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Geomorphic Signatures of Ore Deposits – A Case Study from Sukinda Chromite and Nickel Complex, Orissa

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ABSTRACT

The present scientific pursuit attempts to quantify various geomorphic parameters associated with the Chromite and Nickel ores of Sukinda valley and to establish geomorphic features like land forms, slope, relative relief, drainage pattern, density and frequency, lineaments and erosion surfaces. The present morphologic features of the valley were studied by taking inputs from relevant False Colour Composite, Toposheets and by undertaking ground truth checks. It is observed that both these ores are associated with parallel drainage pattern, which is prevalent in the valley, and are characterised by low drainage density and frequency. However Nickel ore exhibits a higher range in drainage density i.e. from 0.4 to 3.0 km./sq. km. in comparison to Chromite. As regards to erosion surface Cr is found to be associated with 140m and 200m end surfaces while Ni is confined to only 140 m. Though the range of slope varies for both the ore types from 0 to 5 degrees, Cr is reported to be associated mainly with foothills and Ni with valley flats.

Introduction

Sukinda valley known for its potential reserve of chrome and nickel ore is located at a distance of 180 km. to the north of Bhubaneswar, the state capital of Orissa. The study area lies in the SW quadrant of the survey of India topographical map 73 G/16 and SE quadrant of 73 G/12, bounded by lat. 21°0' to 21°5' and long. 85°42' to 85°53'. The area experiences a hot and humid sub-tropical climate with a highest temperature of 47°c in the summer and a lowest of 7°c in the winter. The precipitation per annum is around 1600 mm.

Although many workers have carried out extensive research in various geological aspects of Sukinda valley such as petrology, geo-chemistry and economic geology, no attempts were made to understand the geomorphologic aspects of this region. The present paper focuses on quantification of various geomorphologic

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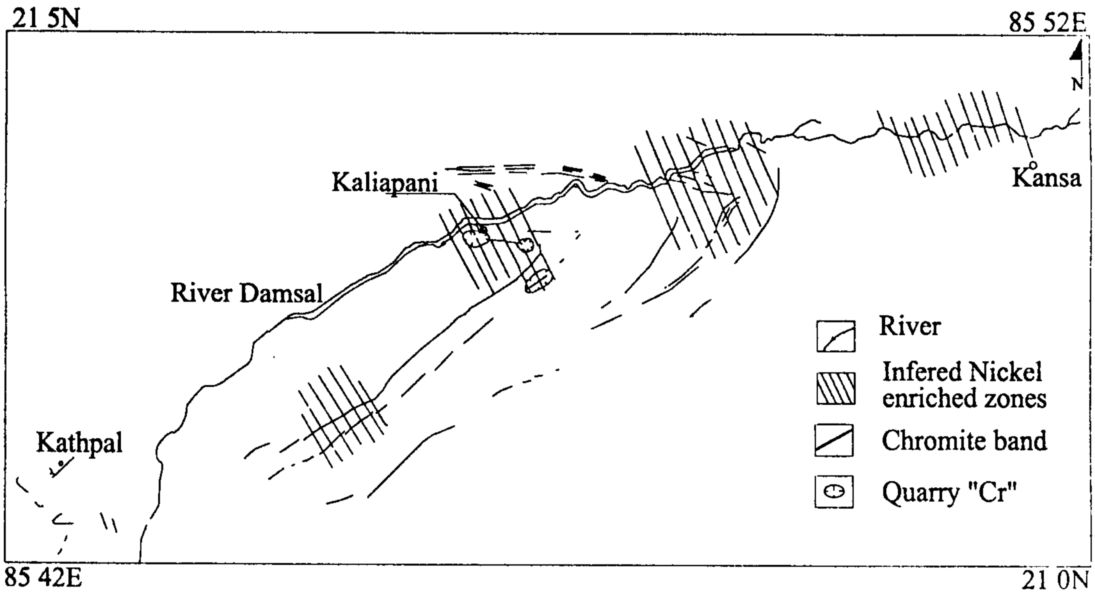


Fig. 1. Ore Body Disposition Map (source : OMC, Bhubaneswar)

parameters such as drainage, lineaments, lithology and slope etc. associated with the Sukinda valley.

Physiography and Geology

The study area exhibits a peneplained topography. River Damsala, the principal drainage of the valley flows westward. It carries the water discharge from Daitari and Mahagiri water divides and feeds river Brahmani. The topography is controlled by lithology as the resistant quartzites form steep scarp faces and the younger ultramafics form synclinal valley flat. This ultramafic rocks, otherwise known as the Sukinda ultramafic complex, is characterised by the chromite lodes, and occurs as intrusive into the Iron ore group of rocks (Chakraborty and Chakraborty, 1984). Petrographicaly the suit comprises of dunites, peridotites and pyroxenites. These lithounits have been subjected to extensive limonitisation and serpentinisation. In the Sukinda area all these rock types are lateritised and except for few exposures of the pyroxenite band, all other types lie under thick veneer of alluvial soil and laterite. In the SW corner of the study area, a few exposures of granite gneisses were also reported.

