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A COMBINED ELECTROMAGNETIC AND RESISTIVITY SURVEY FOR EXPLORATION FOR VEIN GRAPHITE: A CASE STUDY OVER A POTENTIAL GRAPHITE FIELD IN THE SABARGAMUWA PROVINCE, SRI LANKA

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ABSTRACT

Graphite mining in Sri Lanka carries a history of nearly two centuries. Even though the mining activities are extensively carried out, methods of exploration are not up-to-date when compared to rest of the world. Occurrence of vein graphite in the country shows a systematic pattern with respect to the surrounding geology. Understanding of local geology and structures is vital for explorations in extensively deformed terrains like Sri Lanka. Use of immature tools and technology in earlier days restricted the local mining activities to shallower levels, mainly due to the collapsing of pit walls as the excavation depth increases. Deeper subsurface mineralization in such regions can be further prospected with advanced modern geophysical methods. Medagoda in Avissawella region is an area where open pit shallow graphite mining was carried out several decades ago. A Combined electromagnetic (EM) and electrical resistivity survey was conducted to identify the remaining potential of graphite occurrence within the area along survey lines of a pre-arranged grid. Electrical Resistivity Profiling was done along selected survey lines based on the distribution of abandoned pits and mainly to cross check the EM results. Anomalies of resistivity survey matched with EM anomalies with a good precision. Both survey results correlated with abandoned pits to infer the most probable zones of mineralization. Within the depicted mineralized zone, calculated depths to graphite occurrences are ranging 15-30m below surface. Reserve estimation was not possible under the present survey because of largely spaced survey lines and absence of drill hole data for validation. Extended geophysical surveys of Resistivity and Induced-polarization methods are suggested for further clarification of EM results with a higher degree of resolution and to omit the mining dumps of previous excavations.

***Key words**: Combined electromagnetic and electrical survey, Graphite occurrence, Sri Lanka*

INTRODUCTION

The vein-type graphite deposits of Sri Lanka are known world over since they were first worked in 1880 (Cameron, 1960; Goossens, 1981). The graphite ores of the country are well known for high quality vein graphite, containing about 95-99% of pure carbon (Dissanayake, 1981; Katz, 1987). This vein graphite is unique because of its high purity, high crystallinity, large reserves and the mode of occurrence. Tectonically controlled nature of graphite occurrences in Sri Lanka was first reported by Silva in 1974.

Graphite is a mineral with high electrical conductance which can be prospected using geophysical methods such as Electromagnetic (EM) and Electrical Resistivity methods (Keller, 1971) For the current study, Very Low Frequency (VLF) EM method was utilized which is followed by the electrical resistivity method to a lesser extent to evaluate the remaining potential of graphite occurrences in an area of abandoned mining activities in the hard rock terrain in the western province Sri Lanka.

Study area (Figure 1) is located in Medagoda about 5 km North to the Avissawella town at the geographic location of latitude 6° 59’ 4” N and longitude 80° 12’ 20” E.

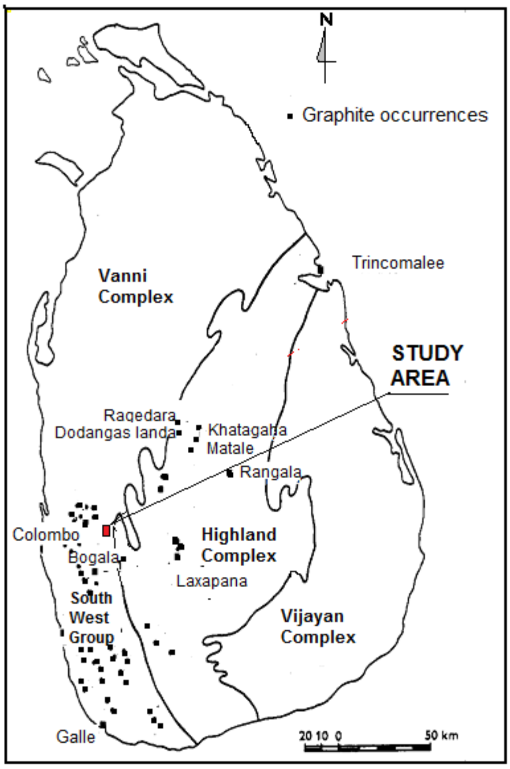

Fig. 1. Map showing the location of the study area and other graphite occurrences in Sri Lanka.

Geologically the area belongs to highland complex of Sri Lanka and the investigated site is underlain by Garnet biotite gneiss and quartzite. Topographically the area consists of discontinuous low elevated ridges and valleys with undulating land surface.

According to local villagers, about 60 years ago, the area has been mined for graphite in small scale open pits. Excavations have been abandoned due to the collapsing of pit walls as the depths were increased. Further explorations were not carried out due to the lack of advanced exploration and mining technology. Thus, the area can be considered as a region with good potential for finding graphite occurrence probably within deeper subsurface.

METHODOLOGY

The basis of EM survey methods is measuring of the secondary EM field generated by subsurface conductors when subjected to a primary EM field. VLF-EM signals (15-25 kHz) are used for long-range communication purposes where they are generated from radio-transmitters situated throughout the globe. These signals are capable of penetrating considerable depths into the Earth curst than EM signals with higher frequencies and these VLF-EM fields can be approximated to a plane wave at very large distances from the station of transmission.

Source of the primary field is selected as the VLF transmission from *Harold E. Holt* Naval Communication Station at North West Cape (NWC), Australia. *Geonics EM16* instrument was used for the current study to measure the horizontal component (In-phase/Real - $tan\,\theta$) and vertical component

(Quadrature hase/Imaginary - ε) of the secondary field.

Before commencing the survey, the survey grid has to be prepared covering the area to be explored (126,472 m^2 - 31 Acre). Parallel survey lines with an appropriate separation should be constructed perpendicular to the direction of the primary field (Paterson and Ronka, 1971). Study area (Avissawella, Sri Lanka) is situated approximately in North-West direction to the transmission station (NWC, Australia). Hence, the perpendicular direction of the survey lines was determined as N40°E. Grid of 11 survey lines (Figure 2) was established by professional land surveyors as follows.

