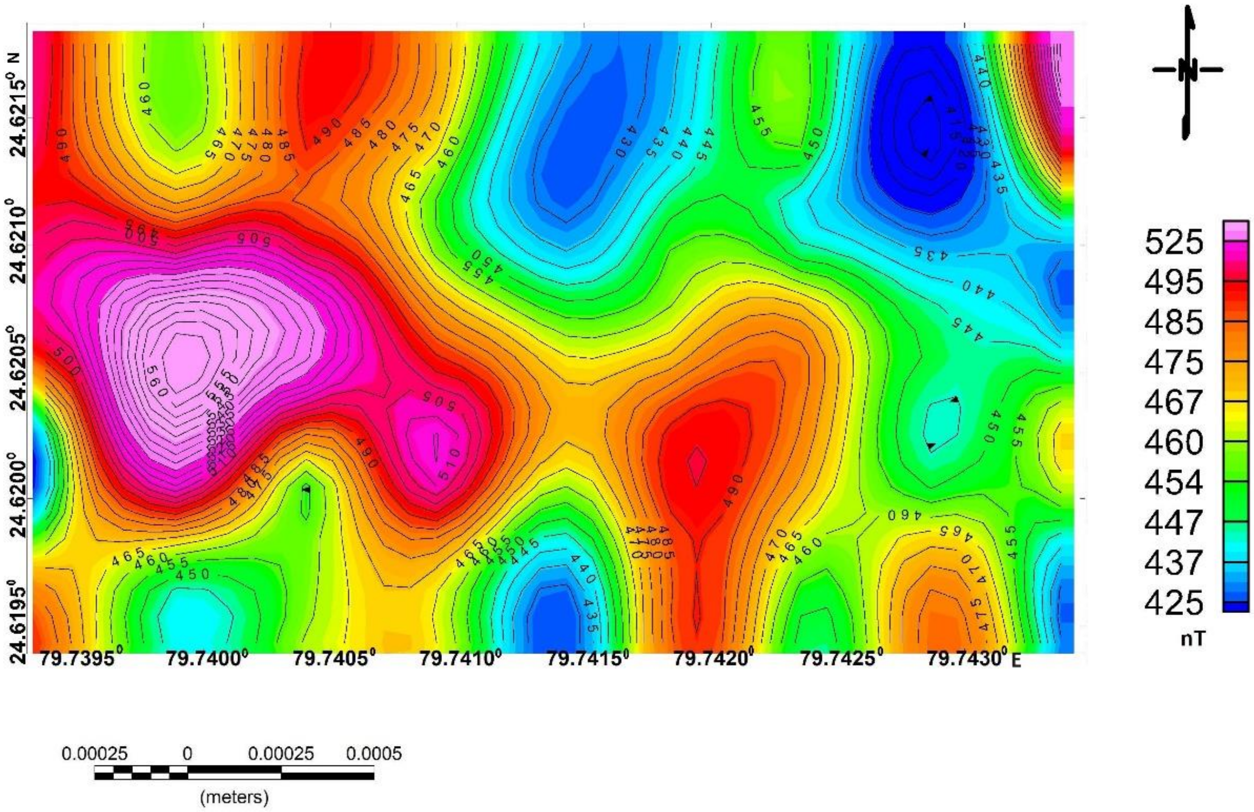

Figure 9. Reduce to Pole Map of Hatinitor Pahar grid-2

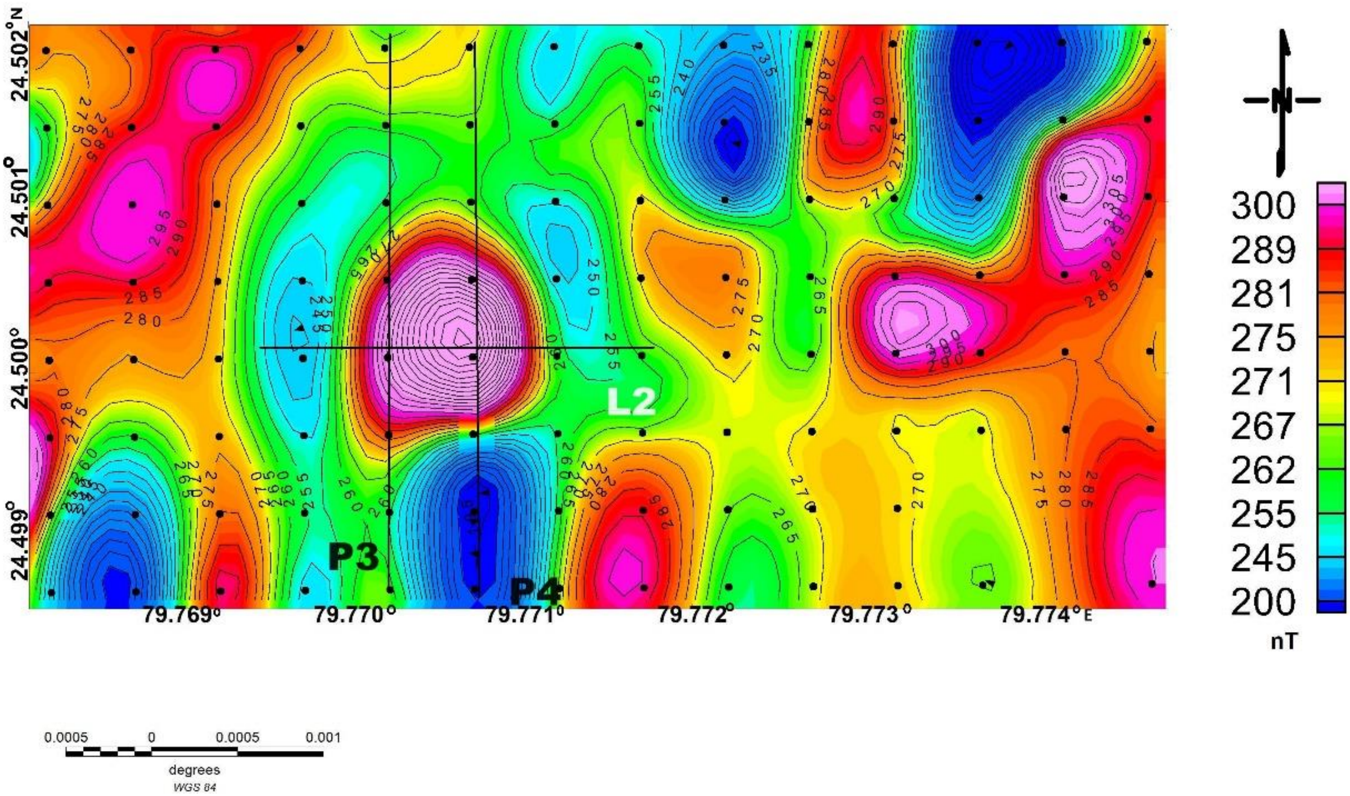

Figure 10. Reduce to Pole map of the Kadwara grid-1

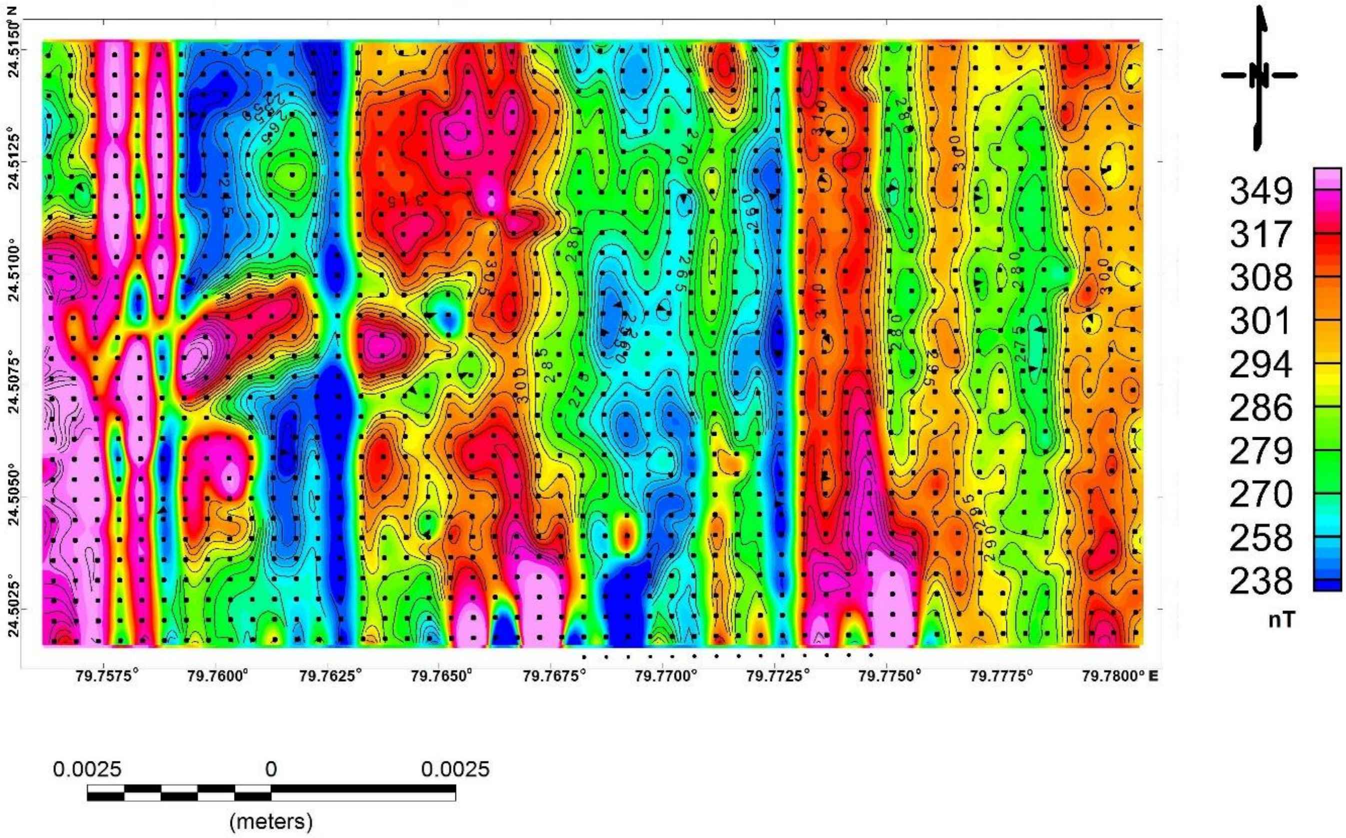

Figure 11. Reduce to Pole map of the Kadwara grid-2

The RTP map of Kadwara-1 (**Figure 10**) depicts a similar circular anomaly as observed for B125 