Methodology

The data products used for the present study includes 1. LANDSAT TM FCC of bands 2, 3 and 4 on 1:50,000 scale (Row :045, Path: 140, Date of Pass: February 22, 1987) and 2. Survey of India Topographical maps 73G/12 and 73G/16 of 1:50,000 scales. Visual interpretation of the False Colour Composite was used to carry out a geomorphological analysis of the study area substantiated by ground truth checks. The quantitative analysis of the landforms, slopes and drainage etc. were carried out on different media (Subramanyan, 1986) and in the field by superimposing the prepared map on the ore disposition map (Fig. 1).

a) *Super Imposed Topographic profiles*: Topographic profiles were constructed at 1' interval across the valley from N to S. While the horizontal scale was maintained at 1:50,000 scales, the vertical scale was exaggerated to 1:2,000. These profiles were then super imposed to get an idea about the possible erosion surface.

b) *Structure section*: The inferred structures were imparted to the drawn profiles, one along the eastern extremity of the valley and the other along the western extremity.

c) *Geomorphological Map*: A geomorphological map was prepared using the data products like topographical maps, satellite images and field observations. The various geomorphic units and their component landforms were identified and mapped.

d) *Digital Elevation Model*: Dividing the study area into 0.25 Sq. Km. elevations were tabulated at the intersection of grid lines from topographical maps. These tabulated data were converted into a graphical 3 -Dimensional model in computer using the SURFER package, which was used to study the valley in any preferred orientation.

e) *Slope Vector Map*: Homogenous slope units were delineated based on the contour spacing of topographical maps. The slopes were calculated by relating the drop in elevation to the horizontal distance. The prepared slope vector map was used to have a better understanding of slopes of the area.

f) *Drainage Pattern Map*: Taking inputs from the topographical map and the FCC, a drainage pattern map was prepared. Further, from this the drainage textures were studied.

i) *Drainage Frequency Map*: The number of streams occurring per unit area is referred as Drainage frequency. Dividing the entire area into grids of 1 sq. km., the streams were ordered and counted for each grid. These values were then contoured after dividing them by the grid area, to generate the Drainage frequency map.

ii) *Drainage Density Map*: Drainage density is defined as the stream length per unit area. On a grid of 1 sq.km. the total length of streams in each grid was calculated using a planimeter. The values obtained after dividing by the grid area were contoured using the SURFER package to obtain the Drainage density map.

g) *Relative Relief Map*: In a grid of 1km. × 1km. the maximum and minimum elevation were noted grid wise. The differences between the two values were then computed and contoured.

h) *Lineament Map*: By visual interpretation of the FCC and the drainage pattern map, the lineaments were identified, traced and a rose diagram was drawn. Utilising grids of 1 sq.km. the total length of lineaments in each grid was determined by the planimeter and contoured to obtain the lineament density map.

i) *Altimetric Frequency Analysis*: The number of peaks, represented by spot heights and closed contours and their elevations were counted from the topographical maps over an area of about 500 sq. km. The data were then grouped at 50m intervals and a histogram was plotted.

j) *Generalised Topographic Contour Map*: A Generalised Topographic Contour Map was prepared by connecting the spur terminations while recent streams were eliminated. This enables to reconstruct the topography that existed before onset of the recent erosion cycle.

Geomorphology

The study area has a peneplained topography with an elevation that ranges from 60 m to 700 m. Two main ridges, the Daitari and the Mahagiri, trend NE-SW with an intervening valley flat. Damsala, the major river in the area flows westward.

a) *Landforms*: The False Colour Composite (FCC) of Sukinda valley was used to identify the following geomorphic units (Table 1)

i) Structural Hills: These are linear to

Table 1. List of Landforms with Characteristics

Landforms	***Description***
Structural Hill	Linear to curvilinear landforms with high relief, steep slopes and parallel drainage
Denudo-structural Hill	Dissected hills having a linear trend along with rounded to sub-rounded crests and rugged topography
Residual Hill	Isolated Hillocks with Dark tone
Pediment	Erosional land with breaks of slope and lighter to medium grey tone.
Peneplain	Reddish colour with relatively low elevation
Burried pediplain	Land use pattern with white to Greyish white colour and low drainage density
Valley Fill	Vicinity of streams with very light grey tone

curvilinear landforms characterised by their high relief, steep slope and parallel drainage pattern. In the FCC, these are identified by alternating ridge and valley topography and moderate to dense vegetation cover.

