

Geophysical exploration for manganese-some first hand examples from Keonjhar district, Orissa

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ABSTRACT

Manganese ores in India are being exploited since the past hundred years. Continuous exploitation of shallower and massive deposits led to searching for further occurrences and also necessitated application of geophysical methods. Geological survey of India since 1940s, has been exploring for manganese deposits in various parts of the country employing different geophysical methods (Ganokar, Das & Srirama 2001).

The authors of this paper had opportunity to conduct geophysical surveys comprising gravity, magnetic and electrical resistivity methods in some selected blocks in the JAMDA-KOIRA belt of Keonjhar District, Orissa. Manganese ore, mainly psilomelane and pyrolusite occur in this belt as small lenses/lumps discontinuously and, in general under cover of laterite. These ore occurrences appear to be confined to near NW-SE or N-S belts and associated with shales/phyllitic shales below which are occurring occasionally brecciated conglomerates with chert and cherty quartz. The basement is Banded Iron Formations, mainly BHJ and BHQs.

In the first block, which is about 300mx300m size, magnetic, gravity and electrical resistivity profiling and soundings were conducted. The geophysical signatures, though feeble, showed the trends and alignments of ore bodies and the intervening faults/ fractures associated with iron concentrations. Based on these results two more blocks (Block – II about 89hectares and Block – III about 24 hectares) were covered by magnetic mapping, electrical resistivity profiling and sounding and gravity survey on selected traverses. The geophysical anomalies in these two blocks also are characteristic in delineating the probable alignments of manganese bodies. Critical analysis of, essentially, the magnetic contour maps and resistivity and magnetic profile data helped visualizing pockets of likely occurrence of manganese ore.

INTRODUCTION

Manganese ores in India are being exploited well over the past hundred years. These ores are mainly of secondary origin and are associated with the older Archean metasedimentaries. The deposits in India were originally classified as three fold (Fermor, 1909), which were subsequently modified as four fold (GSI News 1973; Krishnaswamy 1979). They are as mentioned here under :

(a) Syngenetic Gonditic deposits associated with highly metamorphosed Sauser series of rocks as in Central and Western India, (b) Syngenetic reef deposits associated with the Khondalite sequences of Eastern Ghats, (c) Replacement deposits in the Banded Iron Formations as in Singhbhum, Karnataka and Goa regions and (d) Lateritoid deposits and supergene enrichments associated with all the above three.

Uncertainties of the occurrence, association,

depth, shape and quality which are usual with metamorphic deposits, have led to application of Geophysical methods. Since the initial investigations by M.B.R.Rao in Mysore state in the late 1930s, development of Geophysical techniques and availability of improved and modern technology led to further deployment of geophysical techniques in the search for manganese ores. Geological survey of India is the pioneer in this respect, followed by different institutes academic, research and professional. The first hand experiences of the authors in certain locations in the Jamda-Koira belt of the Singhbhum complex are discussed in the following.

GEOLOGICAL SETTING OF THE REGION

Manganese deposits in peninsular India occur in Precambrian rocks and are confined to several discrete belts. The Jamda-Koira belt of north Orissa is

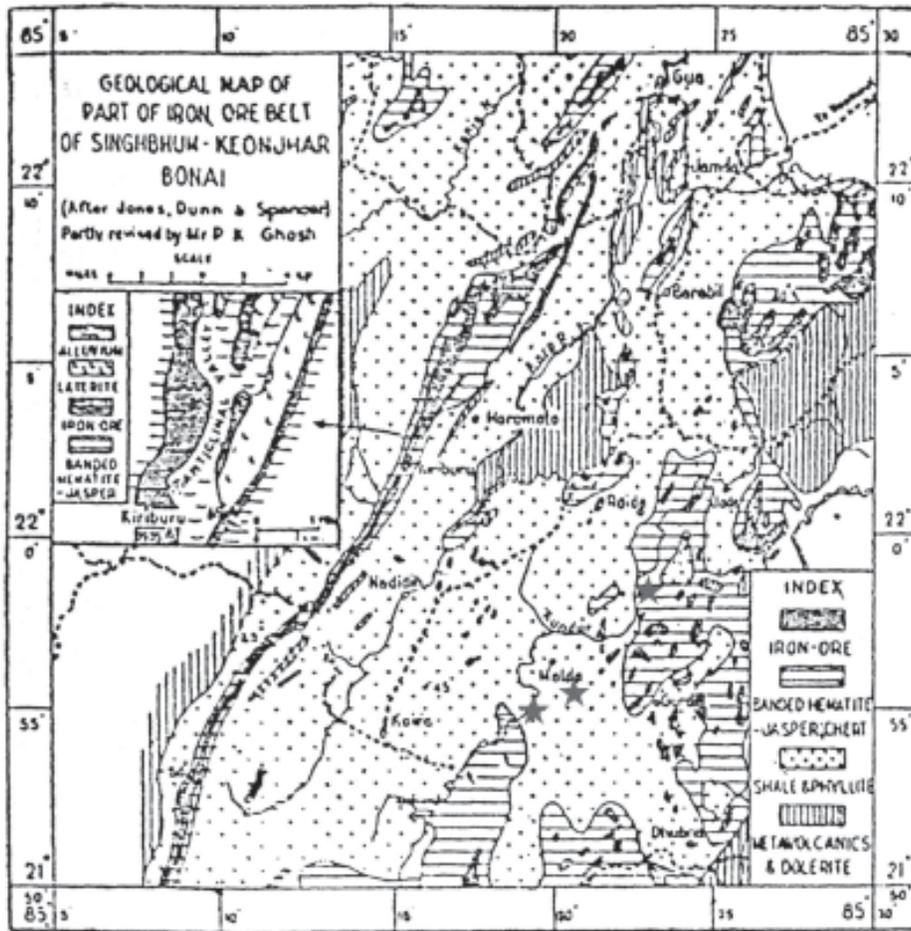


Figure 1. Jamda-Koira Belt- Regional Geology Map (After Krishna swami, 1979) (*Location of Blocks Studied).

manifested by the Iron ore series and is associated with Banded Iron Formation (Fig.1). Trace element studies on manganese of the Barbil area suggest a probable non-volcanogenic origin (Ajmal 1990).

The older metamorphics are highly folded and eroded prior to the deposition of the iron ore series. At the interface between these two an unconformity is marked by the occurrence of conglomerates and quartzites. These are overlain by shales/phyllites and BHQs. The shales contain deposits of manganese ore (pyrolusite and psilomelane) derived possibly from the shales themselves. The BHQs have an overall thickness of about 300m forming isoclinally folded ridges and capped by very high grade hematite. They include alternating layers of chert, Jasper and hematite. These formations indicate depositions in quiet waters far from shore. The surface having been exposed to long duration of intensive weathering, has the cover of goethite, limonite and laterite with occasional occurrence of siderite.

