Application of 2D Resistivity Modelling to Delineate Lamproites in Parts of North-Eastern Dharwar Craton

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Research Article

Keywords: Lamproite, Northeastern Dharwar Craton, Electrical Resistivity method, Wenner Resistivity, 2D Electrical Resistivity Inversion model

Posted Date: January 11th, 2022

DOI: <https://doi.org/10.21203/rs.3.rs-1162405/v1>

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Abstract

Geophysical methods have extensively been used in exploration of Lamproite bodies. Lamproites are significant source rocks of primary diamond deposits other than Kimberlites. The Eastern Dharwar Craton is unique in the way that it hosts numerous Precambrian Lamproites confined to the crescent-shaped Paleo-Mesoproterozoic Cuddapah Basin and its north-western and north-eastern margins. In the present study electrical method was used as a tool for delineation of Lamproite bodies in contrast with country rocks in Gundrapally, Vattikode and Marepally regions in parts of the North Eastern Dharwar Craton in Telangana State, India. The electrical profiling method was conducted in different direction to identify the variation of the lithology of the area due to the anisotropic nature and smaller size of the 2-D intrusive bodies adopting the Wenner electrode configuration. The electrical properties of the Lamproites tended to change with their composition due to weathering and the presence of Olivine and K-Al rich composition. The electrical response on the Lamproite pipes is shows a decrease in resistivity concerning the country-rock in the area.

Introduction

Lamproites and kimberlites are primary source rocks for diamond exploration (Mitchell, 1991) worldwide and have significant economic value. Remote sensing geophysical and geochemical techniques are best suited for the exploration of lamproites. The current (DC) electrical resistivity technique is the most commonly used geophysical exploration method aimed at estimating the electrical resistivity of the subsurface (Parasnis, 1986; Telford et al., 1990; Reynolds, 2011). The recent development in electrical instrumentation in electrical methods in mineral and groundwater exploration has proven to be suitable for detecting metalliferous ore bodies because the minerals they contain are often good conductors of electricity (Defourny et al., 2020; Francis, 1987; Loke et al., 2013; Hoover et al., 1995; Vallee et al., 2011). The magnetic method in combination with the electromagnetic method or the resistivity method has proven to be tools for mapping intrusion bodies as kimberlite or lamproite (Macnae, 1995). In the last few decades, due to significant progress in instrumentation and data acquisition, processing and interpretation procedures, electrical resistivity tomography (ERT), in 2D or 3D configurations, is among the most widely used techniques for DC resistivity measurements in the field of geophysical prospecting, as it allows very high-resolution imaging of the electrical properties of the subsurface (Revil et al., 2012; Loke et al., 2013).

Earlier studies have successfully demarcated Lamproite bodies using the electrical method, as in the case of Ellendale Lamproite pipes in Western Australia that show a conductive nature (Graham Jenke et al., 1994; Michael, 1994). The economic significance of lamproite became known with the discovery of Ellendale E4 and E9 lamproite pipes (Jaques, 1986) and the better known 1979 discovery of the Argyle diamond pipe in Western Australia. (Scott, 1979). In tropical and subtropical climates, Kimberlite was shown to possess an electrically conductive nature and show a good response (Kamara, 1981). These discoveries led to the intense study and re-evaluation of other known lamproite occurrences worldwide; earlier, only Kimberlite pipes were considered economically viable sources of diamonds.

The lamproites of the present study area fall under the part of the northeastern Dharwar Craton in Telangana state, India, as shown in Figure 1. The villages of Gundrapally, Vattikode and Marepally were mapped in the present study, and the lithology, structure and lamproite pipes of this area are shown in figure 2 in parts of the northeastern Dharwar Craton. The dimensions of the intrusive bodies in the area range from a few cm to a few 100 meters. Hence, to locate these bodies, an electrical resistivity profile was carried out in two or three different directions on the lamproite pipe (Chandra et al., 1987). The Wenner resistivity profiling method (Dias et al., 2010) was used with a potential electrode separation of 30 m and a current electrode separation of 90 m. For the Wenner electrical method, the resistivity is given by $\rho = 2\pi a(V/I)$, where 'a' is the electrode separation between any two electrodes, 'V' is the potential difference and '2 πa ' is the geometry factor for the Wenner configuration (Minarto et al., 2021; Igboama et al., 2011; Dobrin and Savit, 1988).