ii) Denudo-structural Hills: These are highly dissected hills having a nearly linear trend. These are characterised by rounded to sub rounded crests and rugged topography. Effect of leaching and weathering is quite conspicuous in these units.

iii) Residual Hills: These are isolated hillocks having a relatively dark tone. In the Sukinda valley this land unit occurs in the western part.

iv) Pediment: This erosional land unit is associated with breaks of slope and comprises of mainly floats. In the FCC, its lighter to medium grey tone can very well delineate this unit.

v) Peneplain: This unit is well identified by its reddish colour and relatively low elevation. In the Sukinda valley this unit carries lateritic cover, which may be regarded as the duricrust.

vi) Buried pediplain: It is characterised by white to greyish white colour. The major bulk of it forms the residual soil and alluvial cover. The land use (cultivated lands) and a very low drainage density are the other factors that help to identify this unit.

vii) Valley fills: These are the areas delineated in vicinity of the streams having a very light grey tone and occur as narrow belts along the streams.

In addition to all these landforms, features like springs, ridge crest, physiographic trends etc. have also been mapped (Fig. 2).

b) *Morpho-structure*: The topography of the area is more or less controlled by litho units with resistant quartzite forming the steep scarp faces and the younger ultramafics forming the valley flats. The superimposed topographic profiles (Fig. 3) and the structure sections (Figure 4) bring out the litho-morphological relations in the area very well. Morpho-structurally the area comprises of anticlinal ridges i.e. Daitari and Mahagiri ranges and a synclinal (Sukinda) valley. The triangular facets as observed from the FCC on either side of the ridges indicate the dip-slopes. In the Mahagiri range narrow triangular facets in the NW slopes indicate steeper dip-slopes, where as the SE slopes are characterised by broader triangular facets indicating gentler