These iron ore series are intruded sporadically by basic lavas and at certain places by ultrabasic rocks. The manganese deposits of Keonjhar area amidst the lateritic iron ores are due to concentration near the surface by meteoric water. The ores, in general, are of irregular shapes confined to the zone of weathering. In addition to psilomelane and pyrolusite, wad and limonite also occur. They are mostly of low to average grades, though occasionally rich pyrolusite bands are seen. They are also associated with considerable amount of iron. Drilling and mining information from numerous working mines in Barbil-Joda belt suggest that the manganese occurs as discontinuous lensoid bodies confined between shales at the bottom and BHQs, BHJ, laterite sequence on the top. However the orientation of these lensoid bodies are highly altered due to intensive folding and structural deformations of the region. Each of the manganese occurrences may be of about a meter to over 5m thickness, a few meters to over 100m in length and a

few meters to 20 to 30 m in depth extent. The overburden cover may be varying from a few centimeters to a few meters.

Basis of Manganese exploration through Geophysics

Earliest geophysical surveys in India for mineral deposits were perhaps by late M.B.R.Rao in the 1930s under Mysore geological survey. He employed magnetic and electrical resistivity methods (Rao & Sinha 1957) for manganese. Later Jenson (1954) reported electrical equipotential survey for manganese in Central India. Bhimasankaram & Rao (1958) conducted magnetic and electrical resistivity surveys in the Garividi area of Eastern Ghat region. Since late 1940s Geological Survey of India has been exploring for manganese deposits in various parts of the country employing different geophysical methods like gravity, magnetic, electrical resistivity, S.P. (Dash, Venkateswarlu & Reddy 1978, Gaonkar, Das & Srirama 2001). Unconventional approach of helicopter borne electromagnetic (HOISTEM) survey was conducted by LEME research group (Meyers 2003) in

Pilbara region of western Australia where 1.6 million tones of conductive manganese ore of hydrothermal origin associated with resistive dolomite was discovered.

Selection of Geophysical methods depends essentially upon the possibility of prevalence of detectable geophysical anomalies. These, in turn are governed by the physical property contrast between the mineral ores of interest and the host rocks. Under favorable conditions of massive, shallow occurrence of deposits in a geological environment of minimum noise the geophysical methods will become direct tools. Sometimes when the mineral occurrence is of smaller size located at larger depths and has low contrast in physical property with the host rocks geophysical methods may be used as indirect tools. That is, the search will be for other associated minerals, or structural, or lithological configurations which can lead towards the mineral of interest.

In Table 1 are presented the physical properties of Manganese ores and other minerals and host rocks relevant to the geological setting of the Jamda-Koira region. These values are collected and consolidated from available published literature including text books.

Table 1. Physical properties of Manganese ore and country rocks

Ore (origin) / rock	Chemical Composition	Mn Content	Density (g/cc)	Mag.Suc. Micro CGS	Elec.Resis Ohm-m	Dielectric constant
Pyrolusite (secondary)	MnO ₂	63%	4.70-5.00	Paramag.	5x10 ⁻³⁻¹⁰	2101
Psilomelane (secondary colloidal)	MnOMn ₂ OH ₂ O		3.70-4.70		4.5x10 ³	2977
Braunite (Secondary (or) Primary)	Mn ₂ O ₃ Mn ₆ O ₂ (colloidal)	64.3%	4.75-4.82		0.16-1.2x10 ³⁻⁷	
Rhodochrosite (primary or sec.)	MnCO ₃	47.8%	3.40-3.60	100		6.8
Rhodonite	MnSiO ₃	41.8%	3.40-3.6	Paramag.	5x10 ¹⁰	13-30 Water saturated
Jacobsite	MnFe ₂ O ₄		4.95	200-3000		
Haematite	Fe ₂ O ₃	70%	4.90-5.30	100-300	10 ⁻³ -10 ⁶	25
Limonite	Fe ₂ O ₃ 3H ₂ O	59.9%	3.60-4.00	50-150	10 ⁶ -10 ⁸	3.2-5.9
Goethite	Fe ₂ O ₃ H ₂ O	62.9%	4.00-4.40	40-2000		11.7
Gabro			2.79-3.11	33-7650		
Dolerite			2.89-3.28	Vary with Fe		
Shales			2.50-2.70	100-10000		
Phyllites			2.40-2.50	Vary as per composition		
Laterite			2.30-2.70	50-500		
BHJ/BHQs			2.72-3.10	100-200		

From the table of physical properties it is clear that the manganese ores pyrolusite and psylomelane have significantly high density values compared to laterite, phyllite, shale or BHJ/BHQ. Iron ores namely hematite, limonite or goethite show higher density values comparable to manganese. In the case of magnetic properties manganese (pyrolusite & psylomelane) show paramagnetic (antiferro magnetic) responses comparable to that of hematite. However amidst the environment of phyllite, shale, conglomerate or quartzites the manganese ores can be expected to show detectable magnetic responses. The intergranular pore spaces in the manganese ores and their shallow occurrence in the region make them relatively conductive compared to the BHJ/BHQs or laterite. The difficulty is however, in distinguishing manganese ores from the phyllites and shales. In view of these physical properties information and the experience of the earlier scientists in other areas we have chosen magnetic method as the primary tool which is given support by electrical resistivity and gravity. Cost effectiveness and ease of conducting field

surveys were also given due weight in the selection of geophysical methods and their sequence.

Present Geophysical Investigations

The scientific interest of the present authors and the economic interest of private lease holders in different blocks of the Jamda-Koira belt have led the authors choosing three blocks (marked in fig.1) for the present geophysical investigations. In view of the limited sizes of occurrence of manganese deposits in these areas an almost uniform network of 10mx20m size for magnetics was chosen. Electrical resistivity profiling points with two spacings of AB/2 = 10m and 30m, soundings with AB/2 up to 90m and gravity observations were located along related traverses in each block. The instruments used are proton precession magnetometer of IGIS & Terra Science make, Resistivity meters Aqua Meter-Pune and DDR-III of IGIS and Lacoste-Romberg Gravimeter (Model G1106). Elevation and position location data were obtained using Total Station.

