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Geological interpretation from Bouguer gravity data over the Singhbhum-Orissa Craton and its surroundings: A GIS approach

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ABSTRACT
The Digitized Gravity Model (DGM) of the Bouguer anomaly map of Singhbhum – Orissa Craton and its surroundings obtained using GIS techniques brought out several gravity highs and lows which bear a strong correlation with the surface geology. The aspect map of the Bouguer anomaly is calculated, which helps in demarcating transitions in gravity values and thereby indicates subsurface geology. Thus the gravity transitions observed in aspect map also delineate aspect lineaments and infer a new horizon to understand the tectonic activity over the Singhbhum Shear Zone.

INTRODUCTION

This paper utilizes different GIS techniques for better interpretation and understanding of gravity data in terms of geology. First, the Digital Gravity Model (DGM) has been built from the gravity data. Then, geological interpretation has been performed from both DGM and aspect map. Singhbhum-Orissa Craton is an area of geologically complex and mineralogically rich belts of the Indian subcontinent, approximately between latitudes 21^0N to 23^0 15′ N and longitudes 85^0E to 86^0 45′ E. The gravity field in the area has been significantly influenced by the Iron Ore geosyncline starting from about 3200 Ma (Sarkar & Chakraborty 1982). Further, the occurrences of sedimentation, volcanism, basic and ultrabasic intrusions, granitic intrusions of batholithic dimensions, differentiation of granites, and thrust movements of major dimensions had significant role in controlling the gravity field of this area. Sarkar & Chakraborty (1980) have suggested that the area had experienced at least three orogenic cycles in the past history. The different geological episodes that had taken place during various orogenic cycles have kept their imprints which are reflected as gravity highs and lows and transitions in the gravity gradient. Such types of gravity interpretation can be made from the Digital Gravity Model (DGM), Gravity Aspect Map, and by draping of geology map over DGM using GIS.

GEOLOGICAL SETUP

The area has been extensively surveyed and studied systematically using ground-based geological techniques (Dunn 1929; Sarkar & Chakraborty 1982; Acharya 1984; Ghosh & Sengupta 1990; Chetty & Murthy 1994; Saha 1994). The stratigraphic sequence of the study area as revised by Sarkar & Saha (1977) and Sarkar, Boelrijk & Hebada (1979) is shown in Table 1. This revised sequence considers that "Singhbhum Group" and Dalma Volcanics are much younger than the "Iron Ore Group" rocks, both evolving into two separate orogenic belts (closing at 850 Ma and 2900-3000 Ma respectively). Large-scale N-S displacements of the rocks along the thrust belt have brought these two orogenic belts in an intersecting disposition.

The Older Metamorphic Group, found in Champua (22^0 N, 85^0 40′ E) in the central part of the basin, is the oldest (3200 Ma) rock formation and it consists of metasediments associated with basic intrusions (Sarkar 1980). Rocks of Older Metamorphic Group, comprising predominantly schists, form the basement rocks. The Iron Ore Group rocks overlie the basement rocks and are exposed over vast areas in the western part and over some areas in the east. The Iron Ore Group succession is believed to have formed a broad NNE plunging synclinorium with overturned western limb. Massive batholiths of granite to granodiorite composition occupy vast areas in the