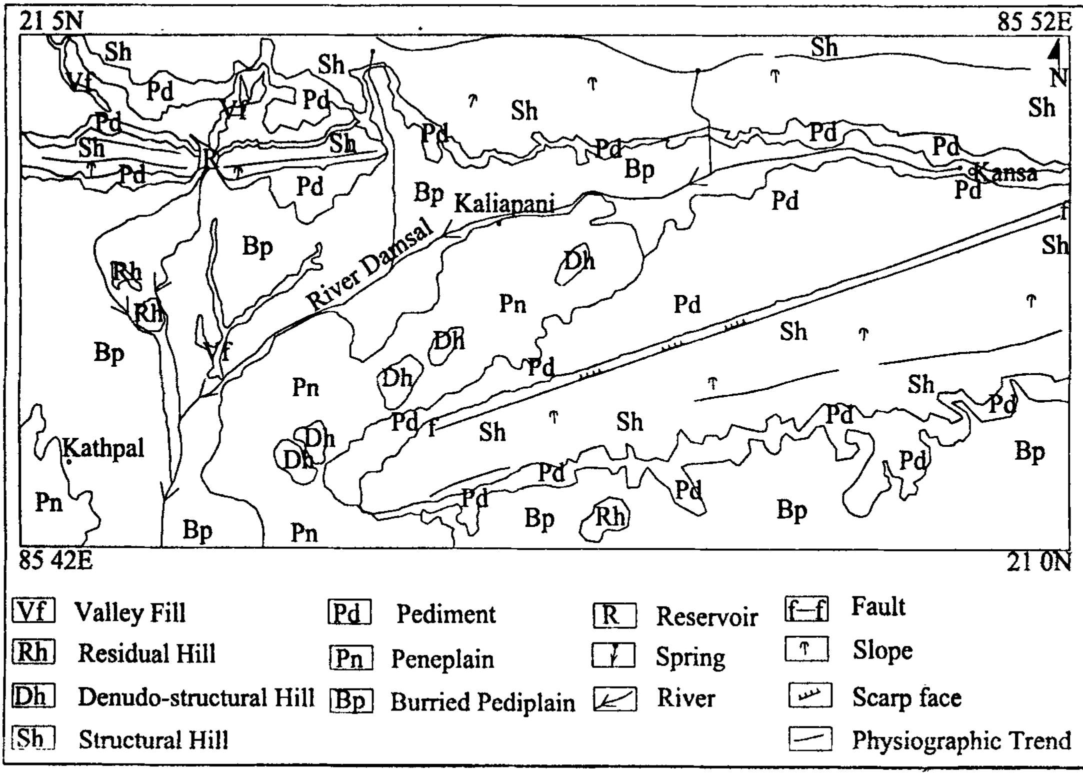


Fig. 2. Geomorphological Map of Sukinda Valley

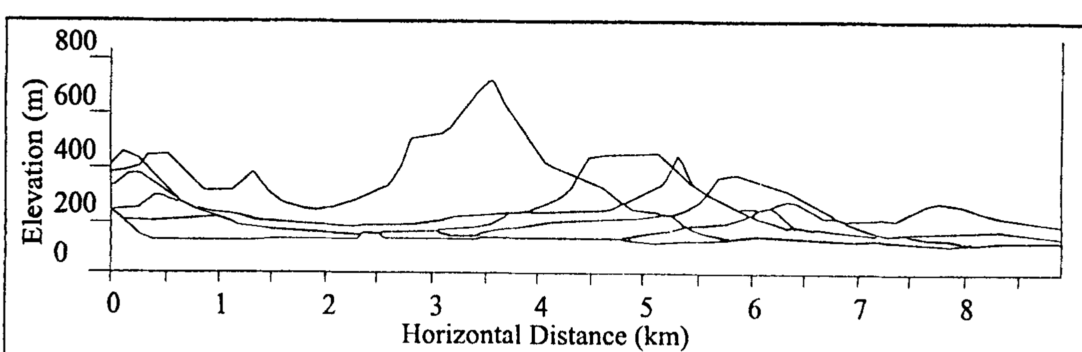


Fig. 3. Super Imposed Topographic Profiles

dip-slopes. The steeper dip-slopes have been attributed to the effect of faulting (Sivasubramanian, 1991). In case of Daitari range, the SW slopes are characterised by gentle dip-slopes as evidenced by broader triangular facets. The structure sections drawn across the valley indicate the morpho-structural set up in the area. The plunging synclinal valley is well represented by the closure of the two ridges as depicted in the Digital Elevation Model (Fig. 5).

c) *Slope*: The slope vector map (Fig. 6) shows the distribution of slopes in the area. The slope angle varies from almost horizontal to as much as 45°. A few scarp faces characterise the northern slope of the Mahagiri range while the southern slope exhibits a greater range in the slope value. The slopes are gentler in the Daitari range i.e. up to a maximum of 13°. The median plain has a very gentle slope towards the south West. The mining areas of Chromite in the valley and foothill zone have slope ranging from 0° to 5°. The inferred Nickel enrichment decline from east to west along the valley in conformity with the decrease of slope from 5° to 1°. The relative relief map shows that the high relief areas are characterised by the quartzites and are devoid of ores while the low relief areas i.e. 0 to 120 m forms the loci of the ores.

d) *Drainage*: Damsala, the major river of the valley flows westward being parallel to the inferred fault of the Mahagiri range and takes a south ward turn in the western extremity of the range. The drainage pattern (Fig. 7) is incipient trellis in the Mahagiri range since the tributaries meet the main stream at right angles. In the valley flat, streams individually have a dendritic pattern, but collectively the pattern is sub parallel. In the western part of the study area, a distinct radial pattern of drainage is clearly demarcated. The drainage density ranges from 0 to 3.0 km./sq. km. In the study area, these values are higher in the ridges due to low residence time and higher surface run off in the resistant quartzites. In the valley, values are considerably low as the presence of laterites and alluvium facilitate greater infiltration. For chromite occurrences the value ranges from 0.0 to 1.2 km./sq. km. while the inferred Nickel enriched zone is characterised by a higher range i.e. from 0.4 to 3.0 km./sq. km. The drainage frequency values are also in conformity with the drainage density and are higher for the ridges in comparison to the valley. The estimated quantities for chrome occurrences and inferred nickel-enriched zones are 0.8 to 1.6 and 0.8 to 2.4 per sq.km. respectively. The higher range of values of the Drainage density and frequency for nickel-enriched zones are due to its increased concentration towards the valley closure thus a greater amount of surface runoff.

e) *Lineaments*: The river Damsala flows along the axis of the plunging syncline and forms one of the most prominent linear features of the study area. The lineament map (Fig. 8) shows three distinct trends, namely ENE-WSW, N-S, and NW-SE. A rose diagram indicates that the dominant trend is N72E-S72W. The lineament density map shows lower range of values for the valley i.e. the chromite bearing lateritised ultramafics (0.0 to 0.8 km./sq.km.) while quartzites show a higher range up to 2 km./sq.km.

f) *Erosion Surfaces*: The generalised topographic contour map (Fig. 9) shows a flat surface between 100 and 200 m. Another surface is brought out at around 450 m. The superimposed topographic profiles show a coalescence of the profiles at 140, 200 and 450 m. The altimetric frequency analysis (Fig. 10) shows three peaks at 150, 300 and 450m.There are about 25 peaks each of these elevations. Based on the cumulative evidences from all these analyses, it can be inferred reasonably well that there are two erosion surfaces; one at 150 m representing 140 and 200 m and the other at 450 m. While the former represents the valley flat and foothill the later corresponds to the ridge. While chromite is reported from levels of 140 and 200 m the nickel-enriched zones are confined to the 140 m levels only.