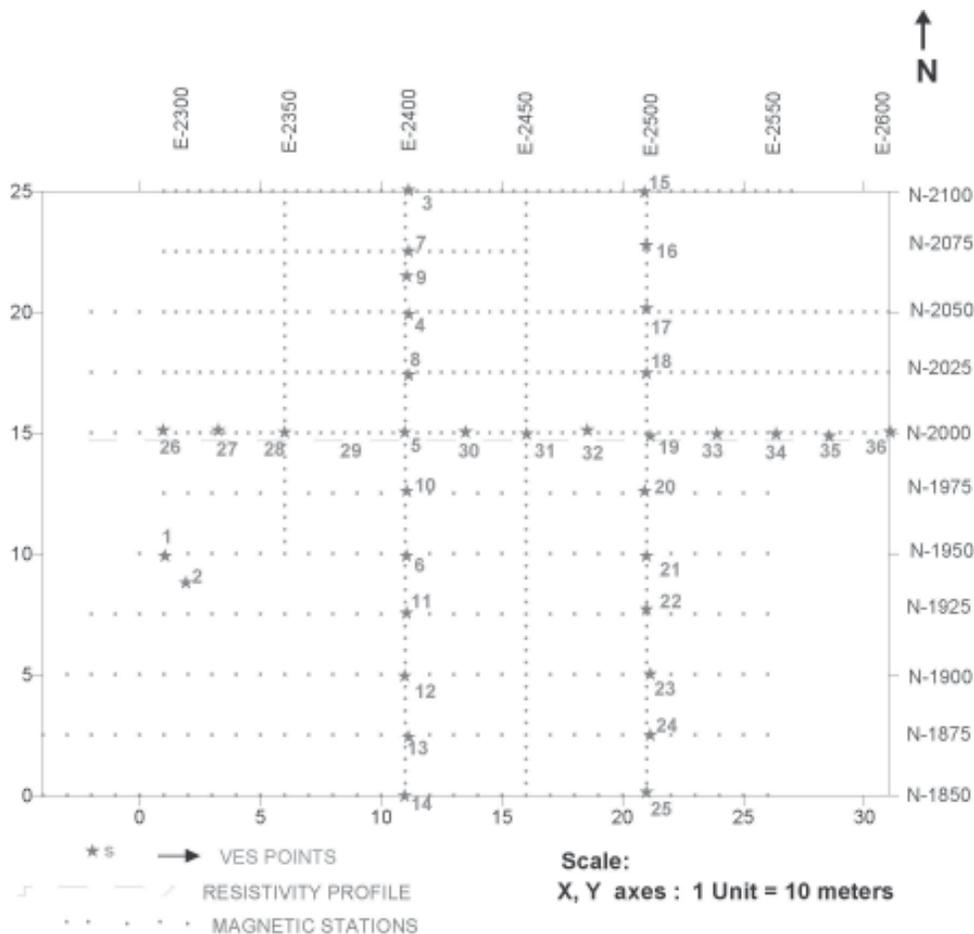


Figure 2. Block-1 Layout of Geophysical Survey Net.

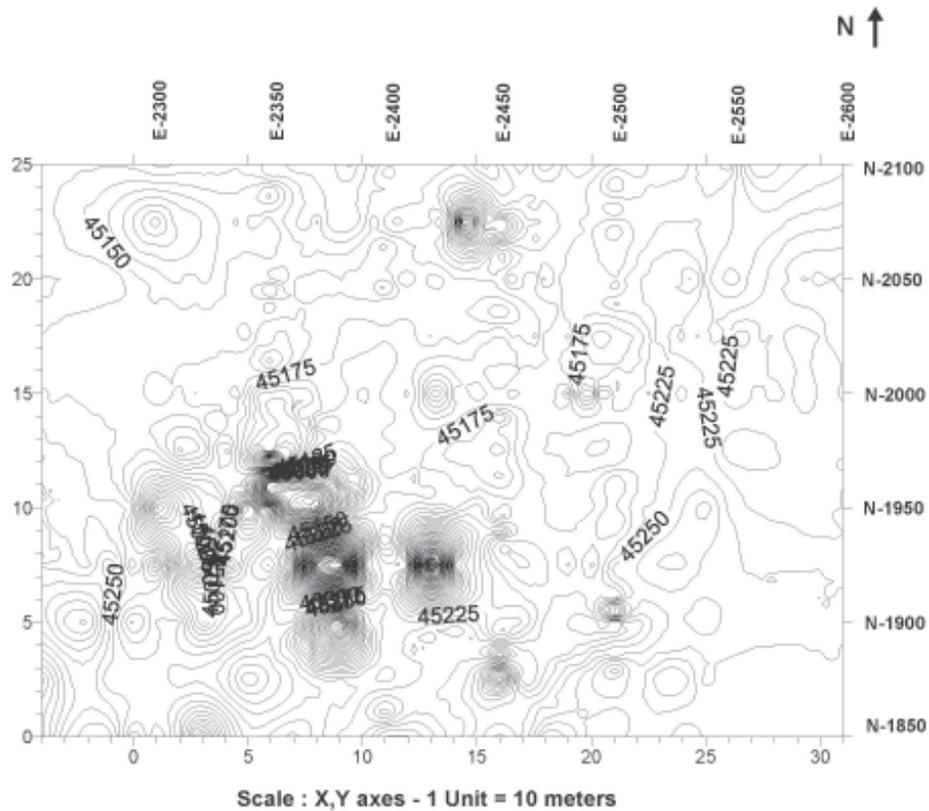


Figure 3. Magnetic Total Field Map of Block-1 : (Contour Interval: 25n T).

BLCOK-1

This block is nearly in a square shape spreading for about 25 hectares. The topography of the area is in a fashion that is elevated towards SE with a relief of about 60meters. The surface is covered by thick forest. From east to west the area is marked by laterite capping; BHJ, BHQs in the central elevated portions and gradually thickening soil cover towards west and southwest.

Though number of boreholes were drilled earlier in the area by a private mining company, no geological log about the occurrence or otherwise of manganese at depth was available to the present authors. However, a rough idea of the surface distribution of some pockets of manganese lumps/lensoids with or without the association of iron and/or laterite is available from the lease companies.

Geophysical traverses (mainly magnetic) were laid in the West to East direction at 25m traverse interval along which stations were located at 10m interval. To have more control, additional traverses were laid in the N-S direction with a view to map the response of ore bodies and also to detect and demarcate their boundaries. Additional stations were laid at 5m

interval on majority of the traverses with a view to trace the lateral spread of ore lenses. In total about 650 magnetic observations, 193 resistivity profiling points, 38 schulmberger soundings and 140 gravity observations were made in the area. The layout of geophysical observations is shown in Fig 2.

Correction for the diurnal variation of magnetic field was effected through maintaining a second instrument at local base.