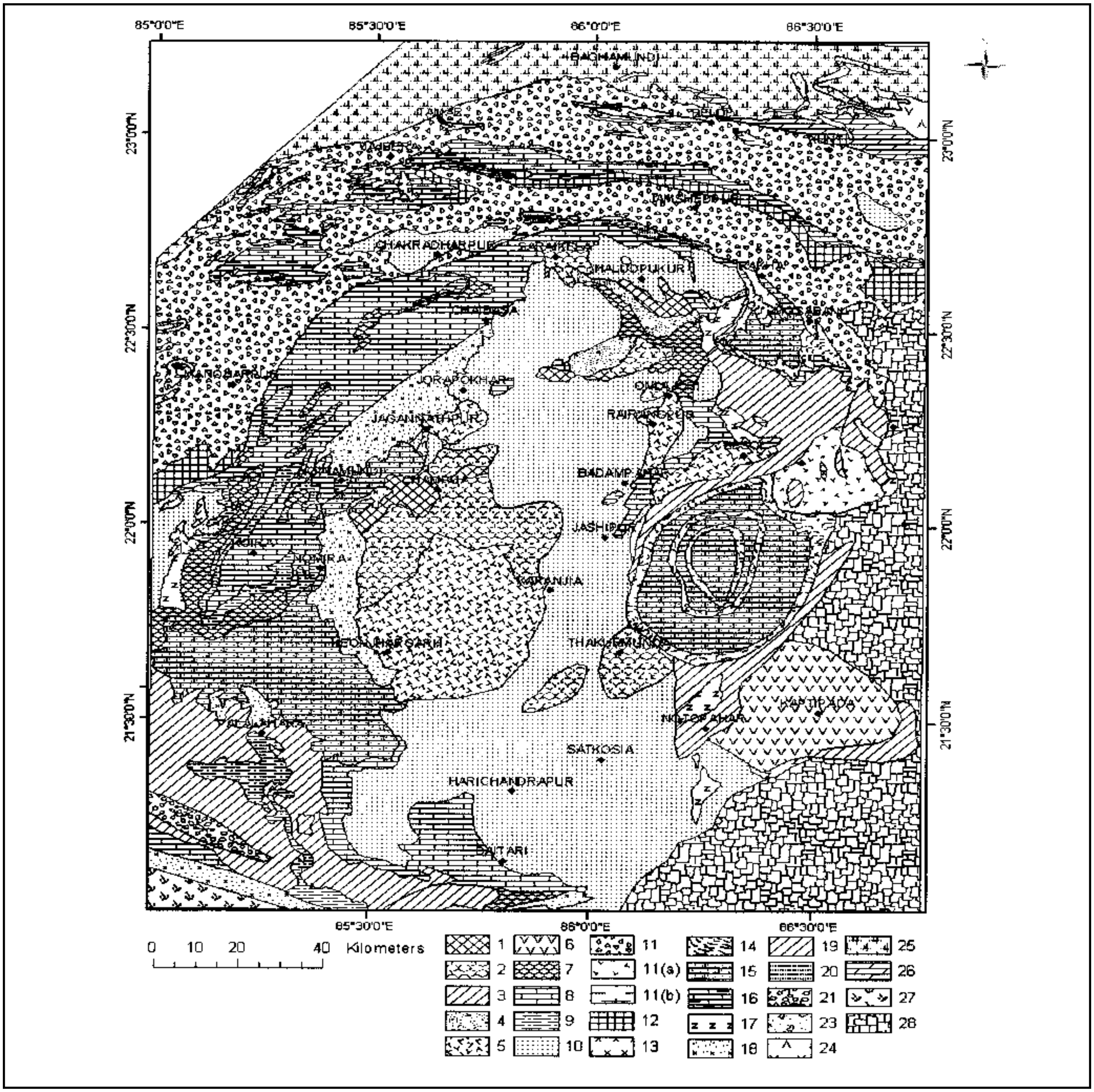

Figure 1. Geological map of the study area (after Saha 1994). 1-Older Metamorphic Group; 2-Older Metamorphic Tonalite-gneiss; 3-Pala Lahara Gneiss; 4-Singhbhum Granite-Phase-I; 5-Singhbhum Granite-Phase-II and xenolith-dominated areas of Bonai Granite; 6-Nilgiri Granite; 7-Iron Ore Group lavas, ultramafics; 8-Iron Ore Group shales, tuffs, phyllites; 9-BHJ, BHQ and sandstones-conglomerates of Iron Ore Group; 10-Singhbhum Granite –Phase-III, Bonai Granite, Chakradharpur Granite; 11-Singhbhum Group pelites, 11(a)-Mafic bodies 11(b)-Carbon phyllites; 12-Singhbhum Group quartzites; 13-Dhanjori Group; 14-Quartzites-conglomerates-pelites of Dhanjori Group; 15-Dhanjori-Simlipal-Jagannathpur-Malangtoli lavas; 16-Dalma Lavas; 17-Proterozoic Gabbro-anorthosite-ultramafics; 18-Kolhan Group and equivalents; 19-Mayurbhanj Granite; 20-Soda Granite, Arkasani Granite, Kuilapal Granite, Alkaline Granite; 21-Charnockite; 22-Khondalite; 23-Amphibolite enclaves (within CGG); 24-Pelitic enclaves within CGG; 25-Chhotanagpur Granite Gneiss (CGG); 26-Porphyritic member of CGG; 27-Gondwana sediments 28-Alluvium Tertiaries

Table 1 : Stratigraphic sequence of Precambrian rocks of Singhbhum after Sarkar & Saha (1977) and Sarkar et al. (1979)

South of Copper Belt Thrust	North of Copper Belt Thrust
- - - - - - - - - - - - - -End of Singhbhum orogenic cycle -	
(ca. 850 ma)	
Granite gneiss, granophyres, gabbro-anorthosites	Granite and granophyres
	Dalma lava
Ultrabasics	———overlap———
Kolhan Group(metasedimentaries) (ca. 1500- 1600 ma.)	singhbhum Group: Dhalbhum Formation, Chaibasa Formation
Dhanjori formation: volcanics and sediments	
- - - - - - - - - - - - - - - - - - Unconformity -	
——— End of I.O. orgenic cycle ———	
(ca. 2900 ma.)	
Singhbhum gra	
Epidiorite	
Iron Ore Group: sedimentaries and volcanics (slightly more metamorphosed)	
- - - - - - Unconformity - - - - - - - - - - -	
——End of older metamorphic cycle——	
(ca. 3200 ma.)	
Granitic and basic rocks	
Older metamorphic group: moderate to high grade metasedimentaries and basic intrusives	

central part to the south of Singhbhum Shear Zone (SSZ). This granitic mass was emplaced after the deformation of the Iron Ore group. Stratigraphic position of Singhbhum Granite has been much debated. Radiometric dating suggests an age of 2950 Ma for Singhbhum Granite. This large granite body extends for about 150 km in N-S direction and about 70 km in E-W direction between latitudes 21^0N and 22^0 45′N and between longitudes 85^0 30′E and 86^0 30′E. It covers a major part of the area of interest. Rocks of Dhanjori Group are exposed in the eastern part of the Singhbhum region. This Group consists of conglomerate, quartzite, mica schist and meta-gabbros close to thrust (SSZ) zone. The equivalent of the bottom part of this succession is identified as Singhbhum Group to the north of the Singhbhum Shear Zone. Similarly, the equivalent of lava flows in the north is called Dalma Lava. Dolerite dikes have intruded in the Singhbhum Granite and occur mostly in southern part of Singhbhum district, Jharkhand and in parts of Keonjhar district, Orissa. Kolhan Group occurs to the SSW of SSZ. It consists of gently dipping purple sandstones, conglomerates, limestones and slates. Fig.1 shows the geological map of the study area.

DATA SOURCES AND AREA OF INTEREST

The Bouguer anomaly maps (Verma, Sharma & Mukhopadhyay 1984) over the study area, covering Singhbhum Shear Zone (SSZ) and surrounding areas occupying parts of Jharkhand, West Bengal and Orissa, have been scanned and geo-rectified on geographic latitude/longitude projection system using fourth order polynomial geometric model. The study area falls between latitudes 21^0 N to 23^0 15′ N and longitudes 85^0 E to 86^0 45′ E. The geo-rectified gravity anomaly map has been projected on Universal Transverse Mercator (UTM).

METHODOLOGY

The Bouguer gravity contour lines as obtained from Verma, Sharma & Mukhopadhyay (1984) are digitized, keeping the scanned geo-rectified (UTM) image in the background. The gravity anomaly values have been assigned to the corresponding contour lines to generate an arc coverage file. This arc coverage file has been converted to point coverage file with vertical coordinate axis (Z - axis) as gravity value in mgal. This point coverage file has been ultimately converted into grid (raster) format using Krigging method of interpolation with output cell sizes of 100 meters. Spherical semi-variogram model has been used to calculate gravity surface image in this Krigging method. The interpolation has been done to prepare a continuous surface of Bouguer anomaly map of the study area. Various surface interpolation methods, such as, Spline, Krigging, Inverse Distance Weighted and Natural Neighbor have been attempted to acquire the interpolated gravity anomaly surface. The gravity anomaly surface map, thus prepared, is then used as Digital Gravity Model (DGM).