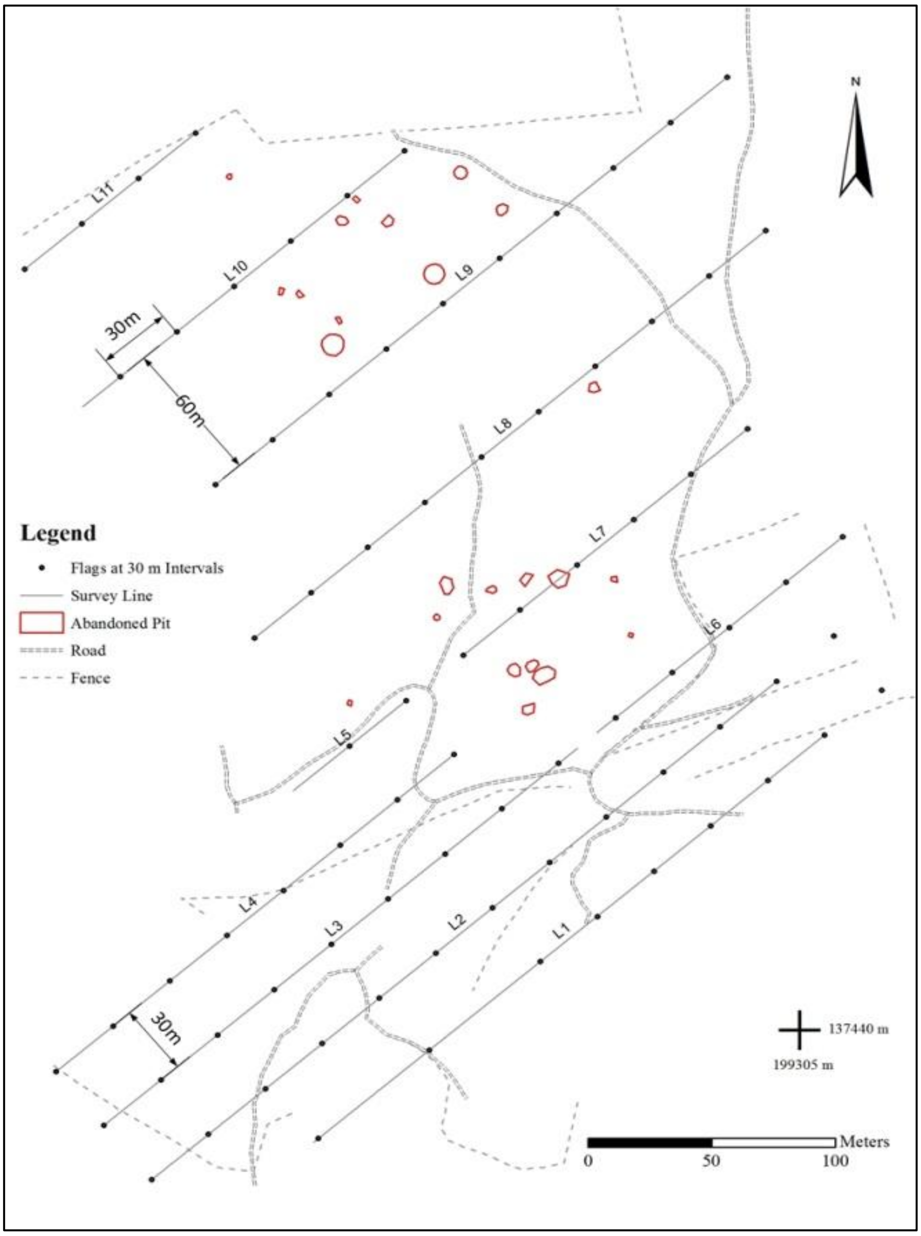

Fig. 2. View of the survey grid showing the distribution of abandoned pits and established survey points.

Five survey lines were prepared with a parallel separation of 30 m. 6 more survey lines with a parallel separation of 60 m. Flags were established on each line with an interval of 30 m as reference points. During the geophysical survey, each interval of 30 m was divided into 10 m intervals as reading stations. Readings were obtained at each station by taking down the $tan\,\theta$ and ε against the station number. It is necessary to face the same direction when taking the readings for particular survey to avoid the reversing of the polarity of readings.

Usual practice is to plot both $tan\,\theta$ and ε values directly on the survey line plane using a suitable scale (Geonics, 1997). Presence of conductive bodies was identified by the zero-crossings of the plotted curves of $tan\,\theta$ assuming they are vertical or nearly vertical sheet structures (Figure 3a). But the process become more complex where there are several conductors available in the vicinity. In such cases, they were identified by the steepest gradients rather than the zero-crossings (Figure 3c). Concentration should be on the centers of slopes. An approximated depth values to conductors were calculated by measuring the horizontal distance between maximum positive and negative peaks of the plotted curves. However, the subsurface conductors can be more easily identified by converting zero-crossings into peaks (Figure 3b). This can be achieved by filtering the raw data using a simple numerical method (Fraser, 1969).