The magnetic map (Fig.3) interestingly is distinct and characteristic in revealing changes in the magnitudes of anomalies, trends and alignments attributable to known and unknown surface and subsurface geological situation. The magnetic variations shown at 25 nT contour interval correspond well with the trends of manganese ore distributed in lumps/lensoid form. These anomalous zones are showing alignments in NW-SE, N-S and E-W directions. In the SW part of the Block, the high intensity anomaly closures are related to the occurrence of iron ores or iron rich BHJ/BHQs. At places manganese associated with iron is also showing localized magnetic anomaly closures like in the south and also in the north. Magnetic anomalies in lateritic zones are also of low order variation. Low order

elongated magnetic closures in the NW-SE direction and the cross trends in the NE-SW direction brought out especially with the 5m interval stations corroborated well with the known distribution of manganese lumps and thus helped identifying possible new occurrences also. The magnitudes of magnetic anomalies due to manganese ore and/or its contact with the host rocks are of the range 100 to 250 nT. However, these anomaly magnitudes depend upon the depth and width of the manganese ore and the nature of the host rock. Besides, the magnitude, sharp variation in character and dipolar nature of anomaly over the contacts are additional criteria in identifying the probable locations of manganese lensoids. On a qualitative study of different magnetic profiles from the area, electrical resistivity profiling data were obtained as stated earlier, along 3 traverses, two of which are in N-S and another in the E-W directions. The first traverse is passing through the major closure

in magnetic contour map (i.e., E-2400), another one is passing through E-2500 and the third one in an E-W direction, is through N-2000.

Resistivity data obtained along these 3 traverses are effectively corroborating with the evidences of occurrence of manganese brought out in the magnetic picture. Manganese zones exposed are occurring at shallow depths in elevated areas and are marked by high resistivity zones relative to the surroundings. Larger AB/2 revealed decrease in resistivity though maintaining relative high over the surrounding. The situation reverses when the manganese is occurring in low lying areas. The correspondence between both the geophysical data is remarkable, especially in revealing the pockets of manganese occurrence, zones of Iron concentration, lateritic zones and soil covered areas. Structural features like faults, fractures and contacts between different lithologic units are also noticeable. The geoelectric section prepared from

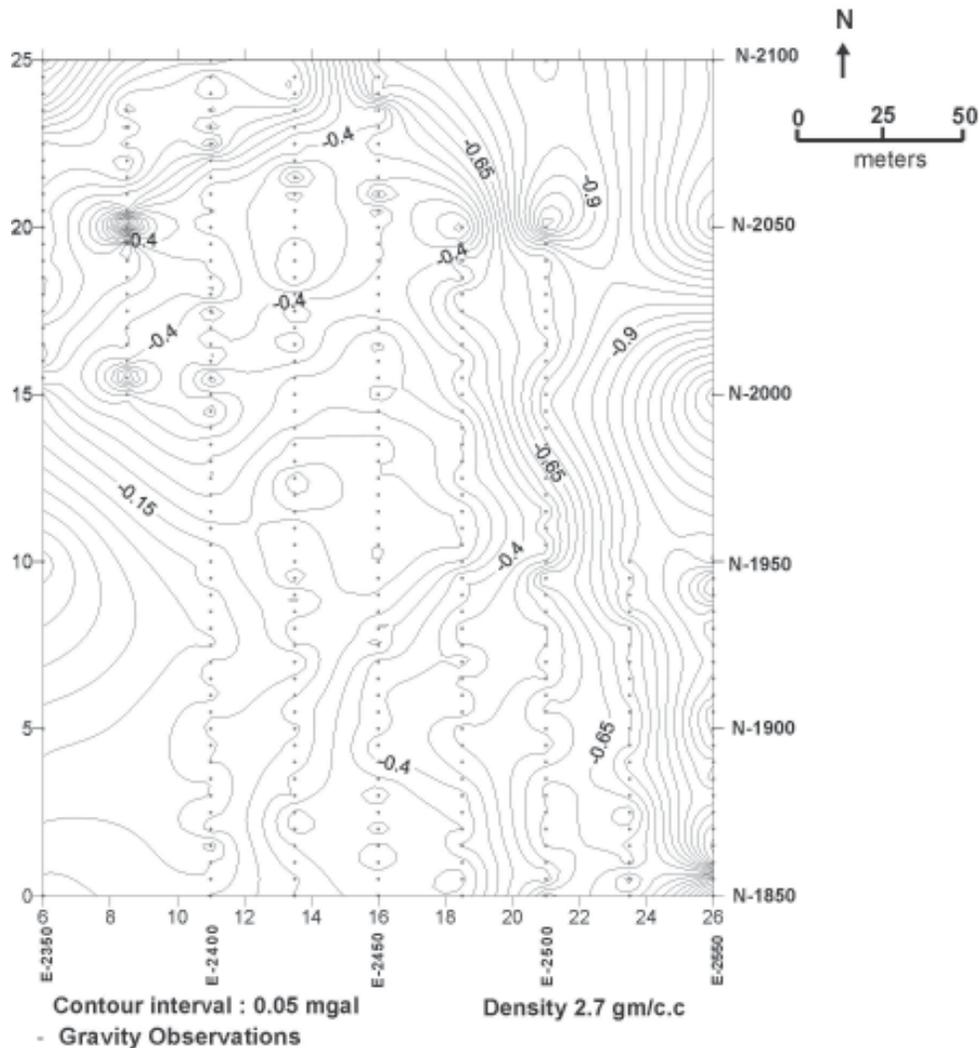


Figure 4. Block-1 Gravity Map.

electrical soundings along NS-III line (E2400) shown in Fig (4) suggests a schematic litho cum structural configuration of the shallow subsurface and therefore favorable zones for manganese occurrence.

The gravity anomaly contour map prepared for this block (Fig.4) has excellent agreement with the magnetic map especially in showing the zone of manganese ore occurrences (from NW-SE) and the pockets of Iron concentration. Pockets of manganese occurrence eventually are revealed by relative gravity highs of the order 0.10 to 0.25mgal. The contour trends also reveal structural trends like faults and fractures and the discontinuities in the occurrence of manganese lenses. The gravity map shown is prepared at 0.05 mgal contour interval and is referred to a local base and therefore the appearance of positive and

negative anomaly closures. Though the topography is relatively gentle, at a few places like along N-2050 and E-2175 the appearance of sharp closures in gravity might be indicating terrain effects, correction for which is not feasible in the absence of detailed elevation data beyond the borders of the block.