From the DGM, the aspect of gravity value has been calculated using ARCGIS software for improved gravity interpretation. Aspect is the direction that a slope faces. It identifies the steepest down slope direction at a location on a surface. Aspect is measured counterclockwise in degrees from 0 (due north) to 360 (again due north, coming full circle). The value of each cell in an aspect grid indicates the direction in which the cell's slope faces. Flat slopes have no direction and are given a value of -1. There are various reasons to use the aspect function; for instance, it may help to find all directional slopes of gravitational field as part of a search for mineralisation occurrences. It also identifies the areas of flat gravitational field.

Study of Bouguer Gravity Anomaly Map

The gravity anomaly map of Singhbhum-Orissa Craton and its adjoining areas has been interpreted in terms of proposed conceptual geological model with the help of GIS (Harris, Viljoen & Renez 1999; Patrick 2001). The Digital Gravity Model (DGM) has been generated by surface interpolation of the digitized contour map, as discussed above and shown in Fig. 2. Figure 3 shows the 3D view of gravity anomaly map over the study area. The geological data has been digitized as a vector coverage, and then converted to a grid (raster) format. Grid values relate to the lithological information and are used to assign colors to the corosponding geology. This final product in color is then draped over the DGM using ArcScene, 3D Analyst extension (McCafferty, Bankey & Brenner 1998), and is shown in Fig. 8.

Gravity Highs and Lows

Eight (H_1-H_8) gravitional highs in the present study have been identified (Figs 2 and 3). The magnitudes of different gravity highs and lows are shown in Tables 2 and 3. H_1 follows the orientation of Iron Ore

Table 2. Details of gravity highs over the study area

Gravity High	Latitude Near center	Longitude Near center	Area covering Gravity High (sq. km.)	Magnitude (mgal)	Geological Attribution
H_1	22^0 8′N	85^0 17′E	1255	-2.6007	IOG sediments
H_2	22^0 45′N	85^0 16′E	1098	3.6767	Singhbhum Group of rocks
H_3	22^0 55′N	86^0 15′E	1562	-1.3085	rocks of Dalma volcanics
H_4	23^0 10′N	86^0 42′E	188	-7.0602	Pelitic enclaves and Prophyritic member of CGG
H_5	22^0 19′N	86^0 20′E	842	-4.3413	rocks of Mayurbanj granite and Dhanjori-Simlipal-Jagannathpur lavas
H_6	21^0 48′N	86^0 18′E	714	-0.9967	Simlipal Basin consisting of volcanics, quartzite, and conglomerates in an alternating sequence
H_7	21^0 25′N	86^0 19′E	898	-0.6683	Nilgiri Granite, IOG and Alluvium tertiaries
H_8	21^0 6′N	85^0 16′E	2043	-4.5329	Pala Lahara Gneiss and IOG sediments

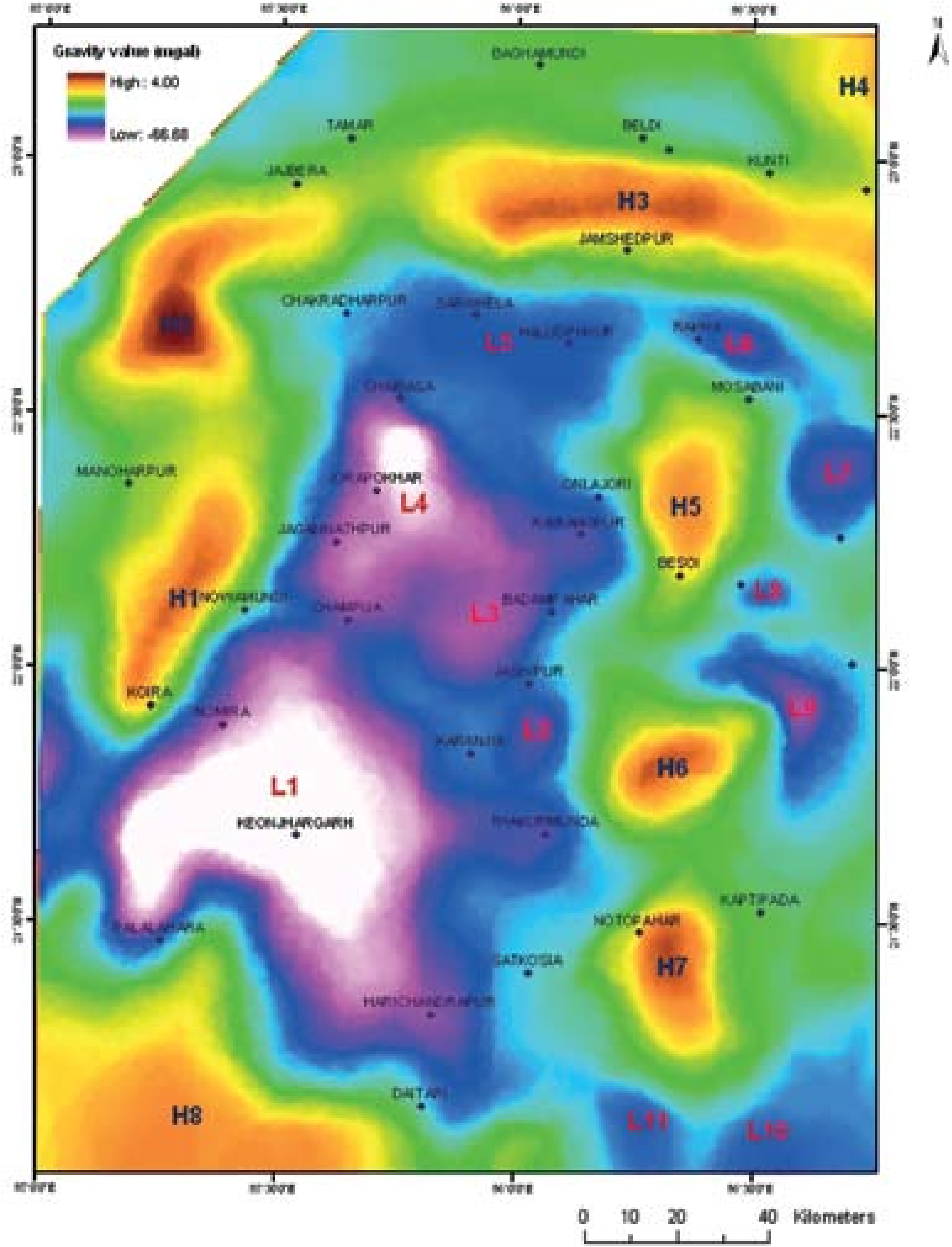

Figure 2. Digital Gravity Model (DGM) generated from Bouguer gravity anomaly (after Verma, Sharma & Mukhopadhyay 1984) over SSZ and its surroundings.