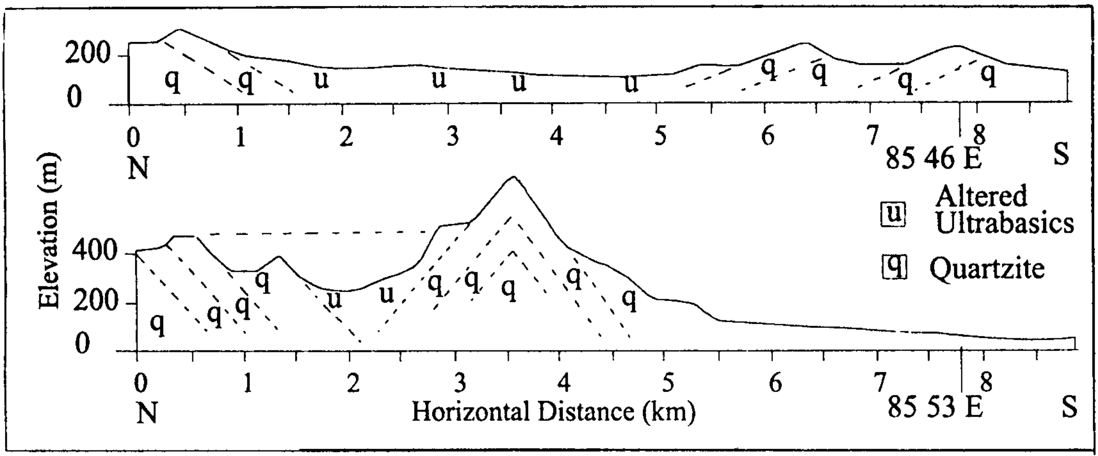


Fig. 4. Structure Sections

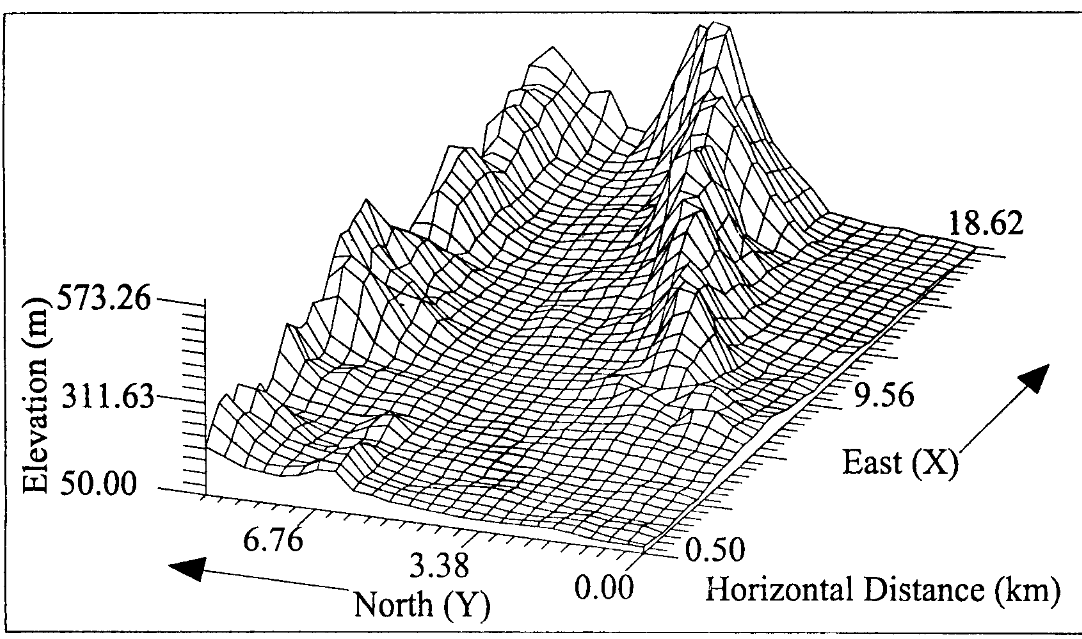


Fig. 5. Digital Elevation Model of Sukinda Valley

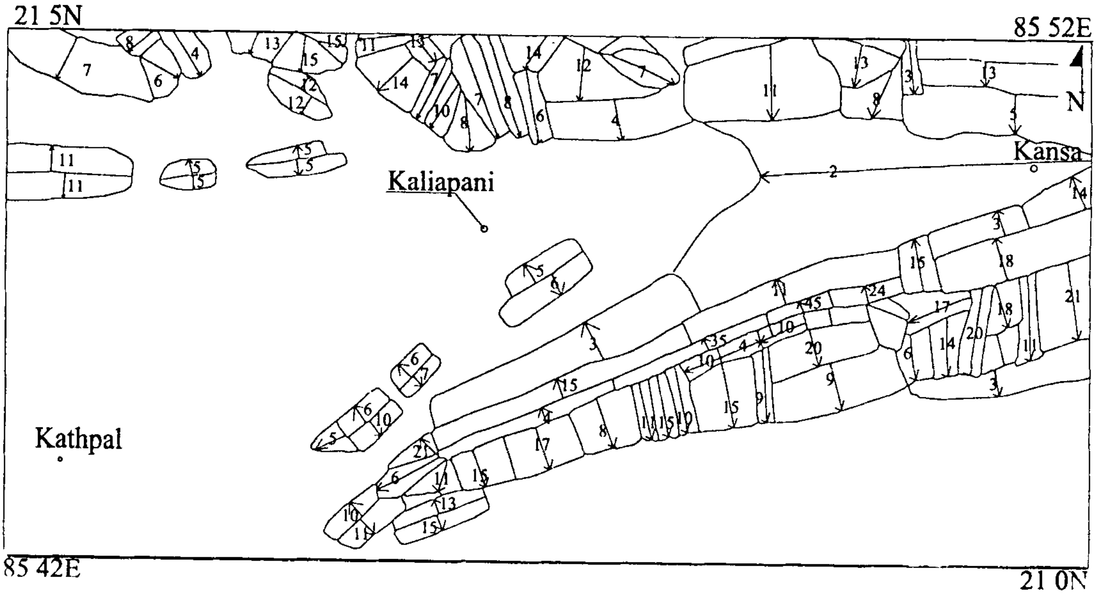


Fig. 6. Slope Vector Map

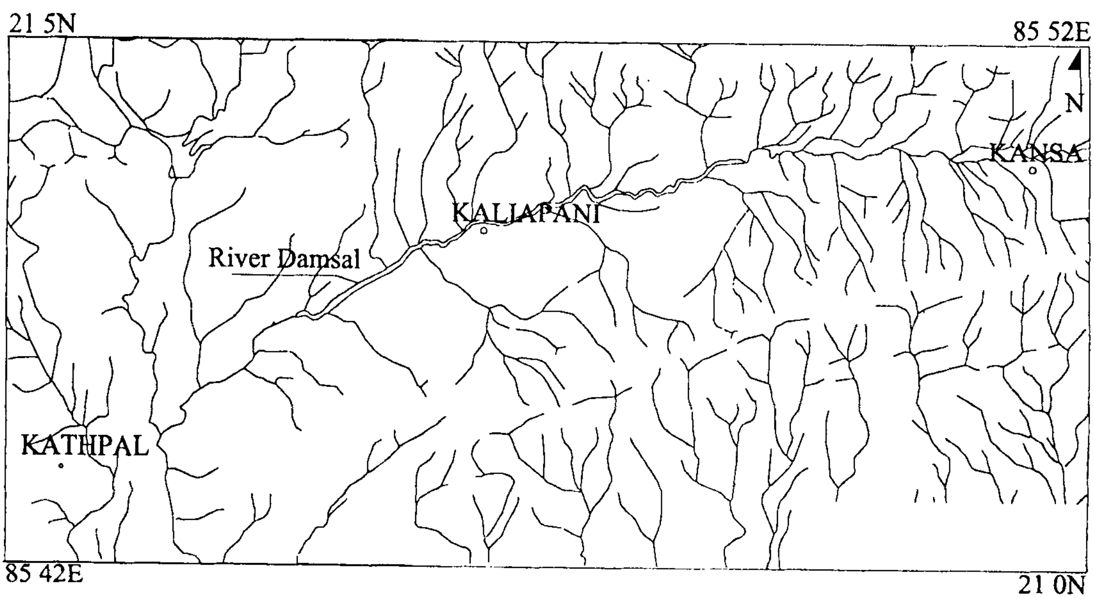


Fig. 7. Drainage Map

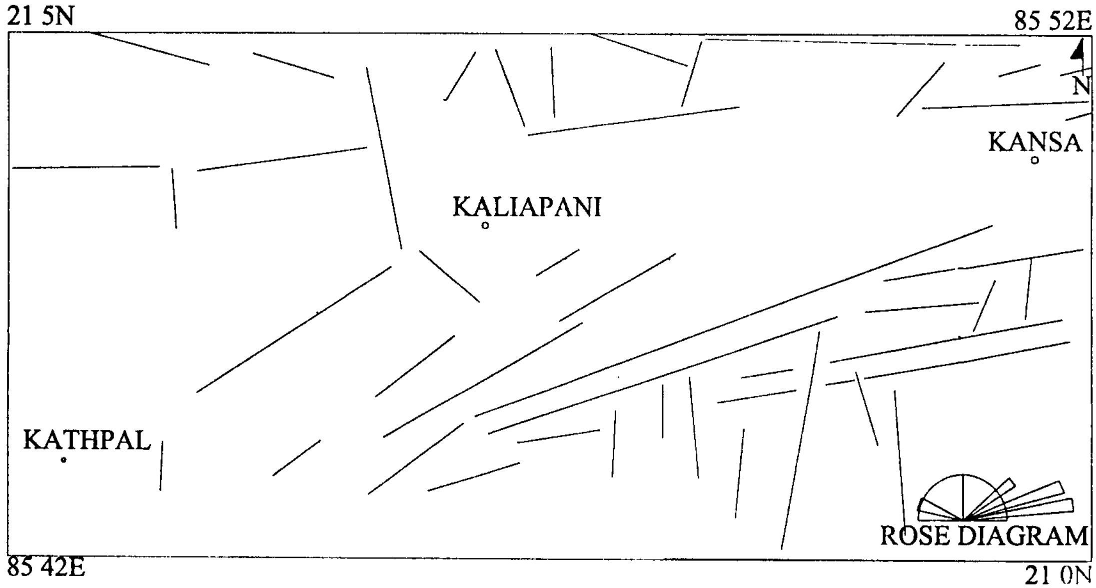


Fig. 8. Lineament Map

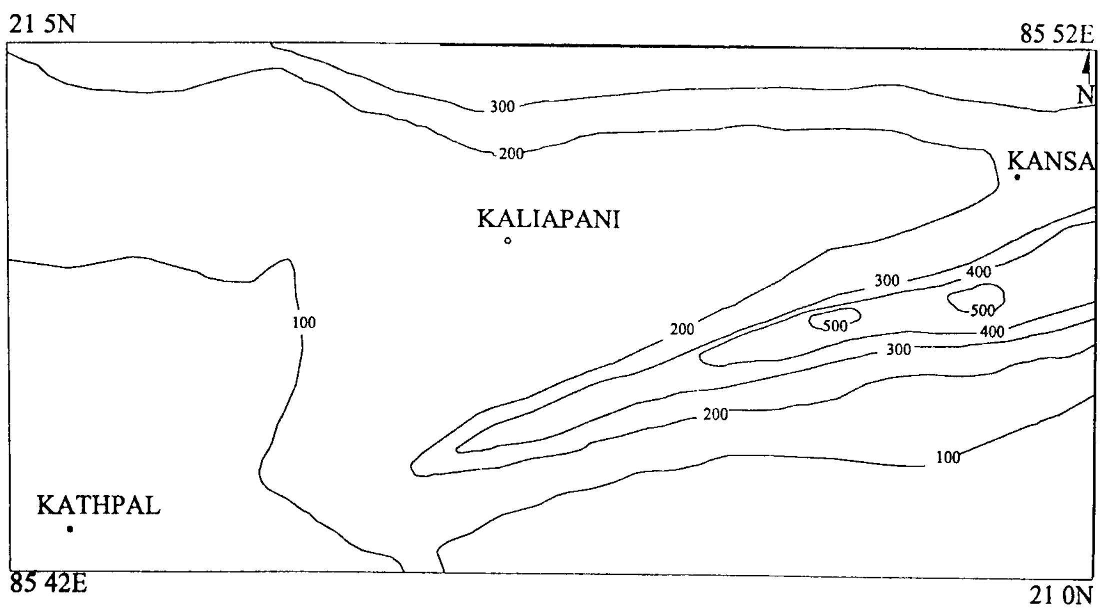


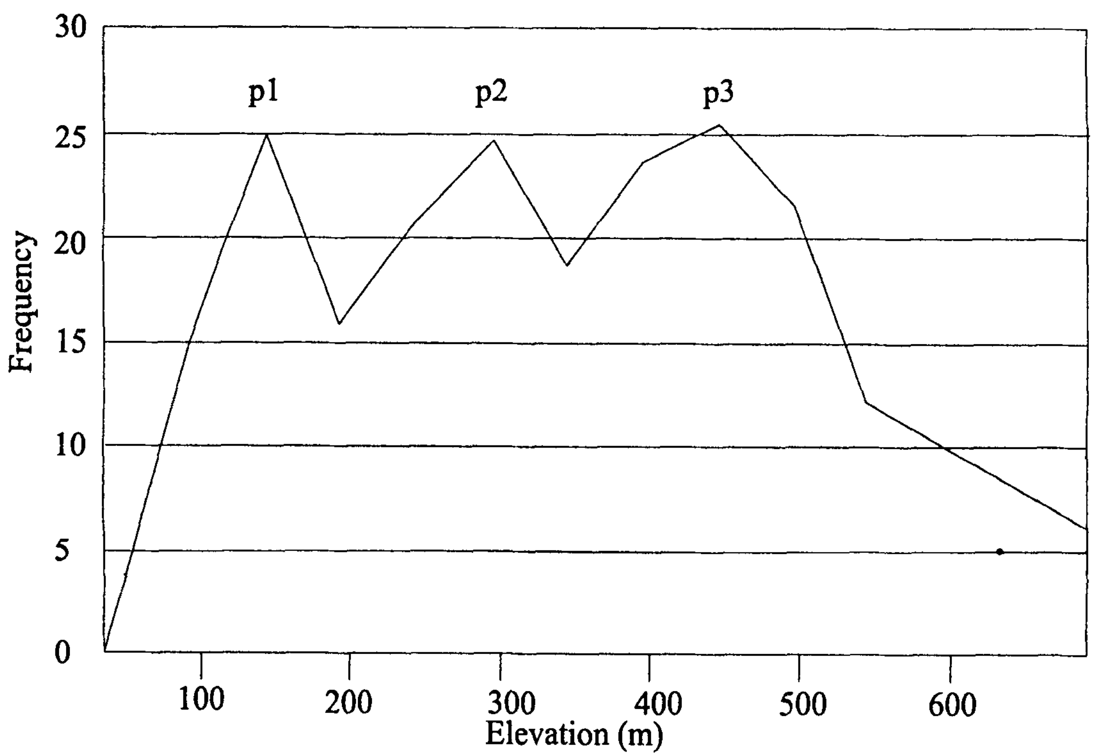
Fig. 9. Generalised Topographic Contour Map

Table 2. Summary of the Geomorphic parameters

Geomorphic Parameter	*Chromite (Cr)*	*Nickel (Ni)*
Land form	Foot hill	Valley fill
Slope	0° to 5°	0° to 5°
Relative relief	0 to 120 m.	0 to 120 m.
Drainage frequency (per sq.km.)	0.8 to 1.6	0.8 to 2.4
Lineament density (km./sq.km.)	0.0 to 0.8	0.0 to 0.4
Erosion surface	140 and 200 m	140 m