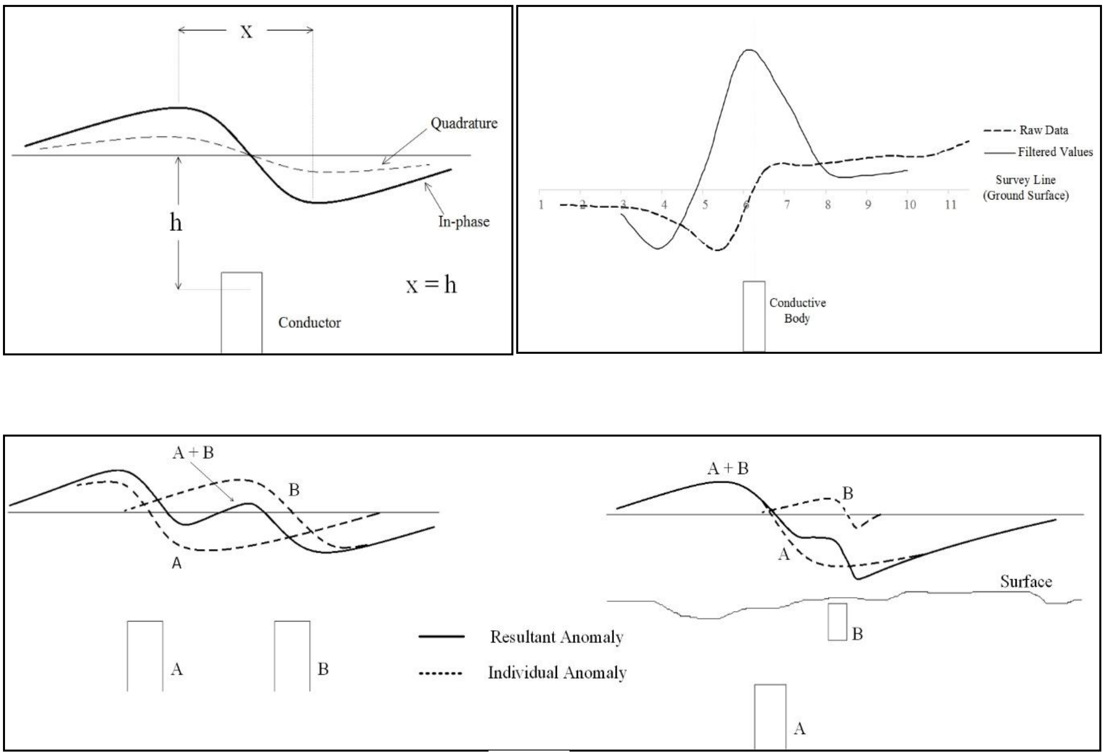

Fig. 3. Analysis of survey resluts (a) Identification of subsurface conductors using plotted curves. (b) Conversion of zero crossings into peaks. (c) Modification of curves due to the presence of several conductors (Geonics, 1997).

Once all the anomalous indications of conductors are marked on the survey plan from both raw and filtered values, closely lying indications were surrounded by a polygon to demarcate the probable zone of mineralization also considering the distribution of abandoned pits.

For the electrical resistivity survey ABEM LUND multi-electrode resistivity and IP imaging system was used to generate two-dimensional imaging profiles. Finally, results from both EM and resistivity surveys were compared with each other to identify overlapping anomalies which indicate the most probable mineralization. Basically, resistivity survey was used to validate and justify the EM results.

RESULTS AND DISCUSSION

VLF-EM SURVEY

Total length of the EM survey is 2.2 km; 231 locations of raw data and 198 locations of filtered values. Interpretation of raw VLF data is shown in the Figure 4 and their calculated depth values to the mineralization are given in Table 1.

Some depth values cannot be calculated due to the discontinuity of survey lines. Area of the inferred mineralized zone from raw VLF data is 27,983 m^2 (7 acre). Similarly, interpretation of filtered values is done (Figure 5 and Table 2). Usually, the analyses of both raw data filtered values are expected to give similar results. But deviations may occur in seldom. Area of the inferred mineralized zone from filtered VLF data is 10,652 m^2 (2.6 acre).

Table 1. Calculated depths from raw VLF indications in Figure 4

Anomaly No.	Approximated Depth to the Formation (m)
1-1	22
2-1	10.6
2-2	9.1
2-3	15.1
4-1	16.2
4-2	14.1
7-2	10
7-3	9.8
8-1	18.6
8-2	27
8-3	19.8
8-4	20.3
9-1	48.7
9-2	21.8
10-1	10.3
10-2	9.4
10-3	-

Table 2. Calculated depths from filtered VLF indications in Figure 5

Anomaly No.	Approximated Depth to the Formation (m)
1-1	16.1
2-1	17.2
2-2	17.5
4-1	21.9
4-2	17.2
7-1	19.7
8-1	19.1
8-2	20.1
8-3	9.3
8-4	33.1
9-1	18.7
9-2	27.3