kimberlite as depicted in the RTP map (**Figure 7**). Further, in Kadwara-1 region apart from the north-south trending bipolar anomalies east-west trending anomalies can also be observed that represent fractures in this region.

The Kadwara-2 RTP map (**Figure 11**) depicts several north-south trends that are bipolar in nature and an east – west trend of the anomalies dissected and displaced in north -south direction. This spatial displacement is inferred as a fault trending in the north-south direction. In order to interpret the anomalies 2-D modelling was carried out over profiles as depicted in **Figure 10,7**.

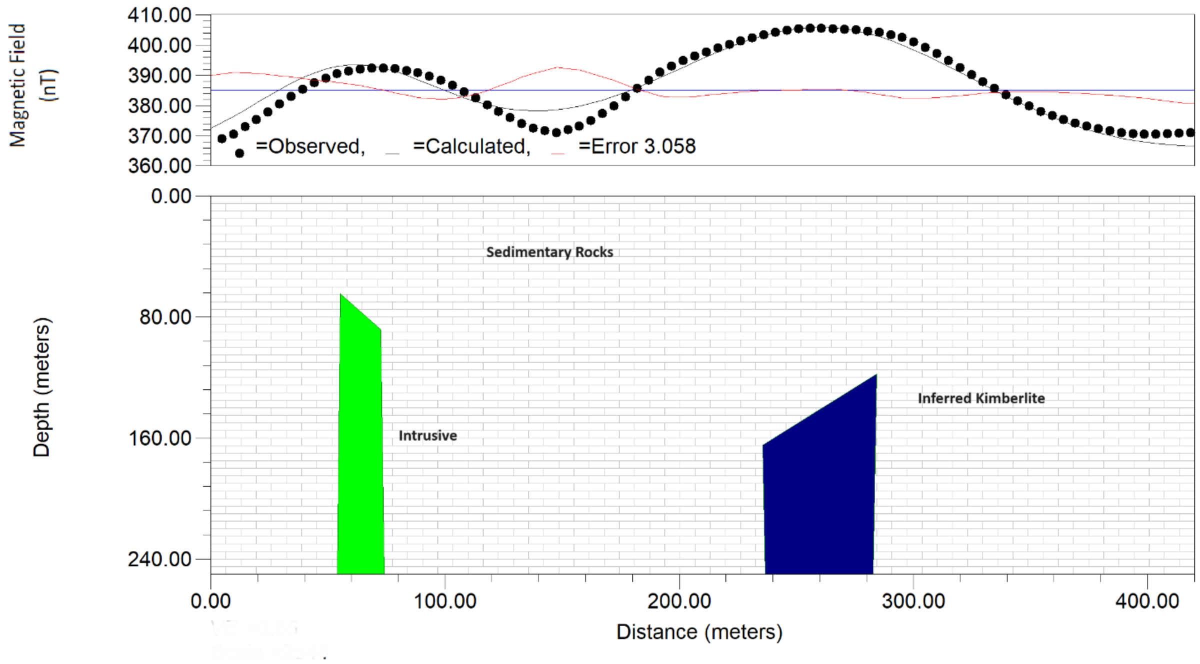

Figure 12. 2D Depth model of the circular anomaly of the profile L1 on B125 kimberlite area (Figure 7)