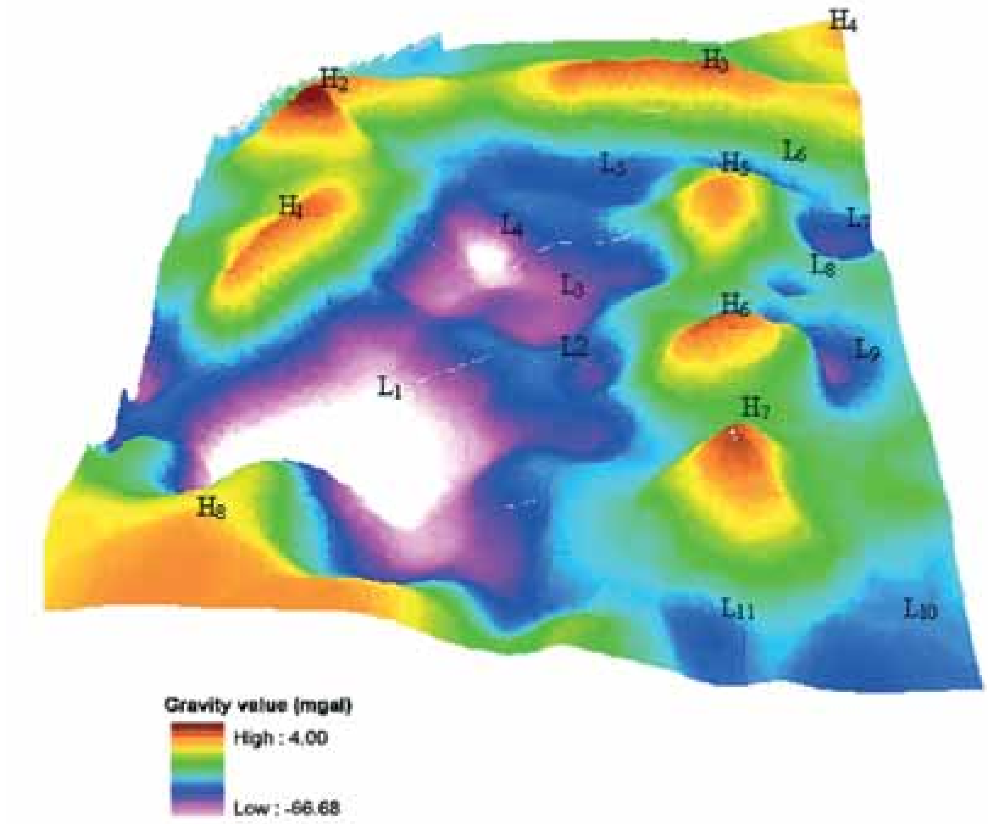

Figure 3. 3D perspective view of Bouguer gravity field as generated from DGM using ARCGIS system.

Table 3. Details of gravity lows over the study area

Gravity Low	Latitude Near center	Longitude Near center	Area covering Gravity Low (sq. km.)	Magnitude (mgal)	Geological Attribution
L_1	21⁰ 40′N	85⁰ 32′E	2720	-62.3260	Singhbhum Granite-Phase II, xenolith dominated areas of Boni Granite, Kolhan Group and equivalents, mostly underlain by volcanic rocks belong to IOG
L_2	21⁰52′N	86⁰E	165	-39.3492	IOG rocks
L_3	22⁰ 6′N	85⁰ 54′E	374	-44.00	Singhbhum Granite-Phase III
L_4	22⁰ 22′N	85⁰45′E	560	-53.9873	Singhbhum Granite
L_5	22⁰38′N	85⁰58′E	698	-36.00	Singhbhum Granite
L_6	22⁰38′N	86⁰ 27′E	260	-39.0161	Singhbhum Group
L_7	22⁰23′N	86⁰ 39′E	478	-38.9996	Alluvium Tertiaries
L_8	22⁰8′N	86⁰ 31′E	173	-34.0155	IOG lavas, ultramafics and Singhbhum Group mafic bodies
L_9	21⁰ 56′N	86⁰ 35′E	530	-43.3349	Alluvium Tertiaries
L_{10}	21⁰3′N	86⁰ 31′E	735	-35.4008	Alluvium Tertiaries
L_{11}	22⁰6′N	86⁰ 15′E	332	-35.6803	Alluvium Tertiaries