Based on the study of the magnetic, electrical resistivity and gravity data a geophysical anomaly trend map has been prepared and projected on to the surface mineral occurrence map (Fig. 5). In the geophysical section prepared along Traverse E-2400in block -I with all three types of geophysical data and the geoelectric section from Schlumberger VES shown in Fig.6, the criteria for visualizing causative sources can be easily imagined. The central high resistivity zone corresponding to the gravity low and flanked by sharp

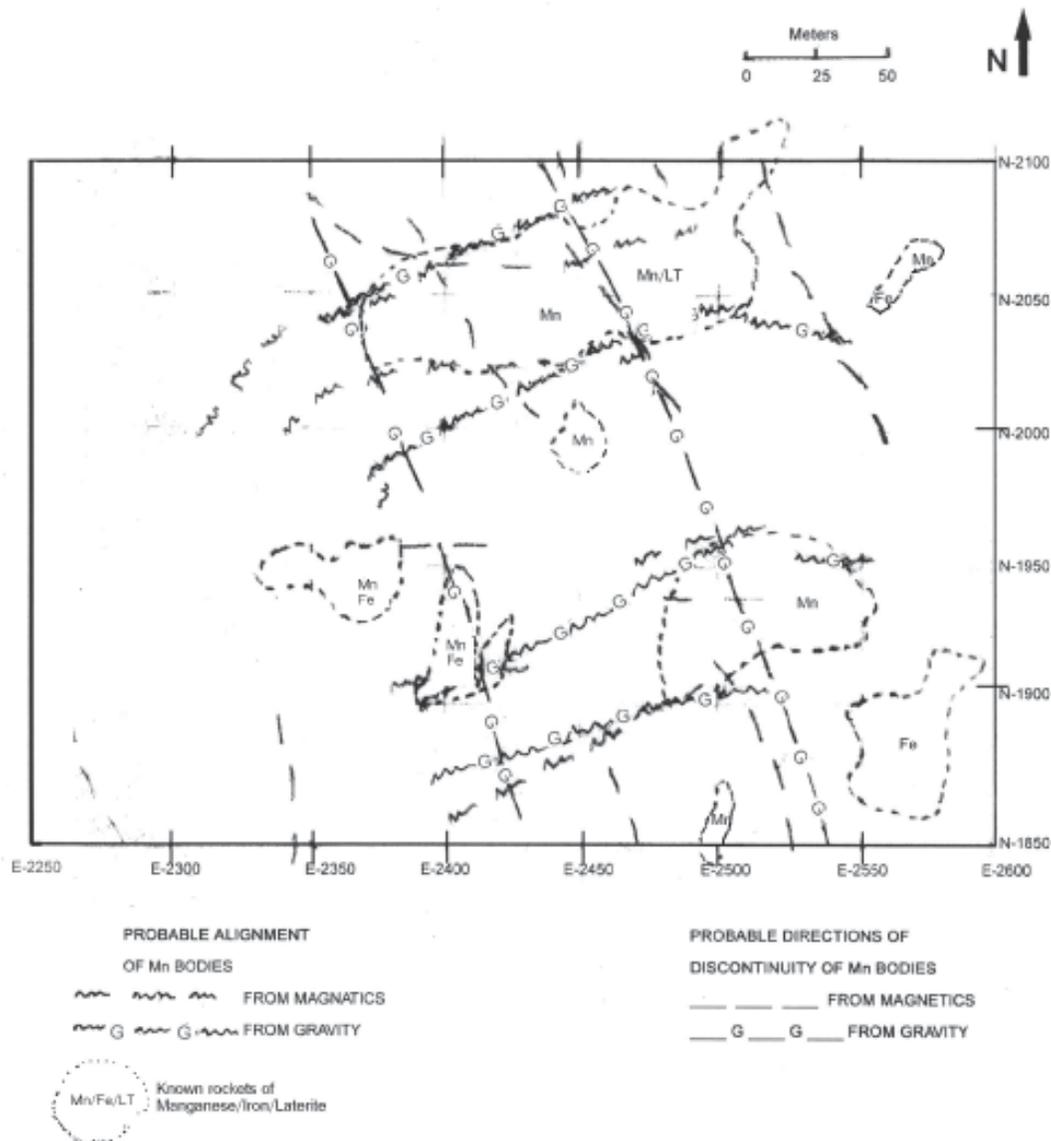


Figure 5. Block-1 Trends From Geophysical (Gravity & Magnetics) Data.

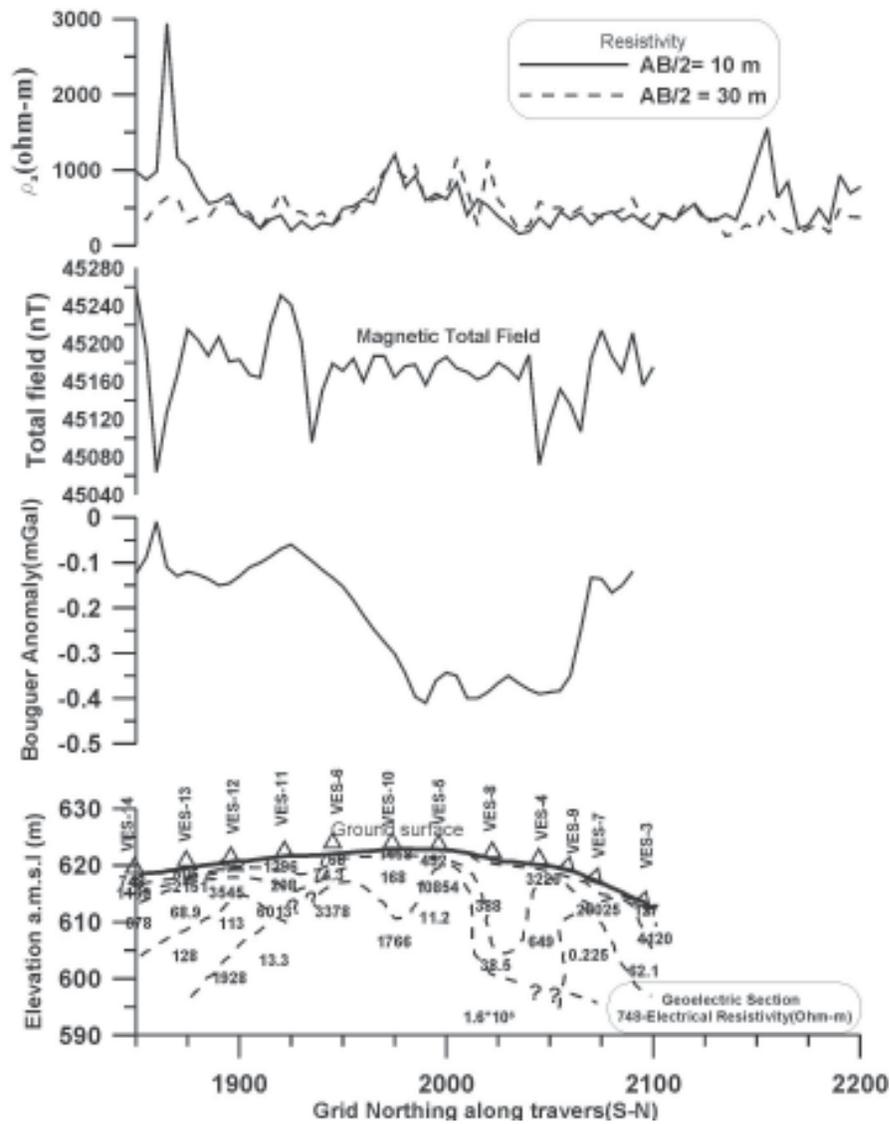


Figure 6. Geophysical Section along Traverse-E2400 of Block-I.