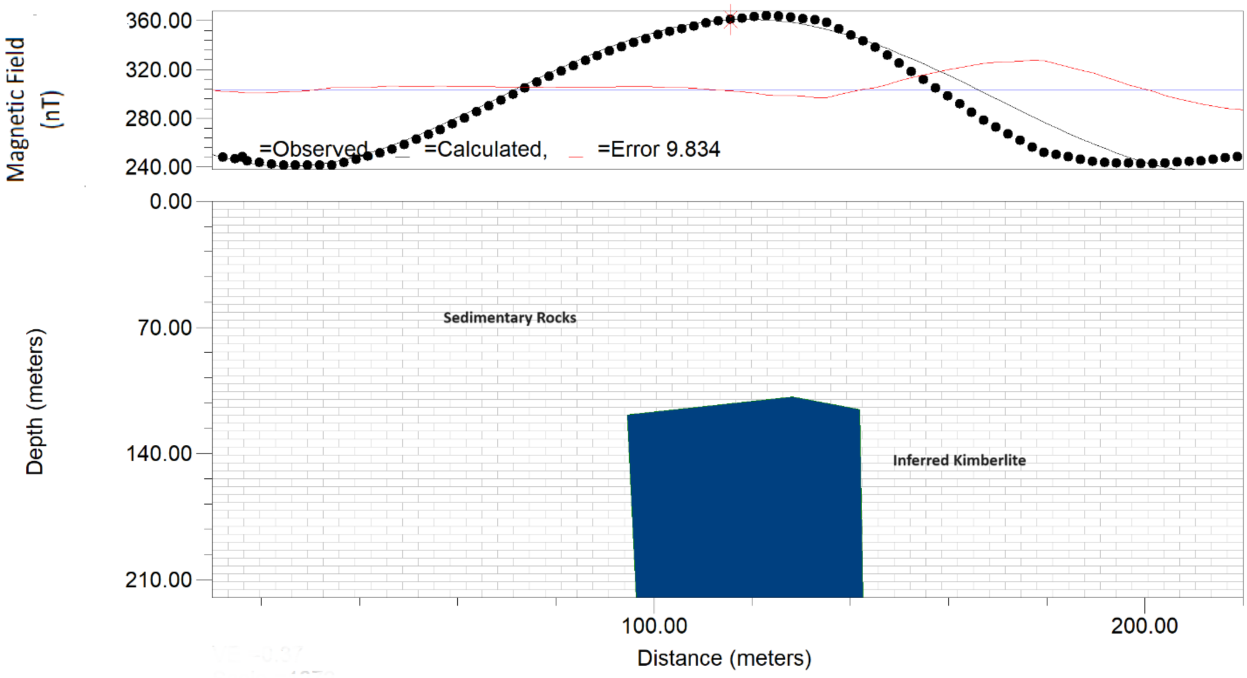

Figure 13. 2D Depth model of the circular anomaly of the profile L2 on Kadwara area (Figure 10)

The 2-D depth model (**Figure 12**) was prepared on known kimberlite pipe B125 anomaly of Hatinitor Pahar area. Depth to known kimberlite B125 is 120m approximately and inferred intrusive body was also defined in the depth modal with depth 75m (**Figure 12**). The susceptibilities for kimberlite rocks were assumed as 0.0867 SI units for the purpose of creating the 2-D models. Depth of the inferred kimberlite of Kadwara-2 (**Figure 13**) is approximately 110m and the susceptibility considered for this model is 0.33 SI units . A susceptibility of 0.02 SI units was considered for the surrounding sedimentary rocks.

VERY LOW FREQUENCY ELECTROMAGNETIC SURVEY

VLF-EM survey is a tilt angle method and it measures the tilt angle and the phase components of the field in the frequency range of 15-30 KHz using the electromagnetic primary field of naval broadcasting stations. The survey has been conducted with ABEM WADI VLF-EM instrument (**ABEM, 1990**). The observation interval along a profile was 50 m over the probable kimberlite locations based on the interpretation of the magnetic survey. The pseudo depth sections for the VLF-EM survey were computed using the Karous and Hjelt filter (**Karous and Hjelt, 1983**) using the Wadi VLF-EM software (RAMAG) (**ABEM, 1990**).