In the study area approximately 9 VES profiles were conducted. On Vattikode lamproites pipes VL4 and VL5, one VES profile in 186° NW -SE direction at location 16°54'58.22"N, 79°5'24.13"E, and another VES profile in 80° SW-NE direction and at location 16°54'58.21"N, 79° 5'24.36"E. On Vattikode lamproites pipe VL8, One VES profile in 10° SW-NE direction at location 16°55'17.73"N, 79° 4'26.10"E. On lamproite pipe VL6, One VES profile in 190° in NE-SW direction at location 16°55'17.67"N, 79° 4'26.96"E. On Marepally Lamproite ML-1, one VES profile in 168° NW-SE direction and another profile in 12° SW-NE direction at location 16°53'0.52"N, 79°14'5.44"E. On Gundrapally lamproite GL-1, One VES profile in 218° NE-SW direction, another 2nd VES profile in 135° NW-SE direction and 3rd VES profile in 177° NW-SE direction on at location 16°56'36.96"N, 79° 2'37.90"E. The Resistivity is affected by composition and its weathering conditions. The objective of the study is to find the resistivity contrast of lamproite pipes with country rock in the study area.

Geology setting of the study area

The Dharwar Craton encompasses the states of Karnataka, Andhra Pradesh, Telangana and Tamil Nadu with Peninsular gneissic complex rocks and greenstone belts (Naqvi and Rogers, 1987). The Peninsular Gneissic Complex is composed of Tonalites, Trondhjemites and Granites (TTG suite), which are emplaced during several cycles of cratonic accretion between 3.3 and 3.0 Ga. Recent geological and geophysical studies have demarcated western and eastern Dharwar Cratons, where the eastern margin of the Chitradurga schist belt represents the crustal-scale shear zone defining the boundary between the EDC and WDC (Fareeduddin et al., 2012, Chadwick et al., 2000; 2007, Ramakrishnan and Vaidyanathan, 2008; Chardon et al., 2011). The Eastern Dharwar Craton encompasses several schist belts: the Kolar, Hutti, Ramgiri-Hungund, Gadwall and Peddavura Schist belts (Rajamanickam et al., 2014). These schist belts are characterized by mafic metavolcanic rocks and subordinate amounts of ultramafic rocks and volcanoclastic sediments. The eastern margin schist belts have been truncated with major shear zone events that are responsible for gold-bearing hydrothermal fluids (Sarma et al., 2011). A notable feature of EDC is the presence of 1.1 to 1.2 Ga potassic ultramafic intrusive Kimberlitic and lamproite compositions (Ashutosh Pandey et al., 2017). These dikes are widespread in the central and northern parts of the EDC, and obviously, there are a large number of mafic dikes. Schist belts, quartz veins, and dolerite dikes are

the result of postvolcanic eruptions from 1100 Ma to 1350 Ma (Ashutosh Pandey et al., 2017) within the craton. Tiny portions of these favourable zones for kimberlites and lamproites. The lineaments of their interactions are also favourable zones for the detection of lamproite and kimberlites. The lineament and dikes map of the study area are shown in Figure 4.

Many Precambrian lamproites are limited to the crescent-shaped Precambrian Cudahy Basin and its edges in the Eastern Dharwar Craton. The Cudahy Basin Lamproites (Chelima, Zangamarajupalle, and Banganapalle), the Krishna Lamproite Field (KLF), the Ramadugu Lamproite Field (RLF), and the Vattikode Lamproite Field (VLF) are the four groups of lamproites (Kumar et al., 2013). Pseudoleucite-phlogopite lamproite is found in the VL4 and VL5 dikes, while pseudoleucite-amphibole-lamproite is found in the VL2 and VL3 dikes. VL6 pseudoleucite-phlogopite-amphibole-lamproite, VL7 pseudoleucite-phlogopite-amphibole-lamproite, and VL8 pseudoleucite-phlogopite-amphibole-TiO₂ (5.6% by weight) and Al₂O₃ are abundant in the phlogopite in these lamproites (7-8 percent by weight). Phlogopite and sanidine predominate in Gundrapally lamproite, with a high degree of phlogopite alteration to carbonate, chlorite, and serpentine. Lamproite Marelli (ML1). This lamproite is dominated by leucite phenocrysts with concentrically distributed glass inclusions set in an aphanitic groundmass rich in carbonate, as well as phlogopite. (Alok Kumar et al., 2013). The study area map with lamproite pipes is shown in figure 1, and the lithology map is shown in figure 2. The grey hornblende granite and Alkali felspar granite are the major lithologies of the study area. The Vattikode lamproites are in the upper part and are weathered and greenish. The Marepally Lamproite and Gundrapally Lamproite are gray in color. The surface exposer of field photographs of Gundrapally and Vattikode shown in Figure 3. The surrounding rocks are gneiss complex rocks biotite gneiss, quartzites, etc. The mineralogy of the Vattikode lamproite pipes is related to that of the Ramadugu, Somavarigudem and Yacharam lamproite pipes, which also occur in the Ramadugu lamproite field.