magnetic fault/dyke like anomalies on either side appear to be due to a major fold, the flanks on either side are the likely seats of manganese occurrence as at VES-II to VES-6 (N-1925 to N-1950) and VES-8 to VES-7 zones (N-2025 to N-2075). The correspondence among these geophysical signatures facilitates formulating and streamlining the geophysical methodology for manganese prospecting in these regions. Based on these inferences a few locations in the block were suggested as at around E-2450, N-1875 for possible occurrence of manganese.

Block – II

This block is about 89 hectares in area, spread in nearly rectangular shape and is mostly covered by thick

forest. Topography is highly undulatory representing the north – northeast sloping limb of a hill range extending in a NE-SW direction. Places of the hills located in the south east are up to 680m a.m.s.l., whereas the minimum elevation are about 550m a.m.s.l. located in the NW of the block. NE – SW trending valleys also are there draining the area towards NE to form almost perennial streams.

The geological formations are similar to that of the earlier block, with exposures of shales/phyllites, laterite, BHQs and limonite and goethite. In this block also manganese ore is associated with laterite and iron and at places covered under soil. The sizes of manganese occurrences as seen in some test pits by industry are relatively small compared to the sizes of laterite and iron exposures. Though no standard

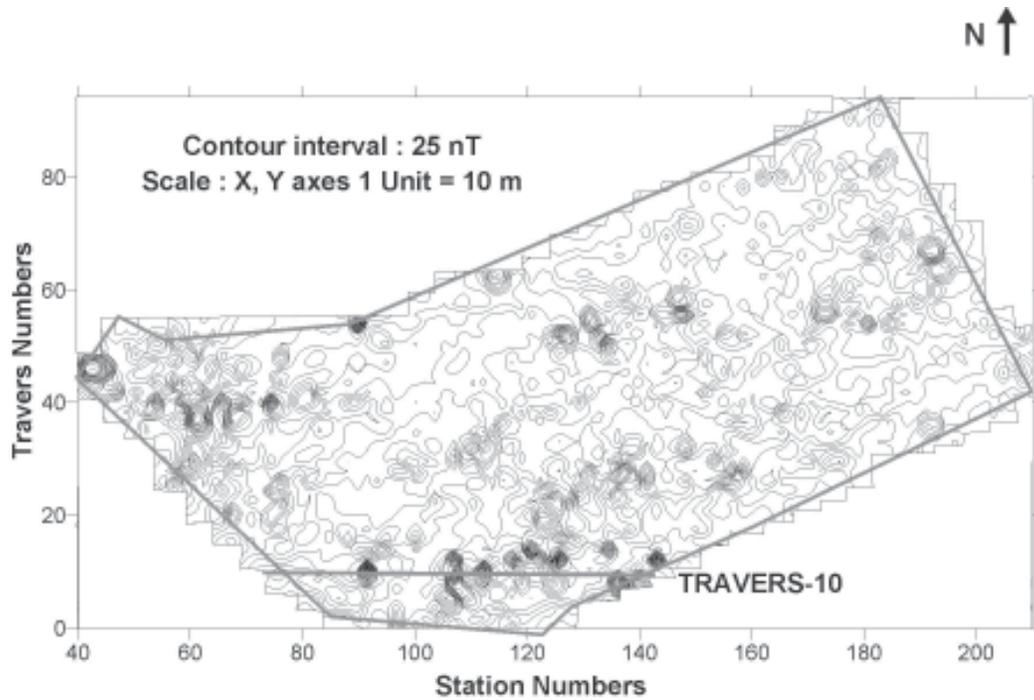


Figure7. Magnetic Total Field Map of Block-II.

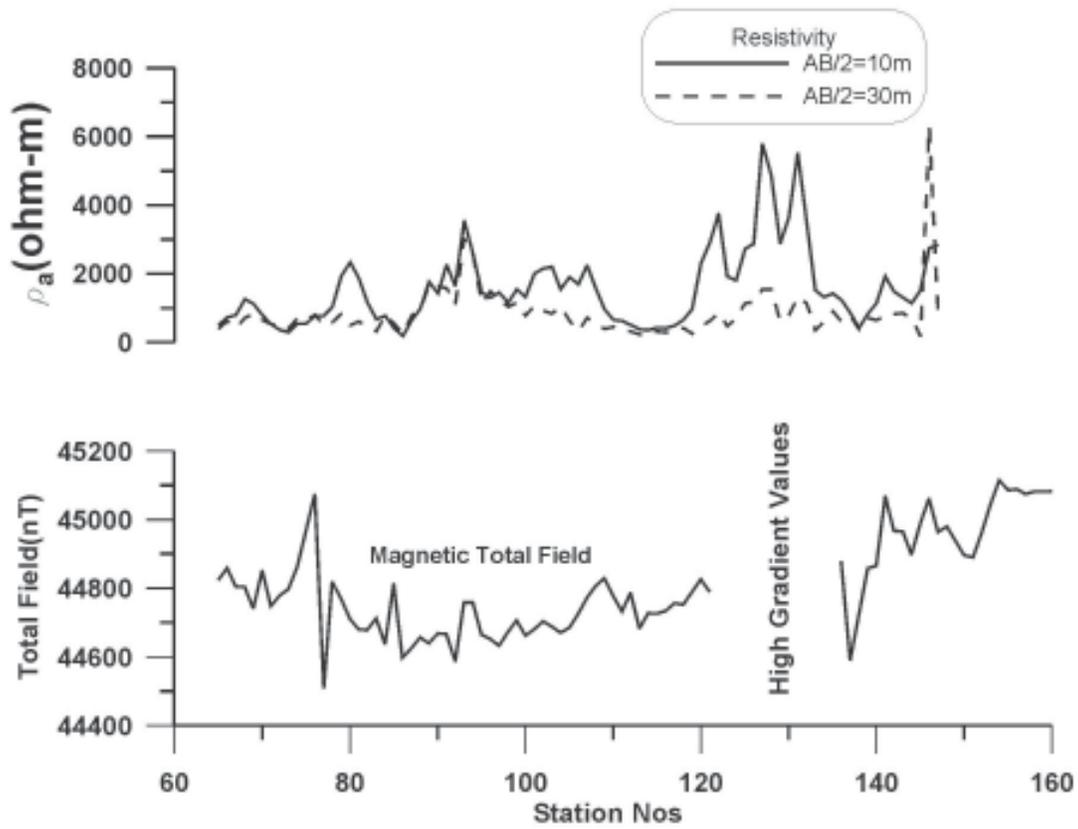


Figure 8. Geophysical Section along Traverse -10 of Block-II.