The VLF-EM profiles P1 and P2 were observed over the known location of the kimberlite B125 (**Figure 7**). To obtain more clarity for the location of the kimberlite, the observation interval for these profiles P1 and P2 was reduced to 30 m in B125. In Kadwara-2 the observation interval was also reduced to 25 m and are shown along profile P3 and P4 (**Figure 10**).

The real and imaginary component for profile P1 is shown in **Figure 14a**. The negative and positive peak of the real component are associated with the fractures as inferred from the magnetic anomalies. This fracture zone is prominently depicted in the pseudo depth section (**Figure 14b**) as the separation between the higher and lower current density contours.

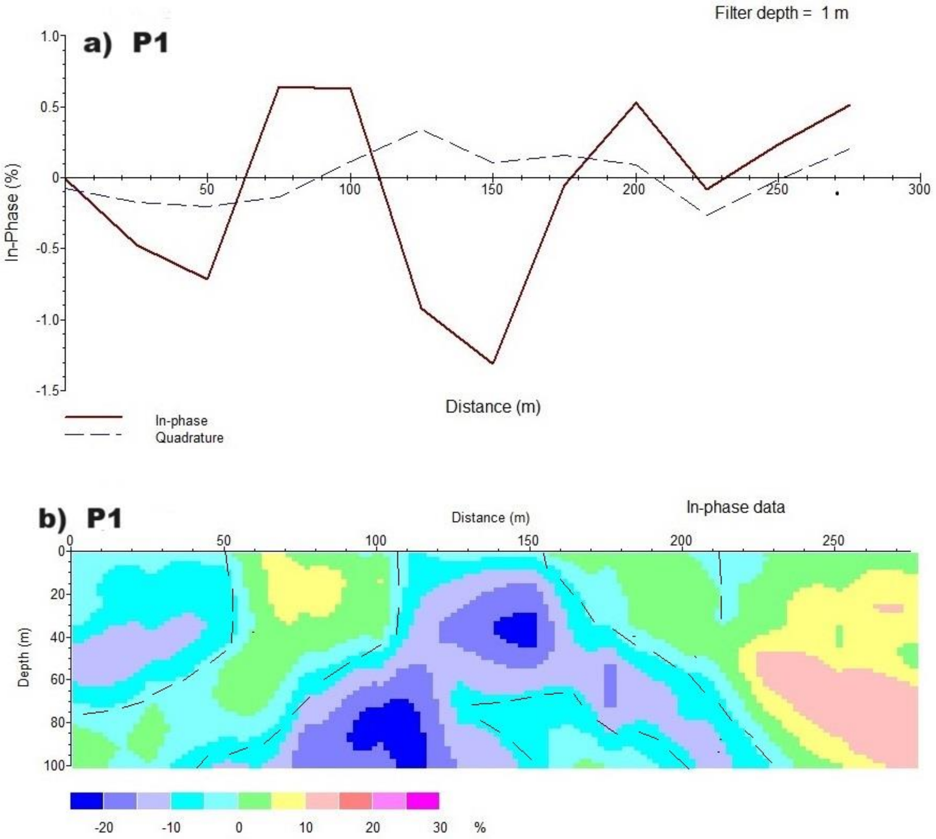

Figure 14. VLF_EM profile P1 on Hatinitor Pahar Grid of B125(Figure 7) a) VLF_EM in-phase and quadrature components b) VLF-EM current density depth section