Geophysical Surveys

The study was conducted considering the regional primary tool maps of lineaments and dikes. The VES profile technique was adopted in the present study to demarcate the lamproites in the area. Electrical techniques are equally popular as magnetic techniques and are as effective as magnetic techniques for lamproite exploration. Lamproites are ultramafic in composition and, as a result, generally tend to weather more rapidly than most surrounding rocks. Crustal rocks conduct electricity primarily via the movement of ions through pore water and minerals in rocks (Yoshino, 2019).

In 1915, Frank Wenner proposed the four-point resistance measuring method for determining concrete surface conductivity. For the measuring of semi-homogeneous materials, this method is commonly suggested (Tuutti, 1982). Due to the nonhomogeneous nature of concrete, the specimen geometry, size, and spacing have an impact on the resistance value obtained by this approach (Chen et al., 2014). Electrical resistivity 2D inversion is one of the most extensively utilised techniques in the field of geophysical prospecting for DC resistivity measurements, as it provides for very high-resolution imaging of the underlying electrical characteristics (Revil et al., 2012; Loke et al., 2013). For the present study

inversion of the Zondres2d inversion, Res2Dinv software was used (Kaminsky 2010, Loke and Barker, 1996; Loke et al., 2003). The Wenner resistivity survey was conducted over lamproite pipes. Approximately 9 such VES profiles have been carried in Vattikode, Gundrapally and Marepally lamproite pipes. For each sounding, the current electrodes were separated by 30 m, and potential electrodes were separated by 90 m. The survey was carried out using an IGIS DDR3 electrical resistivity instrument. The data were processed with the inversion algorithm RES2DINV (Loke et al 1996) to obtain a resistivity section. The inversion routine used by the program RES2DINV is based on the smoothness constrained, least-squares method inversion algorithm (DeGroot-Hedlin and Constable 1990; Sasaki 1992). A lineage map of the study area with an electrical profile is shown in Figure 4.

The two-dimensional model used in this program divides the subsurface into several rectangular blocks (Loke and Barker, 1996), and the resistivity of the blocks is adjusted iteratively to minimize the difference between the measured and calculated apparent resistivity values. The 2D resistivity inversion modelling was plotted using Zond Res 2D Software (Kaminsky 2010). The lamproite pipes of the Vattikode area are approximately 10 to 100 m, and the widths of these pipes are small, ranging from less than a meter to a few meters. Hence, to find the resistivity signature of these pipes, the Wenner VES profile was conducted. Approximately 2 VES profiles conducted on Lamproite pipes VL4 and VL5 were conducted. The parameters Wenner four electrodes, Current electrodes AB/2 distance is 90 m and potential electrodes MN/2 are 30 m.

One profile direction NW-SE is along the body, and another profile direction is perpendicular to the body, as shown in Figure 5, which shows the Zond 2D Resistivity Inversion and Res2Dvin model. Figures .5 and 7, respectively. Lamproite VL4 shows negative resistivity (100-180 Ω m) at 180 to 230 m, VL5 at 280 to 320 (100-180 Ω m) m and granite gneiss at 50 to 170 m. Another profile in the SW-NE direction along lamproite VL5 is shown in figure 6. Lamproite pipe VL6 has low resistivity (240-320 Ω m) at 170 to 320 m, as shown in Figure 6. VL-5 lamproite is observed along the at distance 200m is shown in 2D resistivity pseudo section by using RES2DVIN software shown in the Figure 8.

One Wenner profile is conducted perpendicular to VL8 and VL6. The 2D pseudo resistivity section was plotted using Werner profile data. Along profile P1 in the VL-5 and VL-5 pipes, lamproites are identified by negative resistivity anomalies VL-4 at distances of 190-220 m, VL-5 at 280-300 m and high resistive granite basement rock at 120-160 m, as shown in figure 5. One profile is along VL-5, which is shown in Figure 6, and lamproite pipe VL-5 is identified with negative resistivity at 130-310 m. Three resistivity layers in the subsurface layer model are shown with ρ_1 (2–24-ohm m), ρ_2 (114–870-ohm m) and ρ_3 (870–1900-ohm. m) in Figure 7.