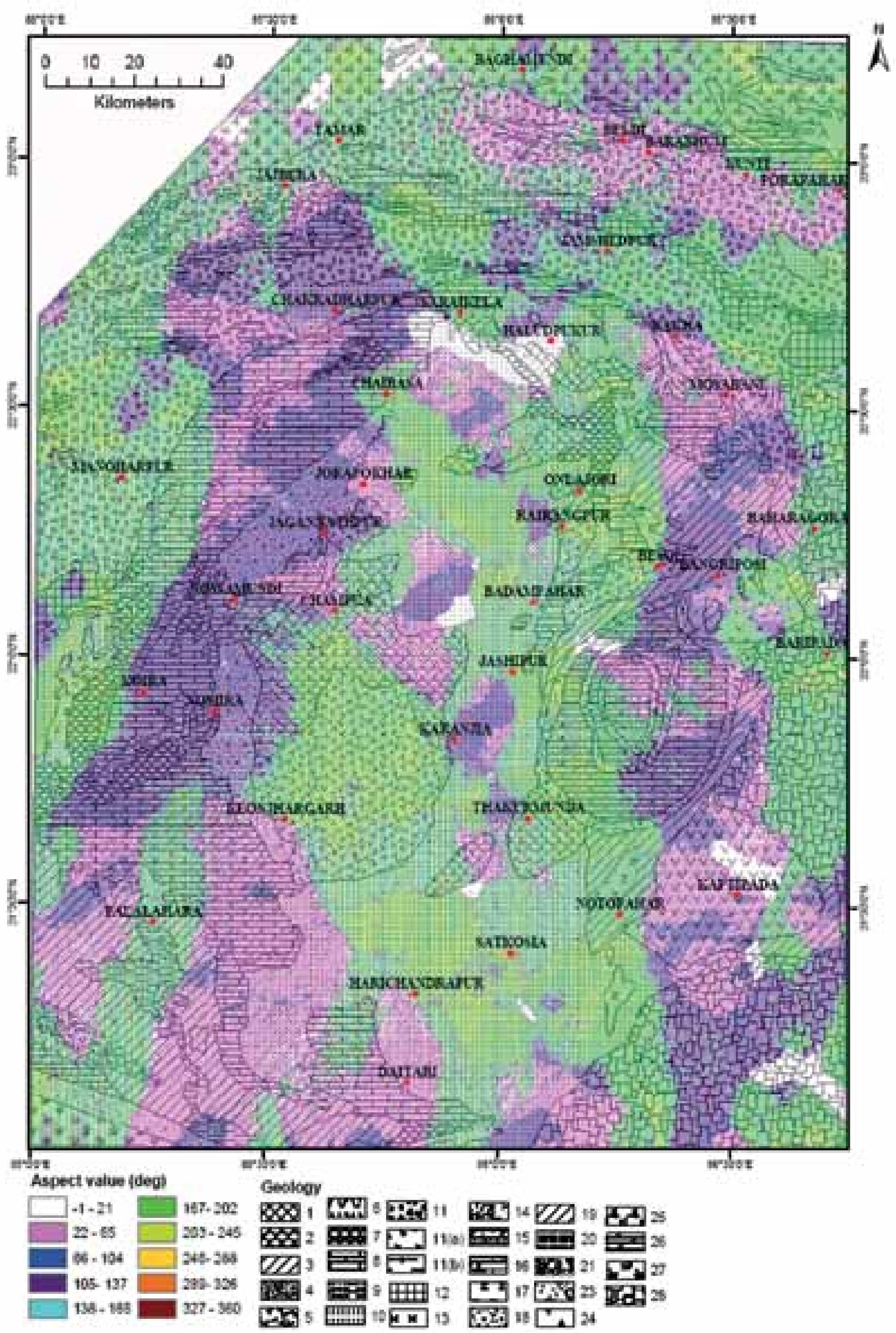

Figure 4. Aspect map generated from DGM and superimposed over the geological map of the study area (Description of geological legends is given in Fig.1).

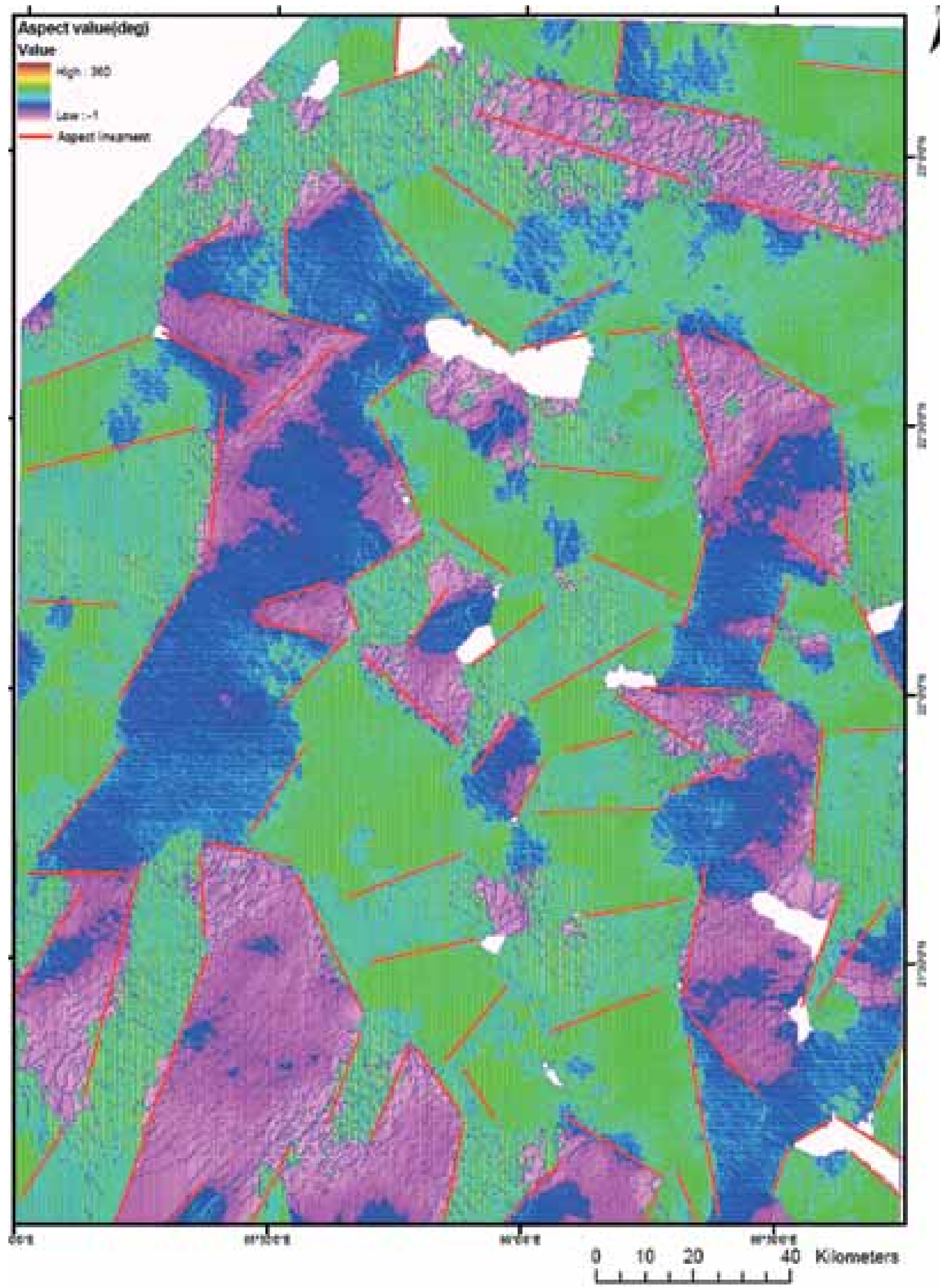

Figure 5. Aspect lineaments obtained from the aspect map.