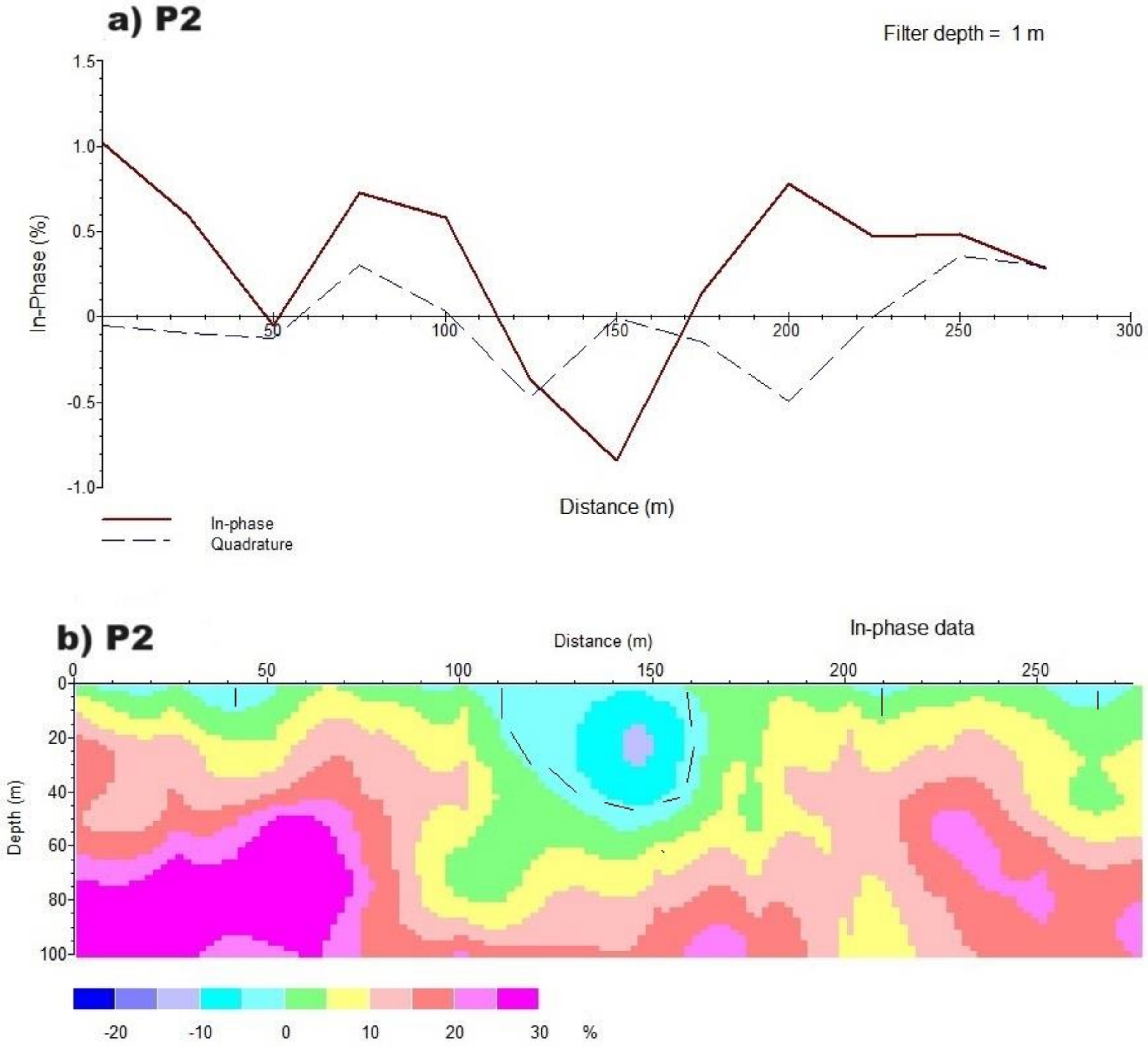

Figure 15. VLF_EM profile P2 on Hatinitor Pahar Grid of B125(Figure 7) a) VLF_EM in-phase and quadrature components b) VLF-EM current density depth section

The In-phase component of profile P2 (**Figure 15a**) are similar to that of profile P1 (**Figure** 14a). However, the 2-D pseudo depth section depicts a shallow zone with low current density separating two higher current density zones. This is due the influence of the north-south fracture zone, unlike the east-west fracture as depicted in **Figure 14b**.

In the Kadwara grid-1 area the VLF profiles P3 and P4 were planed over the near circular anomaly observed in the magnetic survey (**Figure 10**). The In-phase component of the profile P3 (**Figure 16a**) depicts the north-south fracture trend and is correlated with the magnetic anomaly. The pseudo depth section (**Figure 16b**) shows the high and low current density anomalies separated by a sharp edge, which represents the north-south fracture zone as depicted in the magnetic map (Figure 12). The P4 profile (**Figure 17a**) of In-phase component and pseudo depth section (**Figure 17b**) also depict a similar behaviour as observed in profile P3, however the low and high current density contours are reversed, this could be due to weathering.