g) *Weathering*: The resistant quartzites of Daitari and Mahagiri ranges are less susceptible to weathering hence stand out as ridges. However, ultramafics of the valley have been subjected to intensive weathering, which in turn has resulted in the lateritisation. The occurrences of Talc and Serpentinites are indicative of the degree of weathering they have undergone. Both chemical weathering and leaching has resulted the limonitic horizon underneath the lateritic

Fig. 10. Altimetric Frequency Analysis showing three clusters (p1, p2 & p3) of observation at 150, 300 and 450 m elevations



capping. This limonitic horizon forms the potential source of residually enriched nickel silicates in the central and eastern part of the valley while the western part is characterised by the ferricretes. This is in accordance to the decline of slope from east to west as the valley widens. While chemical weathering is prevalent in the study area, the steep scarp faces of the quartzites have been attributed to physical weathering.

The present morphologic features of the valley were looked into by taking inputs from the relevant False Colour Composite and Toposheets. It is observed that both these ores are associated with parallel drainage pattern, which is prevalent in the valley, and are characterised by low drainage density and frequency. However Nickel ore exhibits a higher range in drainage density i.e. from 0.0 to 3.0 per sq. km. in comparison to Chromite. As regards to erosion surface Cr is found to be associated with 140m and 200m end surfaces while Ni is confined to only 140m. Though the range of slope varies for both the ore types from 0 to 5 degrees, Cr is reported to be associated mainly with foothills and Ni with valley flats.

Conclusion

The present study shows that both the co-existent minerals e.g. Cr and Ni at Sukinda are characterised by certain geomorphic signatures. Through this present scientific pursuit it has been the endeavour of the author to quantify the geomorphic parameters, such as slope, relative relief, drainage frequency, lineament density and erosion surface by various techniques. With the associated parallel drainage pattern, the ores are found to be characterised by low drainage density and frequency. With respect to landforms, while Chromite is reported to occur in the foothill, Nickel is mostly localised in the valley fill. The quantification of various geomorphic parameters of Sukinda Cr and Ni complex is summarised at Table 2.

Acknowledgements

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