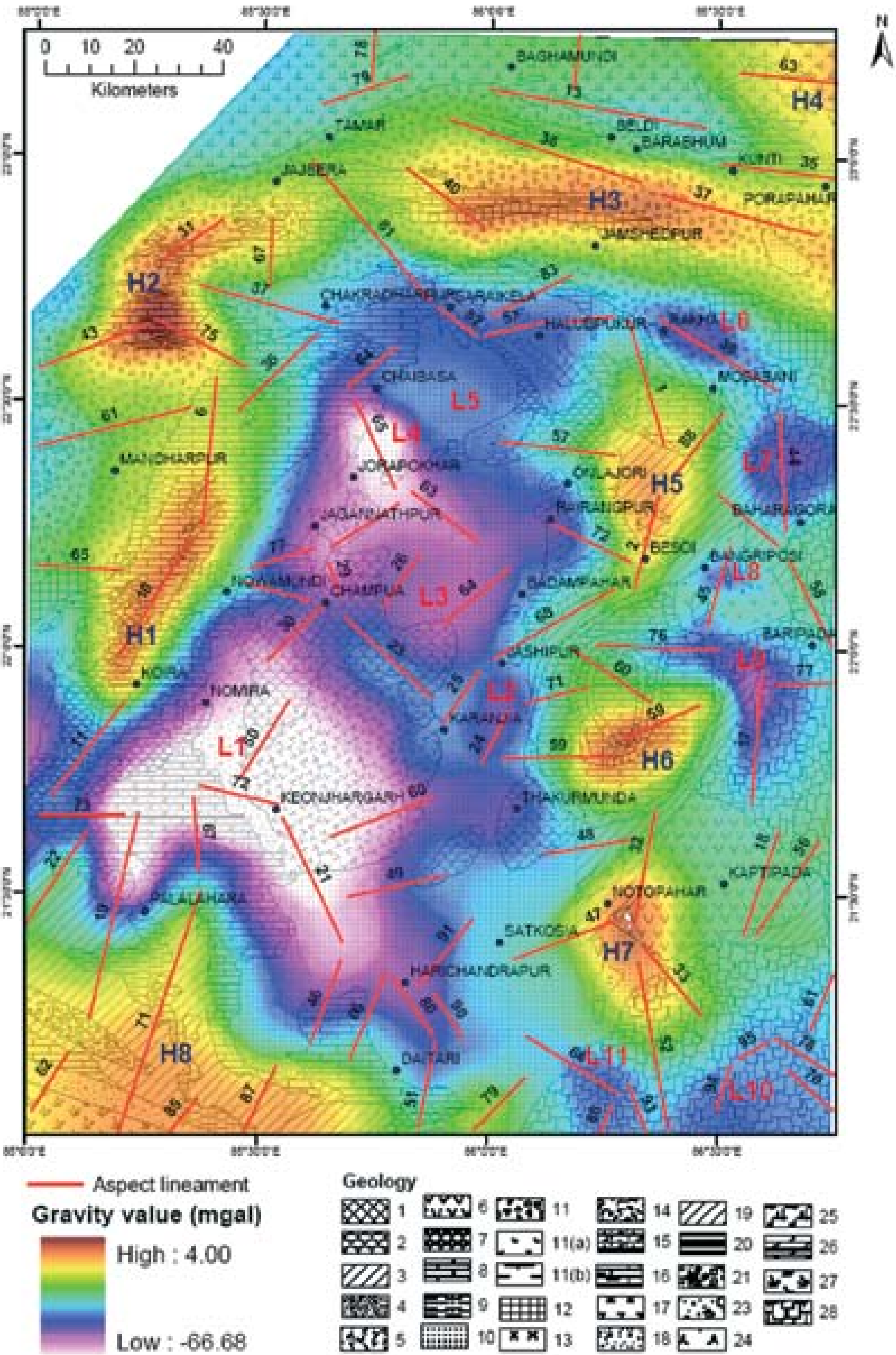

Figure 6. Aspect lineaments superimposed over DGM and geology of the study area (Description of geological legends is shown in Fig.1).