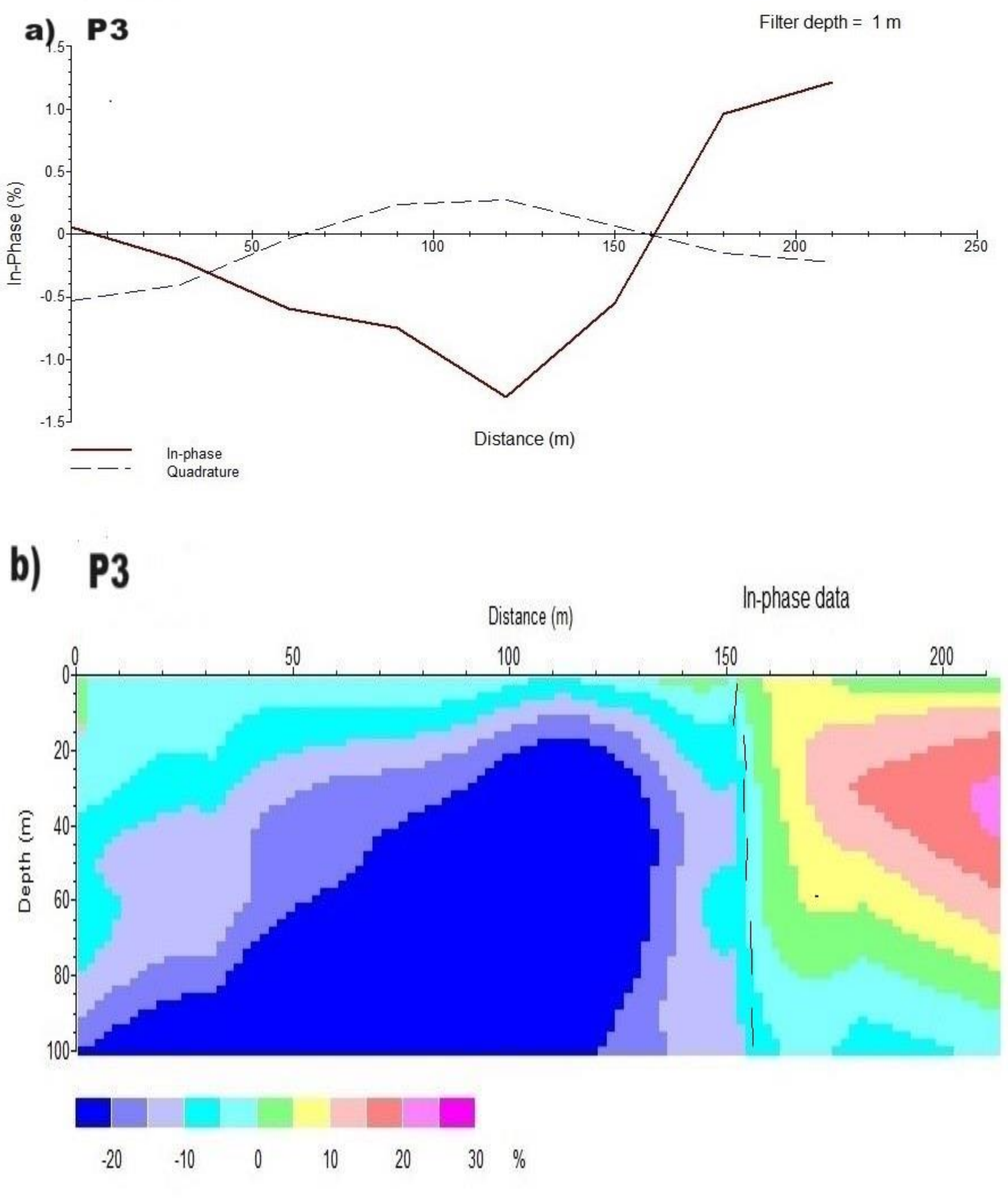

Figure 16. VLF_EM profile P1 on Kadwara grid-1(Figure 10) a) VLF_EM In-phase and quadrature components b) VLF-EM current density depth section