One Wenner profile over lamproite pipe VL-8 is shown in Figure 9. Negative resistivity (-8 to 10 Ω m) values are observed at distances of 90-165 m along with the profile. In a similar technique and one profile along a lamproite pipe, VL-6 is identified as having negative resistivity (-15 Ω m to 15 Ω m) values at distances of 60-120 m, as shown in Figure 10 Three resistivity layers are the model shown with ρ_1 (.5-7-ohm m), ρ_2 (371-196-ohm m) and ρ_3 (5–11-ohm m) Figure 11.

Resistivity Survey over Gundrapally lamproite pipes

Approximately three-well VES profiles were conducted on a Gundrapally lamproite pipe, as shown in Figure 4. Gundrapally lamproite pipe GL1 was identified with negative resistivity (-678 to 250 Ωm) values, as shown in Figures 12 and 13, at distances of 290-360 m in Zond and Res2Dvin software, respectively. In the 2nd profile, at a distance of 300-360 m and high resistive granite basement (PGC) at 340-460 m, the same pipe along the body at 160-340 m is shown in Figure. 14. The same pipe in the 3rd profile lamproite pipe GL-1 at a distance of 120-160 m is shown in figure 15. In Figure 16, three resistivity layers are shown with ρ_1 (15-280 ohm-m), ρ_2 (15-27-ohm m) and ρ_3 (28–1677-ohmm).

Resistivity Survey over the Marepally Lamproite pipe

Two resistivity VES profiles were conducted over the Marepally ML1 lamproite pipe. In the 1st profile, it is identified from the 2D resistivity inversion map that the lamproite pipe shows negative resistivity at distances of 150 – 190 m, and the granite basement (PGC) at 90-120 m is shown in Figure 17. In the 2nd profile, lamproite pipe ML-1 was 70-95 m in another profile, as shown in Figure 18. In Figure 19, the layer model along Marepally lamproite pipe ML1.

Results And Discussions

The 2D inversion resistivity profile is plotted using Zondres2d (Kaminsky, A. E. 2010) and Res2dvin software's (Loke M. H. 2004a). The resistivity survey significance, Vattikode lamproite pipes VL-4, VL-5, VL-6, V-8, Marepally lamproite pipe, ML-1 and Gundrapally GL-1 show negative resistivity with country rocks (Peninsular gneiss complex rocks). The granite basement (PGC) shows high resistivity relative to lamproite pipes in the study region. The lamproite pipes display different resistivities: marepally lamproite pipe shows 0-160 Ωm , Gundrapally lamproite 0-150 Ωm , VL-6 lamproite 0 to 20 Ωm , VL-5 0 to 129 Ωm , and VL-8 -4 to 23 Ωm . For the present study area surrounding the formation, peninsular gneiss complex rocks show higher resistivity ranging from 200 Ωm to 1000 Ωm . An EM study on AK-1 lamproite pipes in Western Australia shows resistivity ranging from 40 to 100 Ωm , and the surrounding formation displays resistivity greater than 200 Ωm (Drew 1986). The hypabyssal kimberlite resistivities range between 100 and 250 ohm-m in South Africa (Arnott 2003). A similarity is observed in the lamproite pipes of the present study area. The weathered layer subweathered area layers are approximately at 0-8 m depth, and the basement below 8 m depth from the resistivity layers is shown in Figures 7, 12, 14, and 18. The lamproite pipes of the Vattikode, Marepally and Gundrapally olivine types (Alok Kumar et al., 2013) are weathered. Subsequently, these lamproite pipes produce strongly negative resistivity anomalies. The lamproite bodies of the study region Vattikode bodies VL4, VL5, VL6, VL8, Gundrapally lamproite and Maritally bodies exhibit ranging negative resistivity with the surrounding rocks. The negative resistivity is due to the fast-weathering nature of olivine type lamproites. According to Pell, J. Different electrical techniques (EM, VLF, resistivity) in airborne or ground geophysical methods are the finest tools for finding lamproites in suitable weathering environments and contrasts with country rocks. In general, clays, particularly smectite, produced during the weathering of lamproites are conductive and hence produce