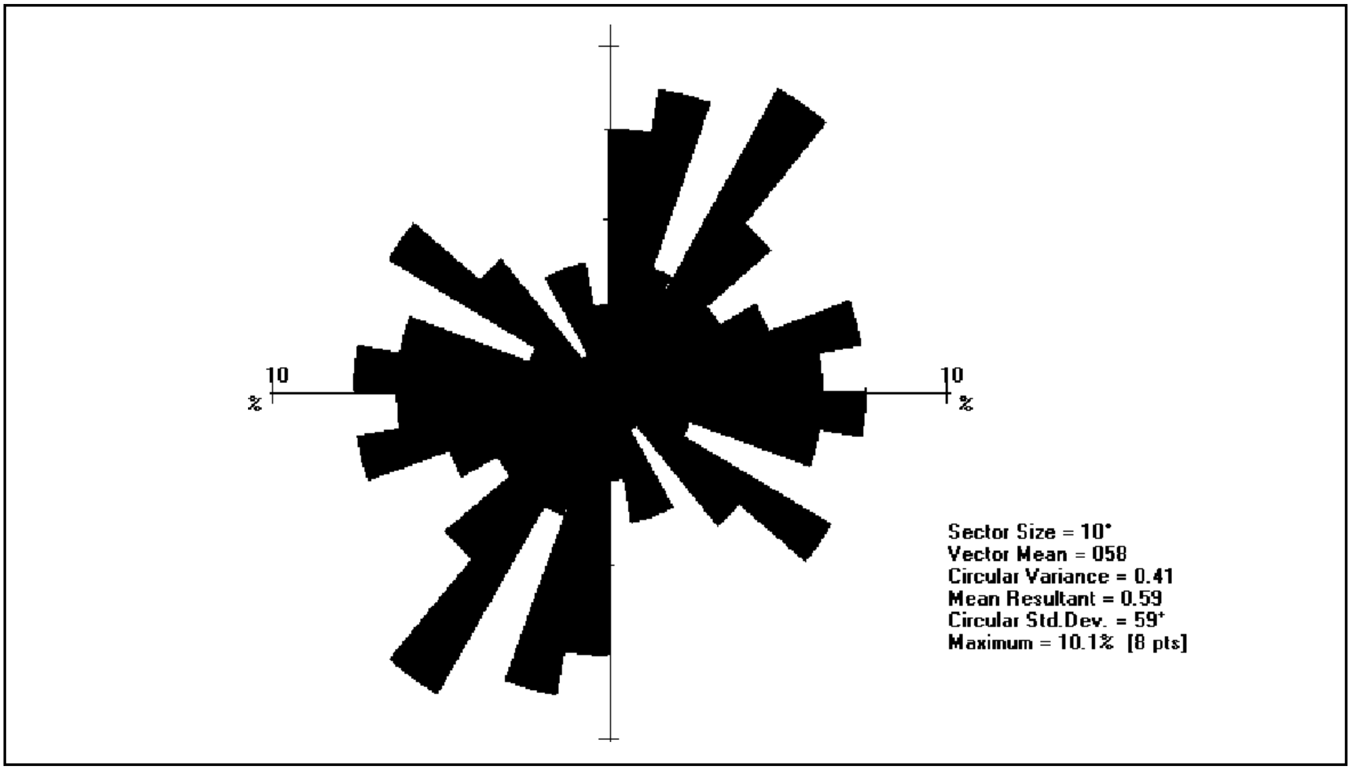

Figure 7. The Rose diagram of aspect lineaments over the study area

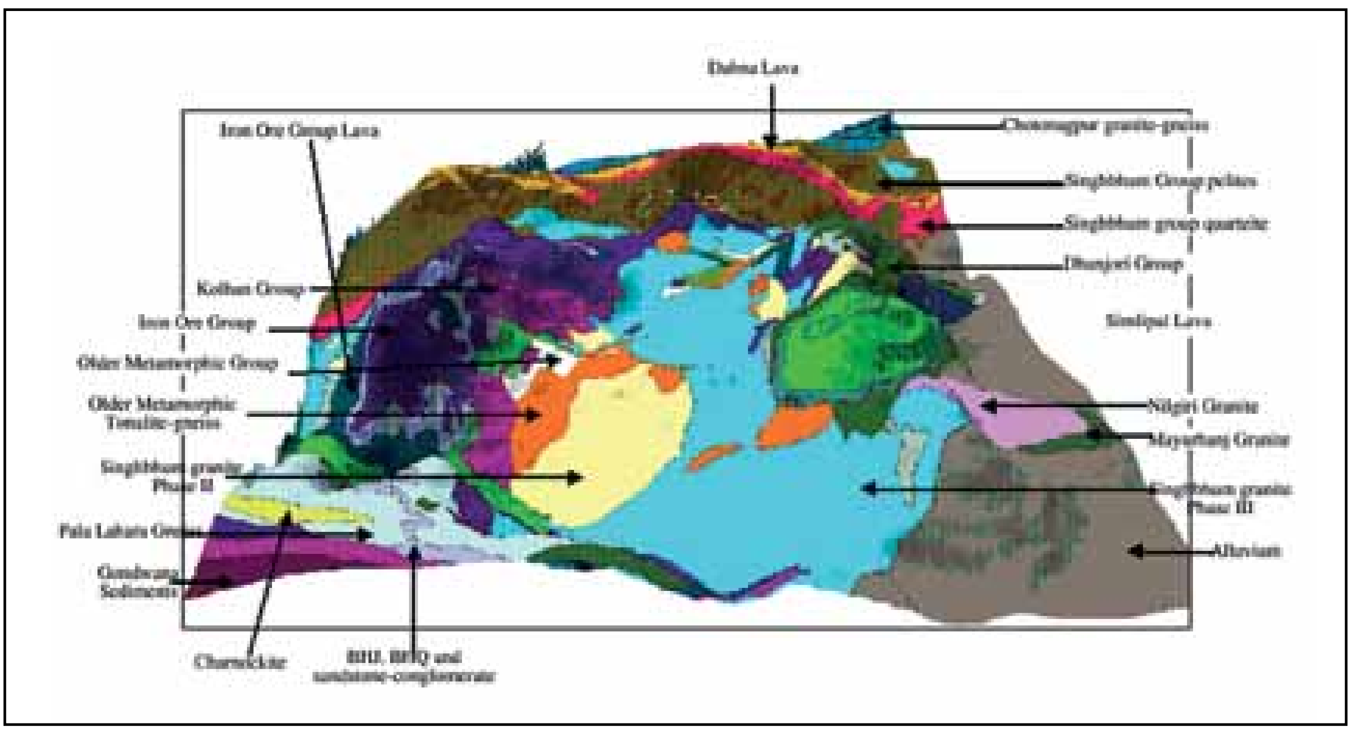

Figure 8. Geological map draped over DGM of the study area (A better perspective view showing different geological formations such as Singhbhum Granite, Singhbhum Groups, Dalma Lava, Iron Ore Group, Dhanjori Group, Mayurbanj Granite and Simlipal Lava)

Group (IOG) covering 1255 sq km. H_2 is prominent over the Singhbhum Group of rocks occupying about 1098 sq km and follows the orientation of Singhbhum Group. H_3 is approximately ahead along the east-west reflecting the rocks of Dalma Volcanics of about 1562 sq km. H_4 reflects the rocks of Pelitic enclaves and Prophyritic member of CGG of about 188 sq km. H_5 prominently prevails over the rocks of Mayurbanj granite and Dhanjori-Simlipal-Jagannathpur lavas covering about 842 sq km. H_6 reflects the rocks of Simlipal Basin consisting of volcanics, quartzite and conglomerates in an alternating sequence in circular shape. Also, H_6 mimics the shape and orientation of Simlipal Basin of about 714 sq km. H_7 covers parts of Nilgiri Granite, IOG and Alluvium Tertiaries covering an area of about 896 sq km whereas H_8 covers parts of Pala Lahara Gneiss and IOG sediments. Clearly, most of these gravity highs are associated with synclinal structures filled with sedimentary / metasedimentary formations, interbeded with basic intrusives in the form of lavas or gabbro-anorthosite massess which have taken place during different orogenic cycles (Quereshy, Bhatia & Subba Rao 1972; Verma, Sharma & Mukhopadhyay 1984).