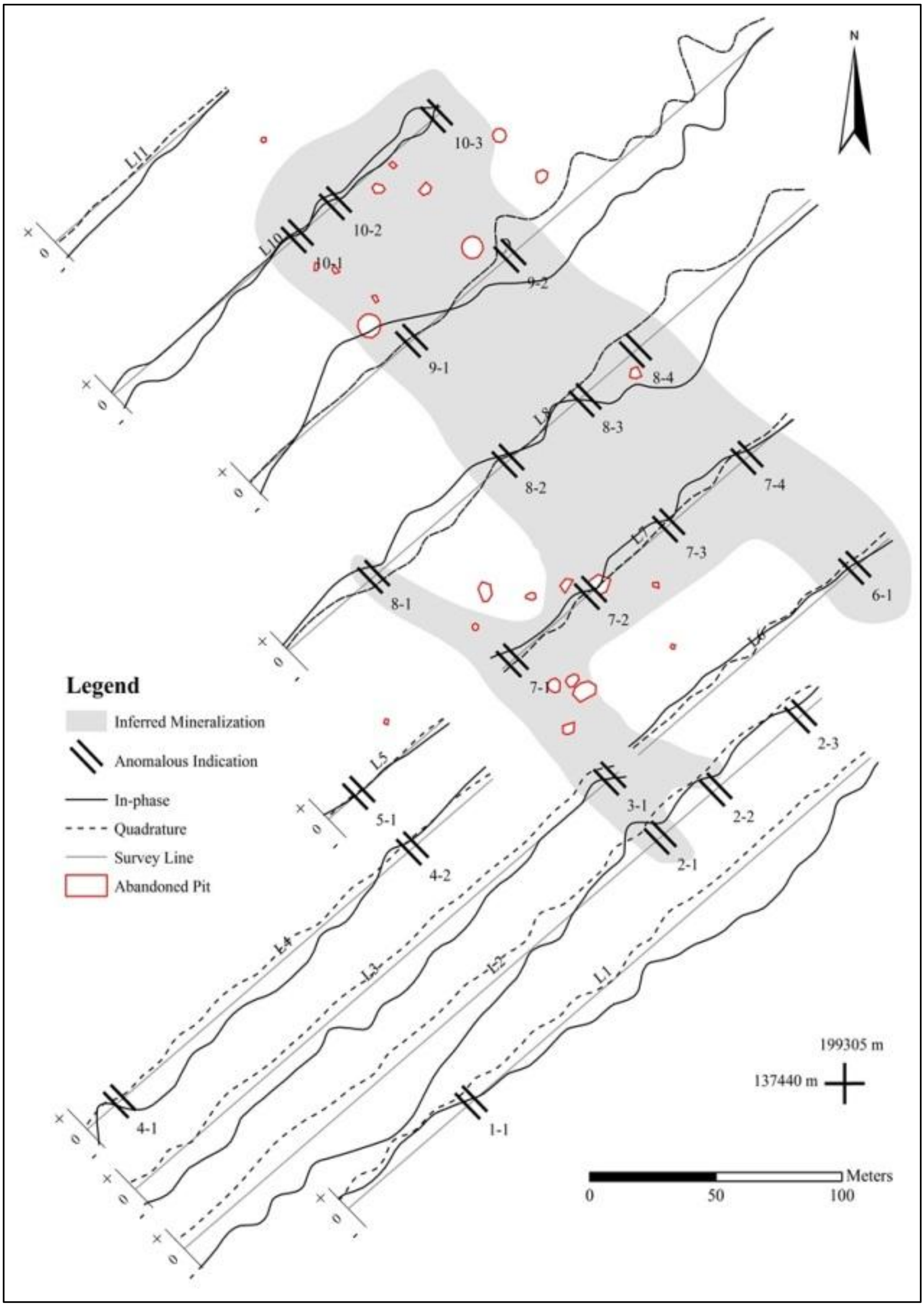

Fig. 4. Survey plan showing plotted curves of raw VLF data and demarcation of a probable graphite bearing zone considering the distribution of abandoned pits and anomalous indications.

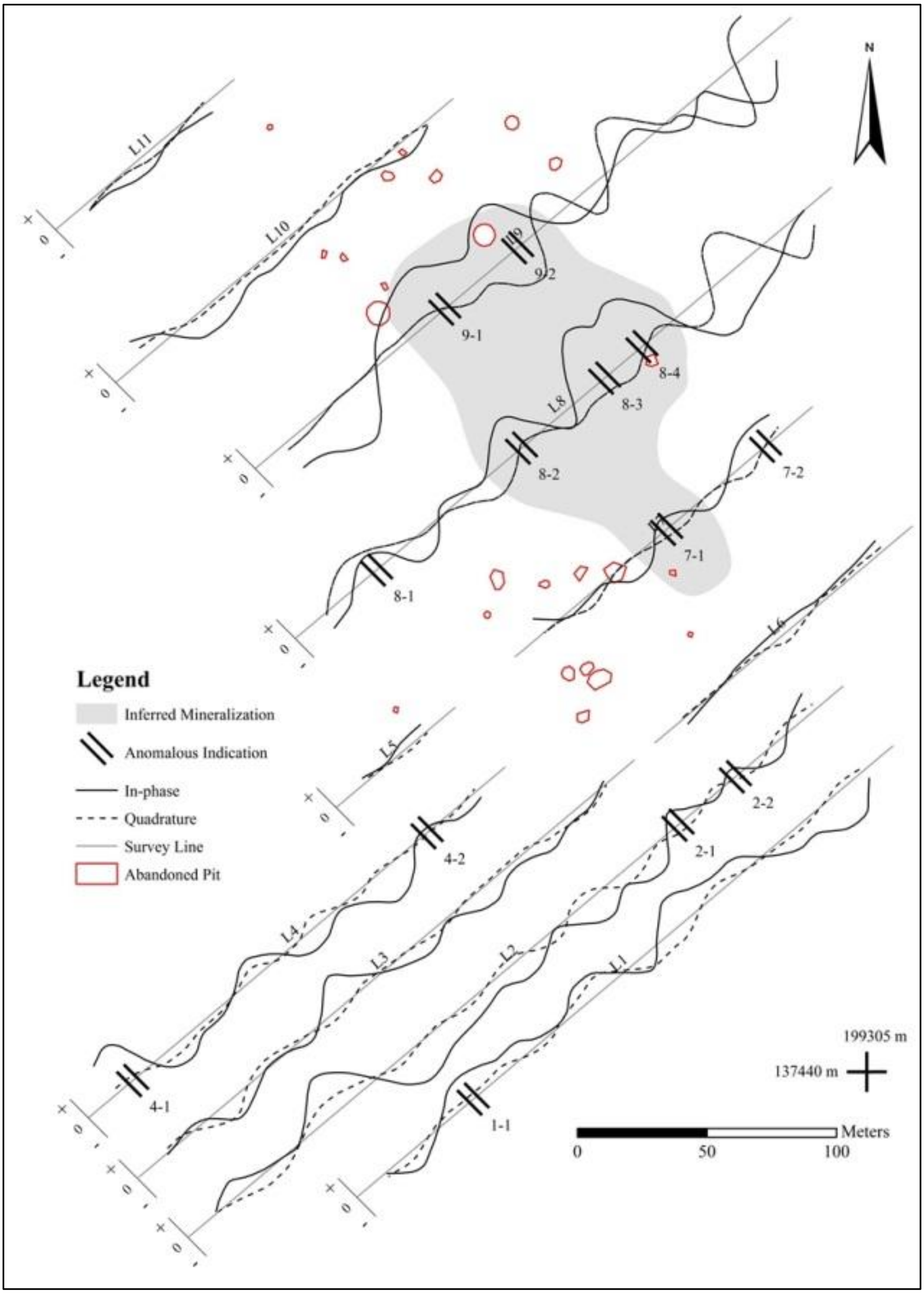

Fig. 5. Survey plan showing plotted curves of filtered VLF data and demarcation of a probable mineralized zone considering the distribution of abandoned pits and anomalous indications.