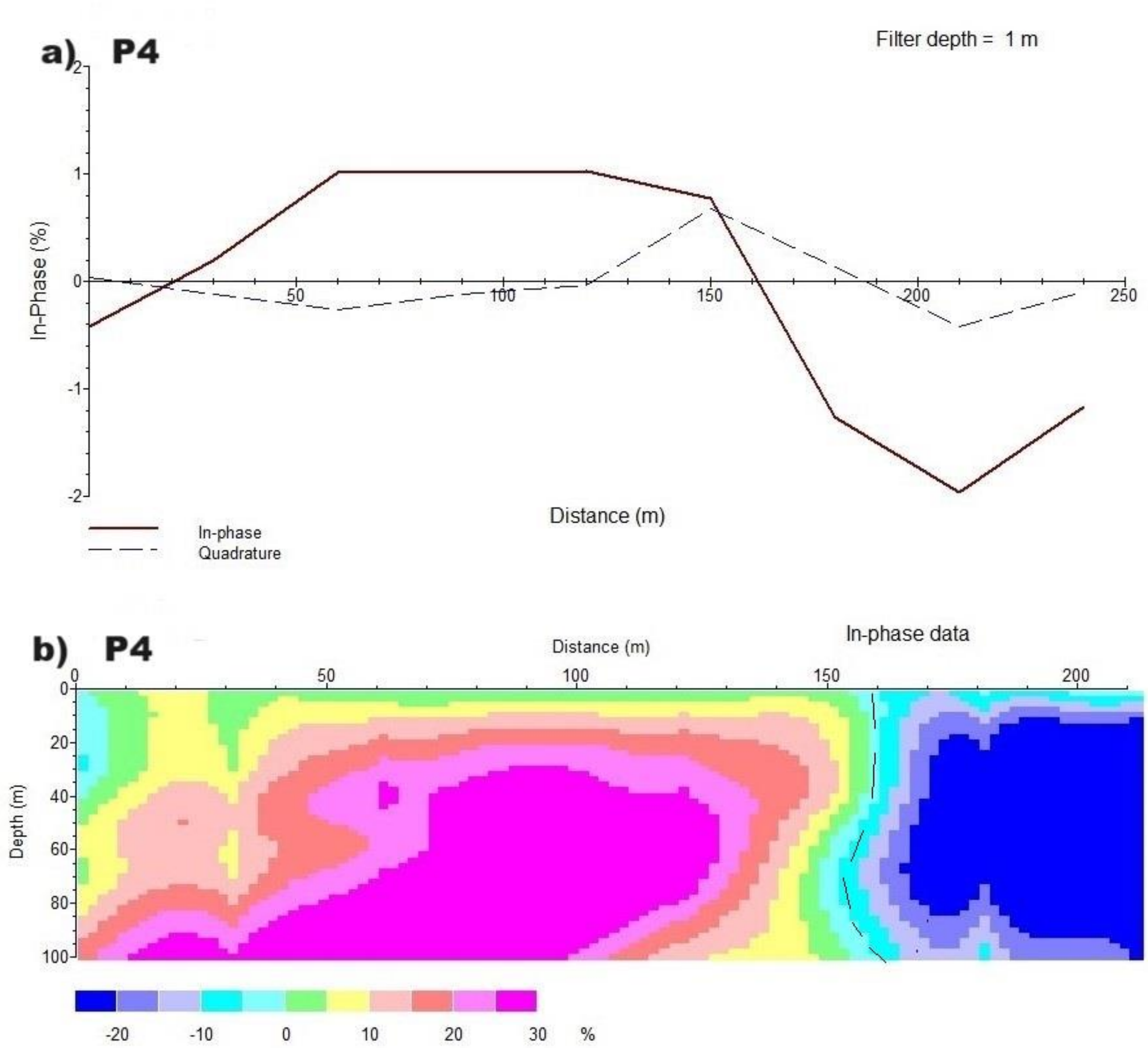

Figure 17. VLF_EM profile B on Kadwara grid-1(Figure 10) a) VLF_EM In-phase and quadrature components b) VLF-EM current density depth section

DISCUSSION AND CONCLUSIONS

Ground magnetic and VLF studies have helped to delineate the kimberlite intrusives in Vindhya Basin Rocks. In the magnetic anomaly map the B125 kimberlite (**figure 2**), Hatinitor Pahar grid-2 (**Figure 4**) and Kadwara grid-1 (**Figure 5**) shown circular or near circular anomalies. The same has been observed in the reduced-to-pole anomalies of B125 kimberlite (**Figure 7**), Kadwara grid-1 (**Figure 10**) and Hatinitor Pahar grid -2 (**Figure 9**). The 2-D psuedo depth sections ploted from the VLF-EM studies for B125 kimberlite (**Figures 14b and 15b**) and Kadwara grid-1 (**Figure 16b, 17b**,) depict the fractures associated with the kimberlites and their contact zones as observed in the magnetic data (**Figures 7, 10**). The depth of kimberlite bodies was computed as more than 100m from the magnetic and VLF-EM data and the same has been confirmed from earlier studies (Mukherjee et. al., 2021; Lingaswamy and Mathur, 2024) in the Panna Diamond Belt.

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