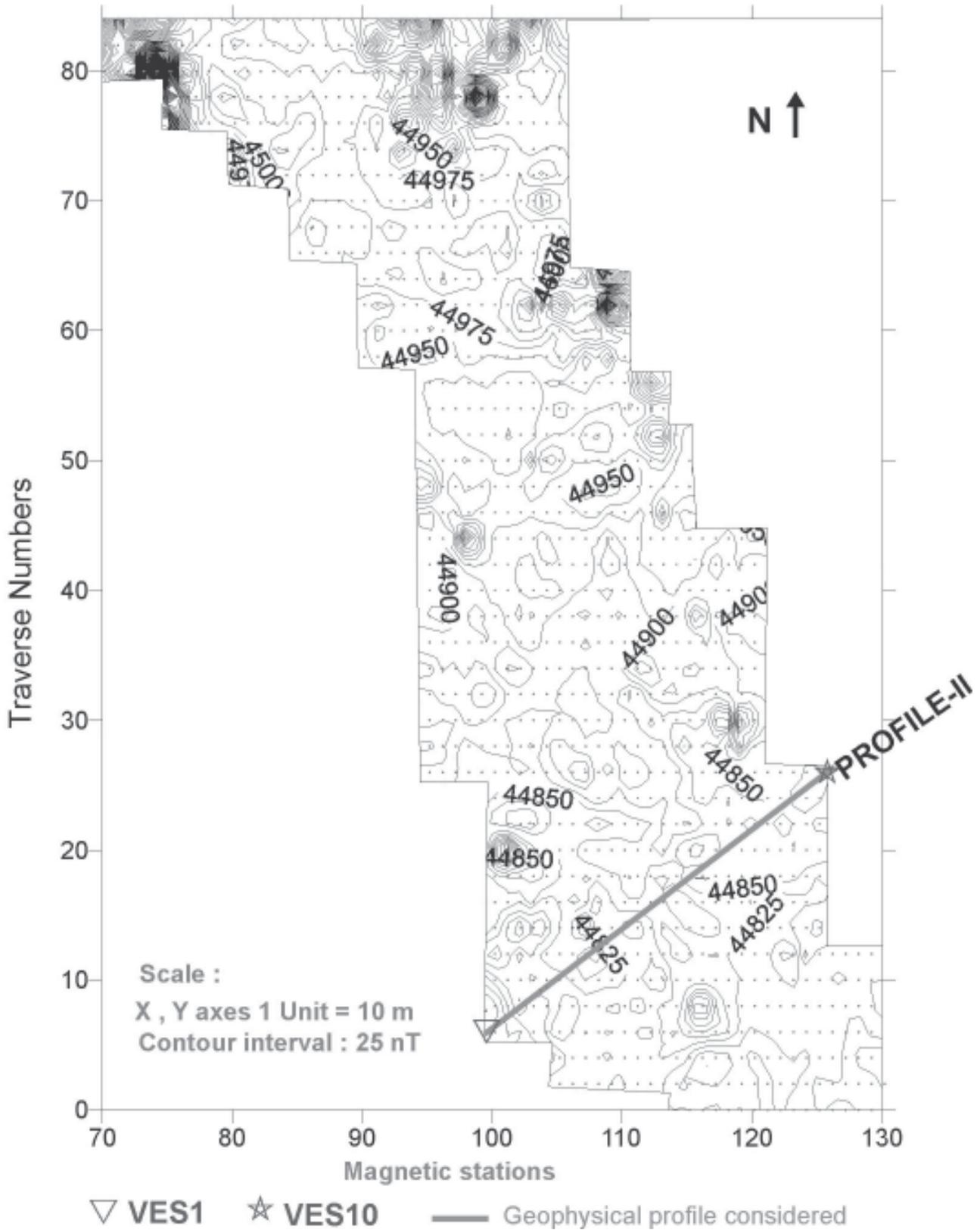


Figure 9. Block-III Total Field Magnetic Map.

correspondence is noticeable between manganese occurrences and the topography, the manganese bodies appear to be located on the hill slopes to go under soil cover thickening towards NW.

In this block also magnetic data were collected, as stated earlier, at the grid specification of 10m x 20m with the traverses laid in an E-W direction with a total number of 4374 stations. A magnetic contour map was prepared at 25nT contour interval (Fig.7). The magnetic picture is very interesting with the two fold character of concentration and alignment of magnetic closures and relatively magnetically smooth and plain regions. The clusters of magnetic closures with a wide range of fluctuating intensities appear to be in two NE-SW extending bands in the major part of the area and a cluster of closures in the western corner of the area. Topography and the location of old mine pits correspond well with the first feature that NE-SW aligned magnetic contour closures reveal the occurrence of manganese ores along with associated iron. The second feature viz., the cluster of magnetic closure located in the west of the area has to be attributed to presence of magnetic iron. Possibility of occurrence of manganese here in association with iron can not be ruled out. The two parallel bands of magnetic closures in the NE-SW direction might represent the two limbs of a fold with its axis aligned in that direction.

Electrical resistivity and gravity surveys were contemplated in this block. In Fig.8 also the behavior of geophysical magnetic and electrical resistivity variations identified in block -I (Fig.6) can be seen especially around station 90 on this Traverse-10. Therefore the zone between stations 85 and 95 is of interest in terms of manganese occurrence. The zone between stations 120 and 140 where high gradient magnetic values correspond to high resistivity at shallow depth may be laterite with iron or iron ore. VES data to prepare a geoelectric section would help drawing more reliable inferences.

Block – III

This block elongated in a NW-SE direction is almost of a parallelogram shape. It occupies about 24 hectares area in the Jamda – Koira belt and is covered by not so dense a forest. Topography suggests a NW-SE trending ridge, (probably an anticlinal fold) with the sloping eastern limb and southern apex portion appearing in the area of study. Elevation relief is about 30m in the area with the highest and lowest values being 640m and 610m. Geologically the area is covered with Quartzites, Laterite, and Alluvium. Manganese occurs in some places in the form of lumps and in

small pockets. Iron ore, mostly lateritic and haematite, appear in the NW border aligned in a NW-SE direction. There is only one pit dug for manganese, located in the eastern edge of the area.