Several anomalous indications are not included as mineralized zone (1-1, 4-1,4-2 and 5-1) due to the lack of evidence to state that they are true indications of graphite. In order to clarify those, extra survey lines are required beside them.

Purpose of the filtering of raw data is to convert the zero-crossings of raw data into peaks as mentioned before. But, peaks can be also created due to the mathematical process of the filter, at locations where no cross over points are available which caused by adjacent values of the point. Those peaks can be recognized by cross-checking the locations of peaks with corresponding location of the raw data plot and were omitted during the interpretation.

Another interpretation of filtered values is the contouring. Only the positive values are contoured to avoid confusions. Probable mineralized zone inferred from contours give more sense than previous two interpretations (Figure 6). Area of the inferred mineralized zone is 5,966 m^2 (1.5 acre).

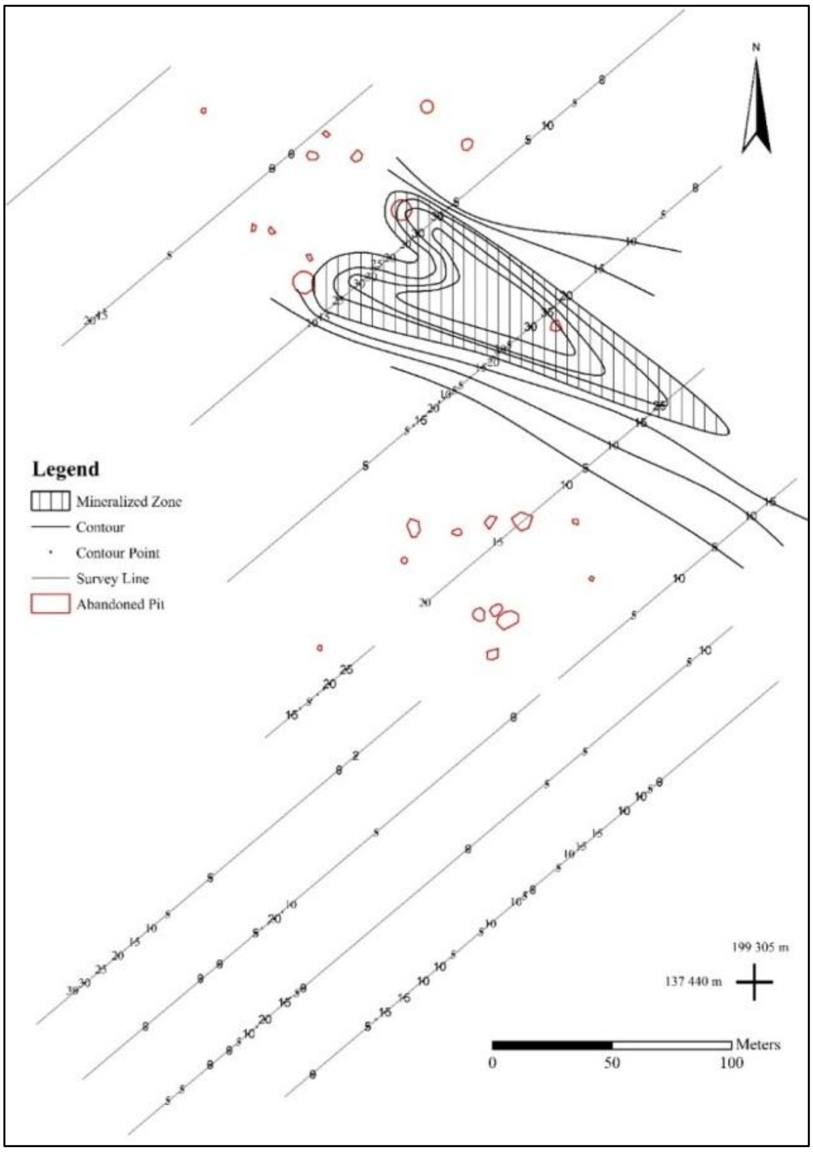

Fig. 6. Survey plan showing the contours of the values of filtered VLF data depicting potential subsurface conductivity zone.

ELECTRICAL RESISTIVITY SURVEY

Resistivity survey is carried out as a supplement for the EM survey. Figure 7 shows the plan of the resistivity survey lines. Total length of the resistivity survey is 400 m where each line is 200 m long. The two resistivity survey lines were planned on the traces of three EM survey lines. Line RL7 is on the traces of L5 and L7 lines and Line RL9 is on the trace of L9. Those two lines were chosen based on the distribution of abandoned pits.

Figure 8 shows the corresponding resistivity profiles. Probable mineralization can be identified as, two strong indication on RL9 and one small indication on RL7. Table 3 gives the summary of resistivity data.

Resistivity sounding on RL9 shows two strong low resistivity zones which should be probable graphite bearing zone. But the resistivity anomaly on RL7 is a considerably weak where it might not be a mineralization but a noise anomaly.

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COMPILATION OF VLF-EM AND ELECTRICAL RESISTIVITY RESULTS

Figure 9 shows the compilation of results of both EM and Resistivity surveys. RL9-1 and RL9-2 are the strong indications of inferred mineralization from resistivity results. Since they are situated in the mineralized zones inferred from both raw and filtered EM anomalies, it emphasis the subsurface mineralization at the two locations. Resistivity anomaly RL7-1 is a rather weak anomaly. Also, it is on the mineralized zone inferred from the raw EM data only. Hence, it cannot be predicted the mineralization exactly as the previous case.