Eleven regions of gravity lows (L_1-L_{11}) have been demarcated and shown in Figs 2 and 3. L_1 is a prominent gravity low surrounding Keonjhargarh covering an area of about 2720 sq km which consists of Singhbhum Granite-Phase II, xenolith dominated areas of Boni Granite, Kolhan Group and eqivalents, mostly underlain by volcanic rocks belonging to IOG. Gravity low around Keonjhargarh has been observed due to granitic rock of lower density (2.63g/cm^3) of thickness about 20 km (Verma, Sharma & Mukhopadhyay 1984). L_2 is gravity low over IOG centered at 21^0 52′N, 86^{0}E covering an area of about 165 sq km. The gravity low L_3 is centered at 22^0 6′N, 85^0 54′E and about 14 km west of Badampahar which covers about 374 sq km area. L_4 is centered at 22^0 22′N, 85^0 45′E over Singhbhum Granite covering an area of about 560 sq km. L_5 has been delineated over Singhbhum Granite centered at 22^0 38′N, 85^0 58′E and it covers an area of about 698 sq km. L_6 is identified over Singhbhum Group about 7 km east of Rakha centered at 22^{0}38′N, 86^0 27′E covering an area of about 478 sq km. L_7 has been demarcated over Alluvium Tertiaries, 15 km north of Baharagora. Both L_6 and L_7 are located over Singhbhum thrust zone. L_8 is attributed to IOG lavas, ultramafics and Singhbhum Group mafic bodies, centered at 22^0 8′N, 86^0 31′E which is about 6 km south-east of Bangriposi. L_9, L_{10} and L_{11} are identified over Alluvium Tertiaries centered at 21^0 56′N, 86^0 35′E; 21^0 3′N, 86^0 31′E; and 22^{0}6′N, 86^{0}15′E respectively. The gravity lows are associated with anticline structures of granitic masses which clearly indicate the intrusive natures of the granitic massess and these intrusions have taken place during different orogenic cycles (Verma, Sharma & Mukhopadhyay 1984).

Gravity Aspect Map and Aspect Lineament

The aspect map generated from DGM has been superimposed over the geological map for understanding the correlation of the generated gravity aspect map with geological evolution of this region (Fig.4). Number of lineaments could be delineated from the aspect map which are interpretated as linear oriantations/ directions, along which the gravity field has abruptly changed (Fig.5). These lineaments give clear indications of sharp changes in gravity slopes. The aspect map, thus, identifies the steepest downslope direction at a location on the surface. These gravity gradients mark the density contrasts between different formations. The aspect lineaments, marked as ID nos. 35, 37 and 38, in the north of the study area (Fig.6), are attributed to rocks of Northern Shear Zone / Dalma thrust, Singhbhum Group and Chotanagpur Granitic Complex (CGC). The lineaments over Dhanjori (ID nos. 1, 38 and 88), Simlipal (ID nos. 59, 60, 71 and 76) and south of Simlipal (ID nos. 47, 32, 33 and 53) reflect the subsurface geological features. One lineament (ID no. 81) has been delineated along the prominent fold axis of Dalma lava centered at 22^0 54′N, 85^0 38′E. It cross-cuts the Singhbhum Group and IOG and follows the surface manifestation of topography. However, another lineament (ID no. 6) centered at 22^0 24′N, 85^0 23′E cross-cuts the IOG between two parallel lineaments (ID nos. 36 and 10), indicating the existence of subsurface strike-slip fault. Most of the lineaments can be attributed to boundaries of intrusive granitic masses of anticlinal structures of varying contrast, and synclinal structures filled with sedimentary/ metasedimentary rocks interbeded with basic intrusives in the form of lavas or gabbro-anorthosite masses. Number of cross-cut lineaments have been observed, which is also clearly understandable from the Rose diagram (Fig.7) generated from aspect lineaments with vector mean 58, circular variance 0.41, mean resultant 0.59, and circular standard deviation 59^0. These results may indicate many phases of deformation. A total of seventy-nine aspect lineaments have been delineated from the aspect map. Out of these, 16 lineaments are ENE-WSW trending, 16 lineaments are NE-SW trending, 15 lineaments are NNE-SSW trending, 11 lineaments are NW-SE trending, 8 lineaments are WNW-ESE trending, and rest 13 lineaments are NNW-SSE trending. Therefore, the predominant orientations of the aspect lineaments are towards north-east. The maximum number of lineaments is oriented in ENE-WSW. The numbers of lineaments along other directions gradually decrease anticlockwise. This may be due to thrust or movement of Singhbhum-Orissa Cratonic block towards NE/ ENE during various orogenic cycles. The maximum length of aspect lineament as delineated from the aspect map is 58.56 km, whereas the minimum length is 6.7 km. The average density of aspect lineaments is 0 .044 km/sq km.

Between the gravity highs H_1 (attributed to IOG) and H_2 (attributed to Singhbhum Group of rocks) there is abrupt change in gravity values (Figs 6 and 8). The intermitant low gravity areas may be the imprint of strike-slip fault which is supported by a set of lineaments (ID nos. 6, 10, 61 and 36). The lineaments with ID nos. 65, 61 and 43 indicate the presence of a common thrust over the IOG from west to east (Fig.6). Further, the gravity highs H_5, H_6 and H_7, can be interpreted as grabens, which are segmented along their lengths and are expressed as chains of sub-circular to oval-shaped gravity highs separated by low saddles.

The boundaries of various geological formations can be delineated from the aspect map of gravity data. The technique has been verified by overlying the aspect map over the geological map (Figs 4 and 6). Further, to consider the correlation between gravity anomaly and geology of the study area, the geological map has been drapped over the DGM (Fig.8) which provides a better perspective view from which different geological formations, such as Singhbhum Granite, Singhbhum Groups, Dalma Lava, Iron Ore Group, Dhanjori Group, Mayurbanj Granite and Simlipal Lava, could be delineated.

CONCLUSIONS

The resulting Digital Gravity Model (DGM) facilitates the visual interpretation of Bouguer gravity anomalies for identification of different geological features. The aspect map generated from DGM plays an important role in delineating various lineaments and fault plains. It also provides an efficient method for delineation of subsurface geological boundaries. In the present study area, number of gravity highs, lows and faulted blocks have been delineated. From economic point of view, these lineaments and faulted blocks may have great significance for mineral and oil/gas exploration (Telford, Geldart & Sheriff 1990). The draped geology map over the DGM exibits good correlation of Bouguer gravity anomaly with the existing geology. The present study shows that Geographical Information System (GIS) can be an efficient tool for Bouguer gravity data interpretation.

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