Following the usual specifications as earlier, magnetic data were collected from the block. Considering the alignment of the ridge and also the magnetic map, additional traverses were laid in this block in the SW-NE direction (7 traverses) and NW-SE direction (2 traverses) along which the magnetic stations were located at 5m interval. Electrical resistivity profiling and soundings were conducted along three of the SW-NE traverses. Totally about 1102 magnetic observations were made to prepare the magnetic map. Electrical resistivity profiling points numbering 542 and soundings 28 were made in this block.

The magnetic anomaly map (Fig .9) is slightly different from that of the earlier two blocks in reflecting the magnetic signatures of the subsurface. The elevated ridge like NW-SE feature with exposures of BHQs and Quartzites and partly covered by Alluvium and laterite is moderately magnetic. Again along the eastern border of the area in the downward slope direction magnetic response is slightly active. The central portion between these two zones extending in the NW-SE direction is magnetically relatively calm. However, there are recognizable trends in the NW-SE direction and in the SW-NE direction similar to those observed in Block – I. Most of the high intensity magnetic closures are corresponding with known occurrence of (lateritic) Iron ore. The clusters of magnetic closures in the NE of the area are probably revealing the occurrence of Iron ores. Manganese being moderately magnetic, the trends and cross trends of magnetic anomaly features and localized closures of moderate values adjacent to the high intensity closures are of interest in the context of manganese exploration.

As in the case of Block – I, electrical resistivity profiling data, geoelectric section prepared from VES data and the magnetic field along three SW-NE traverses were studied. Fig. 10 shows one such section revealing the correspondence between the electrical and magnetic data and the inferred geoelectric subsurface section. It is interesting that the quartzites and BHQs are revealed by high resistivities and smooth magnetic variations. Lateral changes in lithology in the shallow subsurface are also prominently brought out. It is likely that the subsurface configures as an anticlinal fold between VES-4 and VES-7 followed by a syncline between VES-8 and VES-10. The sloping limbs of these folds are of interest in terms of manganese occurrence as in the case of Block-I.

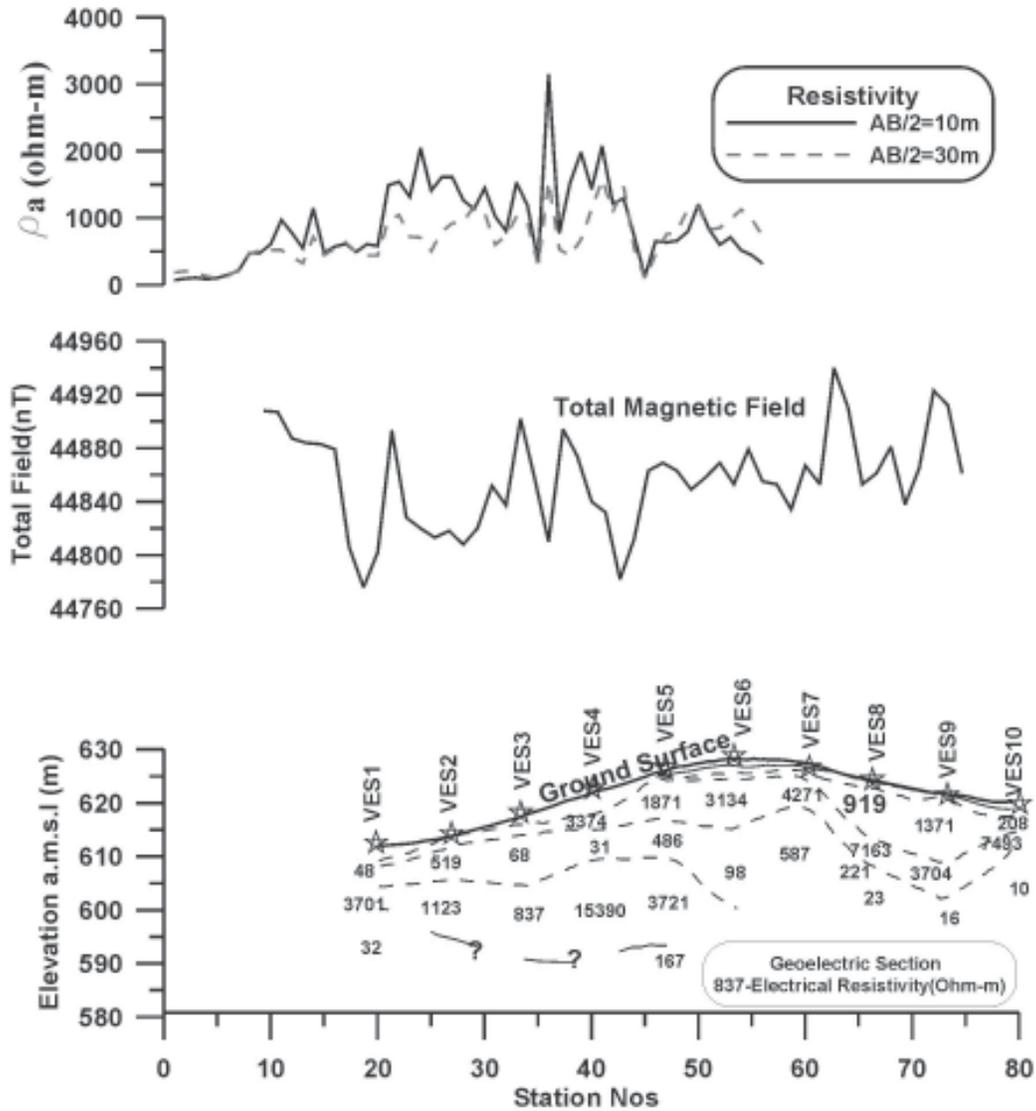


Figure.10. Geophysical Section along Profile -II of Block-III.

CONCLUSIONS

Prospecting manganese is still a puzzle despite the large number of geophysical investigations conducted by earlier researchers. This is because of the varied types of origin and occurrence controlled by the regional geology. In the Jamda-Koira belt of Singhbhum region manganese occurs as small lensoids/lumps located between highly folded structurally disturbed phyllitic shales and BHJ/BHQs of Iron ore series. The magnetic, electrical resistivity and gravity surveys conducted in 3 blocks suggested scope for analyzing and assigning causative sources

for the anomalies and identifying criteria for locating manganese either directly or indirectly controlled by lithology.

The geophysical study presented in this paper forms the first level of investigation. The inferences made out of the present qualitative study needs to be strengthened through first hand physical property studies on rocks and the ores from the field, conducting further detailed gravity and magnetic investigations in identified pockets of the blocks and quantitative interpretation and estimations through verification drilling or pitting at one or two locations in each block.

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