Table 3. Summery of resistivity survey

Anomaly No.	Approximated Depth to the Formation (m)	Resistivity at the Considered Depth (ohm.m)
RL7-1	27	41-56
RL9-1	23	11
RL9-2	19	5

Table 4. Summery of proposed exploratory drill holes

Bore-hole No.	Suggested Depth of hole (m)	Coordinates (m)	
		X	Y
L9-B1	33	137274	199595
L9-B2	25	137309	199624
L8-B1	14	137338	199571
L8-B2	27	137356	199585

Table 5. Summery of proposed new survey lines

Line No.	Length (m)
N1	270
N2	150
N3	90
N4	480
N5	180
N6	480
N7	210
N8	480

SUGGESTIONS FOR FURTHER ENHANCEMENTS

Before any mining activities, exploratory drill holes can be made and new EM profiles can be carried out to refine the results further more (Figure 10, Table 4 and Table 5). Also, new resistivity profiling can be carried out along rest of the EM profiles to clarify them depending on the requirement.

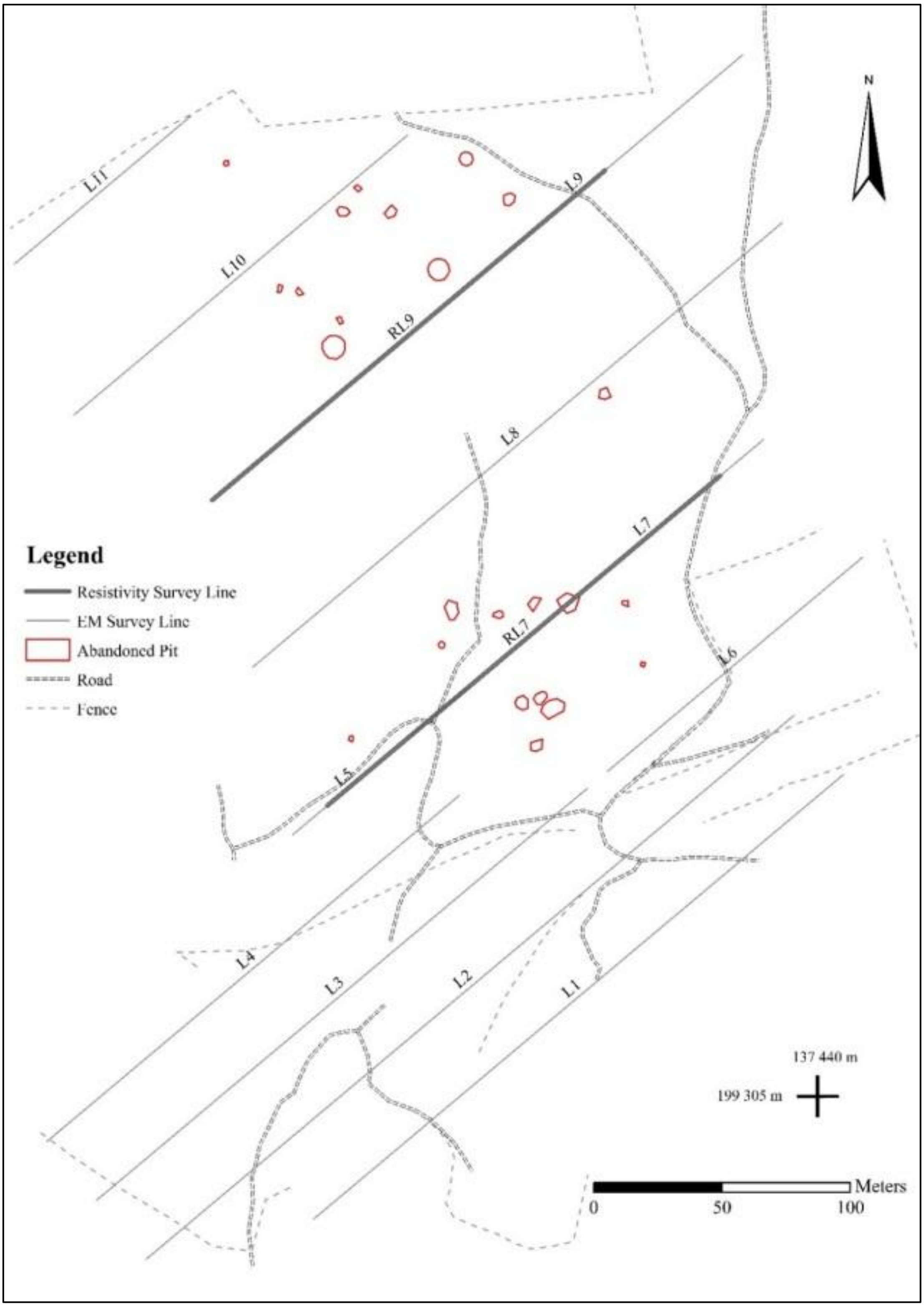

Fig. 7. Survey Plan showing the two resistivity survey lines (thick lines) on the traces of existing EM survey lines.