strong negative resistivity anomalies (Pell J. 1997). Similarly, the heliborne electromagnetic method carried over kimberlites in North Kimberley Kimberlite Province, Western Australia, also showed negative resistivity with souring rocks due to weathering of kimberlite (Reed L.E. et al 2007). While electromagnetic surveys were carried out, the Ellendale lamproite diatremes are located in West Kimberley (Graham Jenke et al. 1994), which states that there is no clear response over the pipes and more resistive areas, but pipe responses were ambiguous in areas covered by conductive black soil. The results are well correlated with other studies, and the lamproite pipes of Western Australia show weak conductivity (Graeme J. et al. 1994) because they are olivine-type lamproites. Graeme J. Drew and Duncan R. Cowan. The lamproite pipes of the current study area dimension are a few meters to 100 smeters similarly, the lamproite pipes of argyle lamproite pipes in Western Australia are 100 smeters (Graeme J. et al. 1994). The present investigation results of the resistivity of lamproite pipes are well correlated with the argyle pipes of Western Australia.

Conclusions

Lamproite pipes of the study area are successfully delineated with the 2D resistivity inversion modelling method. The Wenner profile method has very suitably facilitated the detection of lamproite pipes that are less in dimension (a few 100 s meters to less than centimetres). The lamproite pipes of the study area Vattikode, Gundrapally, Marepally exhibit negative resistivity with the country rocks. Because they are weathered, they show a conductive nature. Granite gneiss complex sheetrock showing a positive resistivity anomaly with surrounding rocks. The lamproites contain phlogopites, and they weather rapidly, hence showing conductive (negative resistivity) anomalies over the pipes. Lamproites of the study area are weathered; hence, they produce negative resistivity anomalies. The lamproites of the study area show a negative resistivity anomaly similar to the lamproites of Western Australia.

Declarations

Acknowledgement

The authors are thankful to the UGC BSR-RFSMS fellowship scheme for awarding Jonnalagadda Ravi to support carrying out the research work.

Data Availability

Data will be available upon demand; this manuscript does not contain any code.

Conflict Of Interest statement

I and coauthur wish to confirm that there are no conflicts of interest associated with this publication and that there has been no significant financial support for this work that could have influenced its outcome against this research paper.

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Figures

Figure 1

study area map

Figure 2

Locations of the lamproite pipes with locations of VES profiles in Gundrapally, Vattikode and Marepally over lithology map of the study area

Figure 3

Field photographs of (a) Gundrapally lamproite and (b) Vattikode lamproite

Figure 4

Wenner profile locations over dikes and lineaments of the study area

Figure 5

2D Resistivity Inversion model along with the profile (NW-SE direction) over Vattikode Lamproites VL4 and VL5

Figure 6

2D Resistivity Inversion model along with the profile (SW-NE direction) over Vattikode Lamproites V4 and VL5

Figure 7

2D Resistivity Inversion subsurface layer model along with the profile with Vattikode Lamproites VL4 and VL5

2D Resistivity Inversion model along with the profile (NW-SE direction) over Vattikode Lamproite VL4 and VL5

Figure 8

2D Resistivity Inversion model along with the profile (NW-SE direction) over Vattikode Lamproites VL4 and VL5

Figure 9

2D Resistivity Inversion model along with the profile in S-N over Vattikode Lamproite VL8

Figure 10

2D Resistivity Inversion model along with the profile in N-S over Vattikode Lamproite VL6

Figure 11

2D Resistivity Inversion layer model along Vattikode lamproite VL-6

Figure 12

2D Resistivity Inversion model along profile 1 (NE-SW direction) over Gundrapally Lamproite.

Figure 13

2D Resistivity Inversion model along with profile 1 (NE-SW) over Gundrapally Lamproite using Res2Dvin software.

Figure 14

2D Resistivity Inversion model along profile 2 (NW-SE direction) over Gundrapally Lamproite

Figure 15

2D Resistivity Inversion model along profile 3 (NW-SE direction) over Gundrapally Lamproite.

Figure 16

2D Resistivity Inversion layer model along Gundrapally lamproite GL-1

Resistivity Survey over the Marepally Lamproite pipe

Figure 17

2D Resistivity Inversion model along profile 1 (N-S direction) over Marepally Lamproite

Figure 18

2D Resistivity Inversion model along profile 2 in the NE-SW direction over Marepally Lamproite

Figure 19

2D layer model along Marepally lamproite pipe ML1