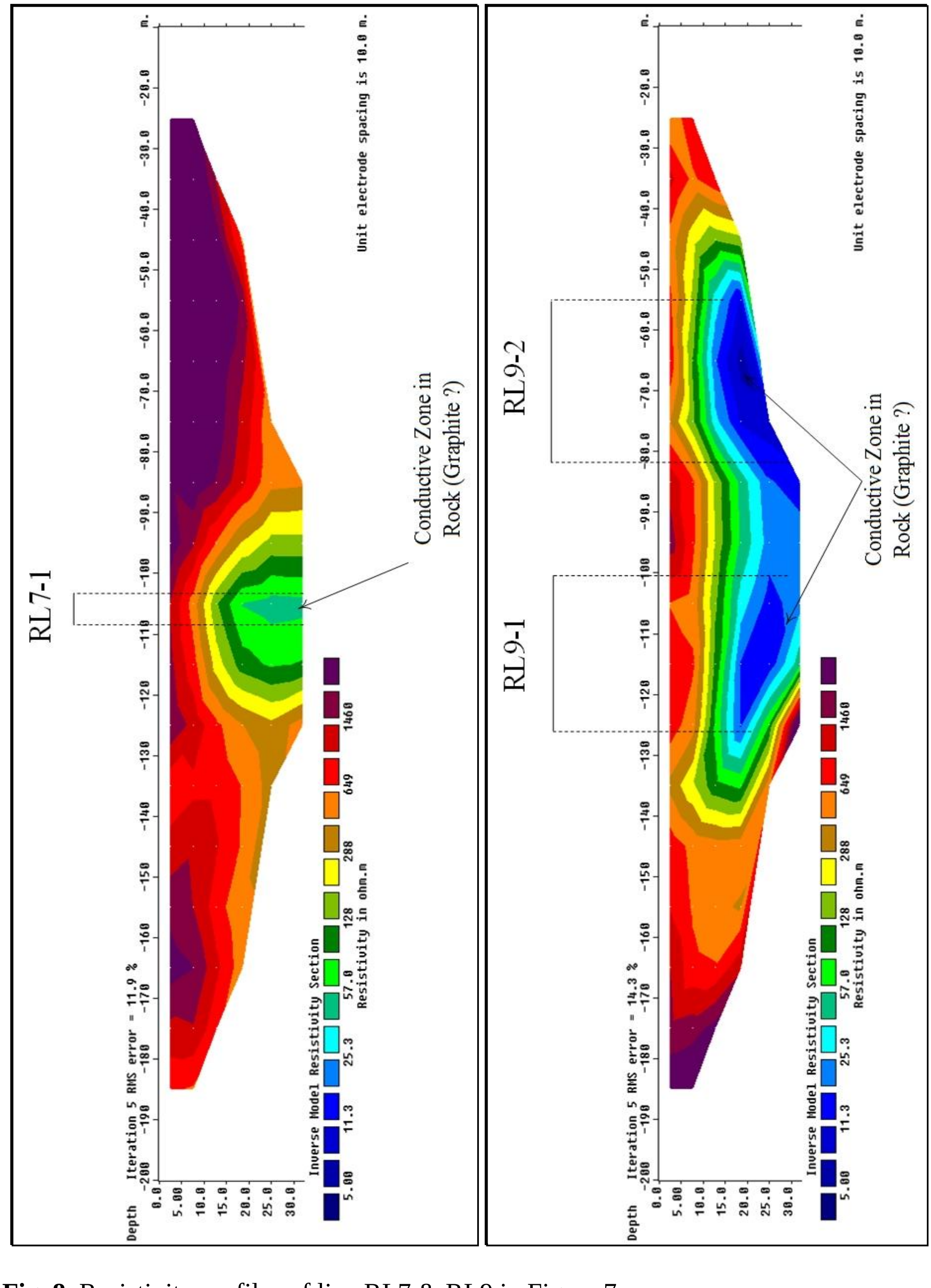

Fig. 8. Resistivity profiles of line RL7 & RL9 in Figure 7.

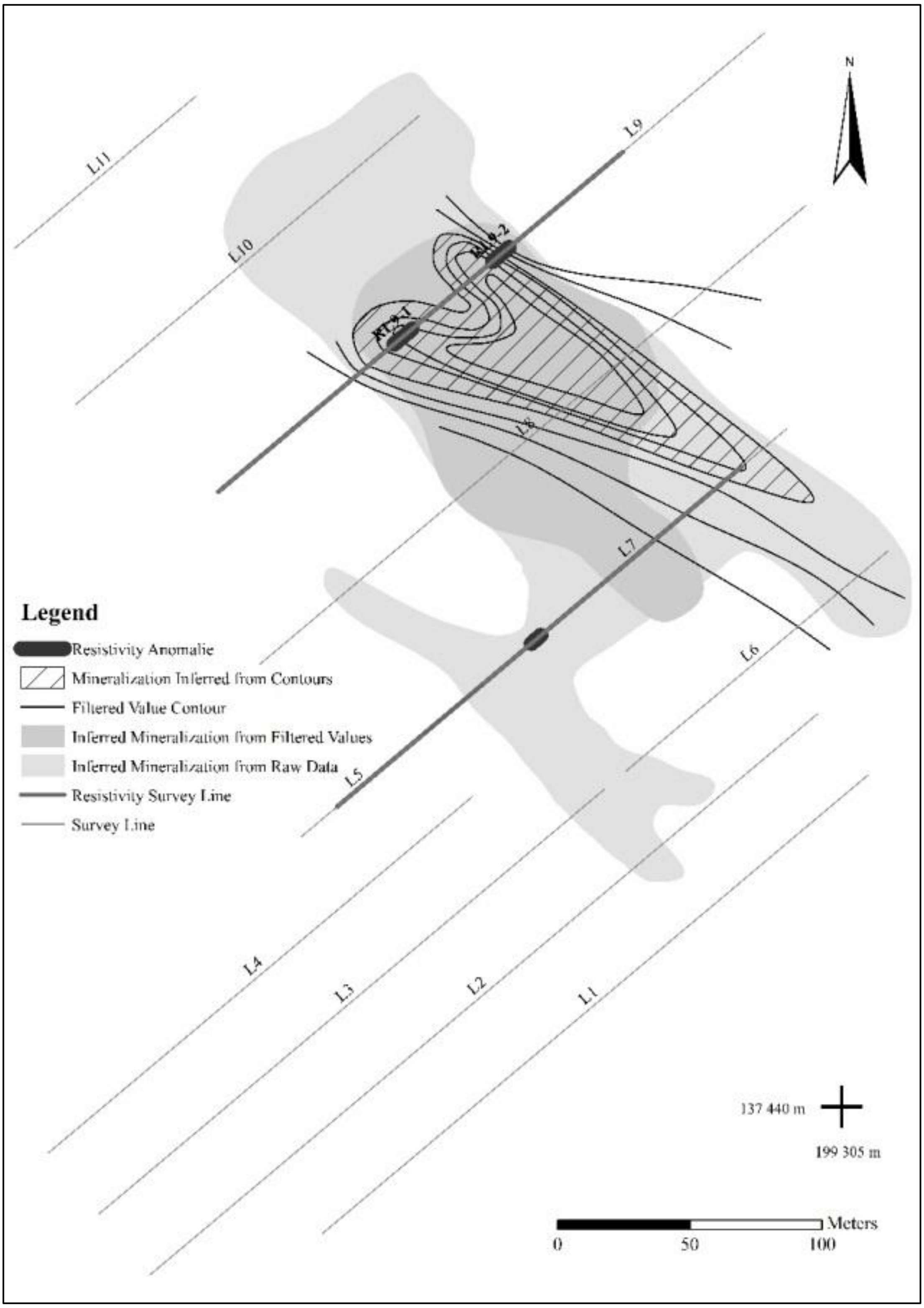

Fig. 9. Combined VLF-EM and resistivity results.

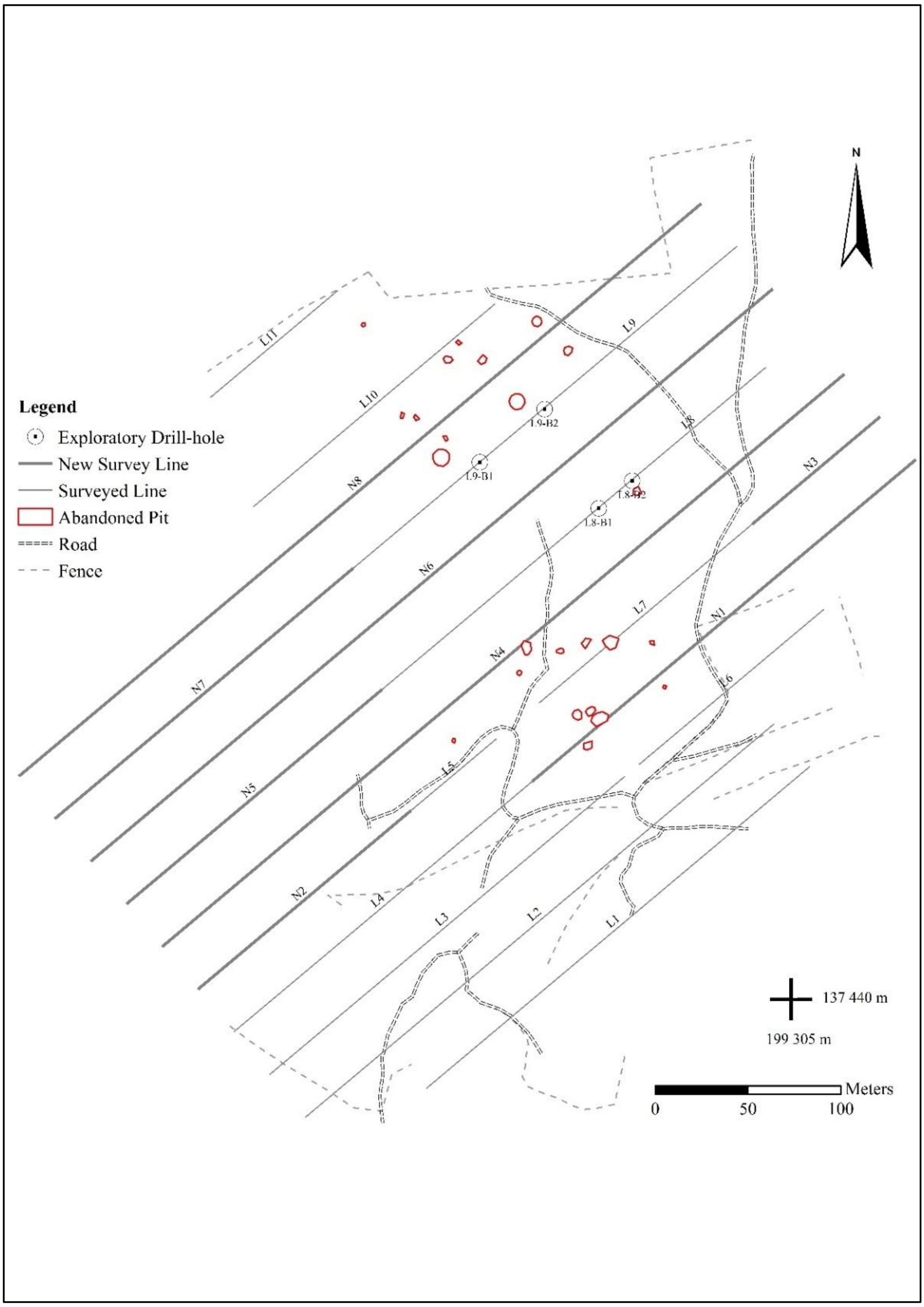

Fig. 10. Proposed further enhancements – Extensions for the existing survey grid and suggested locations for the exploratory drill holes.

CONCLUSIONS AND RECOMMENDATIONS

Present study revealed that, combined Very Low Frequency Electromagnetic (VLF-EM) and Resistivity surveys can be effectively used in detecting vein type graphite occurrence in low-conductive hard rock terrain of Sri Lanka.

It was possible with the combined two methods to eliminate ambiguities and uncertainties of individual survey results with each other and hence to select the most probable locations of subsurface conductive zones by overlapping anomalies of the two methods.

Results indicated that the investigated area has a good potential for occurrence of vein graphite within the rock. Estimated depths to the ore bodies which are inferred from results are between about 15m - 30m from the ground level. However these need to be confirmed after test drilling, which was not carried out under the present study.

The potential graphite bearing zones are distributed randomly over an area of about five acres, excluding the already mined area. Since the present results are two dimensional, an accurate reserve estimation is not possible in absence of drilling data.

In order to further resolve the results, additional EM survey is recommended by changing the direction of measuring to obtain readings with the reverse polarity compared to the previous EM survey for cross checking. Moreover, a survey using Induced-Polarization method is recommended to separate the anomalies within the rock and the anomalies which are created by previous mining dumps.

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