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USE OF REMOTE SENSING IN LINEAMENT ANALYSIS FOR TECTONIC EVOLUTION AND RESOURCE STUDY OF A PART OF VINDHYAN BASIN, JHALAWAR AREA, INDIA

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ABSTRACT

Synoptivity and the exemplified fracture systems exhibited by the space borne imagery data has helped in solving many of the geological enigma in various parts of the world. The study conducted, using such remotly sensed data, in Jhalawar anticline, part of Proterozoic Cratonic Vindhyan Basin, Rajasthan, India, led to infer the history of tectonic evolution of peribasinal deformation which has been a matter of controversy for a century and more.

In Landsat MSS data the Jhalawar region displays a panorama of lineaments and their analysis through azimuthal frequency diagrams, isofracture, lineament incidence and lineament intersection incidence density maps shows that the mean orientation of the lineaments fall in NW-SE and NE-SW and the shape of the various lineament density contours also show NE-SW and NW-SE orientations. In aerial photographs the area exhibits four sets of lineaments in NE-SW, NW-SE, N-S and E-W directions. Amongst these the former two sets are expressed as wide open master fracture systems with prolific vegetation fills along them and the latter two sets are characteristically observed as thin vegetation linears with frequent strike slip faultings along them. The further analysis of these fracture/lineament systems derived from multi-level remote sensing data shows that the Jhalawar anticline, which followed the pattern of flexural slip fold mechanism, was evolved by horizontally disposed $\sigma 1$(greatest principal stress) and 3σ (least principal stress) with the former oriented in NE-SW and the latter aligned in NW-SE directions with vertically disposed 2σ. The inference of such palaeostress environment of the Jhalawar region lead in the identification of a buried rigid basement high southwest of Jhalawar anticline, beneath the Deccan pile and loci of ground water, silica sand and probable igneous plug.

INTRODUCTION

Remotely sensed data exhibit a regional panorama of the various geological formations and the master tectonic fracture systems and faults that are otherwise not possible to perceive by human eye on the ground. A study has been conducted in an area of about 16,000 sq km in Jhalwar area forming the western part of the Proterozoic Cratonic Vindhyan Basin, Rajasthan, India, with an aid of hyper-altitude Landsat MSS imagery and low altitude black and white panchromatic aerial photographs. The lithology and the lineaments interpreted from these multi level data were integrated with data collected from the ground and a model for the tectonic evolution of the area was developed; thereby deduced in tectonic history. This study helped in optimising the meagre natural resources of the region.

GEOLOGICAL SET UP

The western India displays well developed geosynclinal and intracratonic proterozoic basins. Among which the Vindhyan Basin (1250-605 ma), India, which concentrically envelopes the Bundelkhand massif (Fig. 1) follows the pattern of intra cratonic rhythm of sedimentation, deformation and evolution, having a repetitive sequence of shales, limestones and sandstones to a cumulative thickness of 2900 m. This sedimentary pile exhibits negligible deformation in the axial portion and intense deformation in the form of regional anticlines and synclines all along the basin margins with their axial traces trending parallel to the basin margins in the Vindhyans of Rajasthan, which forms the Western part of the Vidhyan basin of Central India.

The Jhalawar area forms the south western peripheral part of the Vindhyans of Rajasthan. In this area, an interlayered sequence of shales, limestones and sandstones of the lower and upper Vindhyans forms a major anticlinal structure (Fig. 1) with its axial trace trending in NW-SE direction and due to subsequent erosion, the older formations are exposed at the core and successive younger horizons are occupying the either sides of the axis. The features observed in the structure, viz. parallel geometry of the fold, uniform orthogonal thickness, absence of axial plane cleavage, development of fold on bedding surfaces, rounded hinges of the fold and wider spacing between the glide surfaces suggest that the regional structure followed the pattern of flexural slip fold mechanism operated in a strongly isotropic medium (Bobbs et al 1976, Peterson and Weiss 1966).

DATA AND METHOD OF STUDY

In the present study hyper altitude satellite imagery (Landsat 2 and 3) data on 1:1 million and 1:500,000 scales on bands 4,5,6 and 7 and false colour composites were interpreted for mapping the lithological trends and the lineaments. The data interpreted on different bands and different scenes were transferred on a single overlay and a map showing the lithology and lineaments was prepared (Fig. 1). After filtering out the lineaments of non structural origin, the lineaments have been subjected to anaytical treatement by preparing isofracture map (Fig. 2) by contouring the number frequency data of the lineaments per 100 sq km area following the method adopted by Harris et al (1960), lineament incidence map (Heman, 1961) by contouring length frequency data per same unit area and lineament intersection frequency data of lineaments per same unit area (Heman, 1961).

Subsequently, an intensive test site of an area of about 300 sq km has been selected at the core portion of the anticlinal structure and studied using aerial photogrpahs. The lithology and the lineaments interpreted from the individual stereomodel has been welded on a single planimetrically controlled overlay and a map was prepared (Fig. 3). These data were analysed in conjuction with ground truth data for the evaluation of tectonic evolution and resource potential of the area.

LINEAMENT ANALYSIS AND RESULTS

Landsat MSS Data

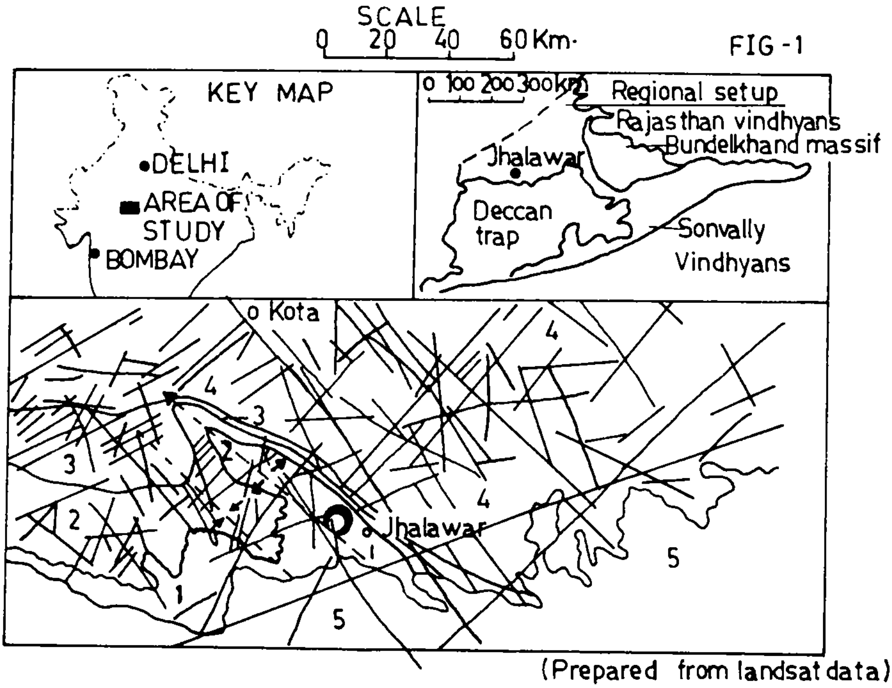
In space borne imagery the Jhalawar anticline area displays a wide ranging azimuthal frequency of lineaments of varying length (Fig. 1). The area in the south is delimited by a major ENE-WSW trending lineament (more than 300 km in length) and rest all other lineaments are less than 300 km in length. Their azimuthal frequency plots show that these fall under two groups with their mean orientations in N 43° W-S 43° E and N 48° E-S48°W directions. Morpho-tectonically these are observed as dark linears with prolific vegetation infills along them at places and strikingly no transverse faulting is observed along these lineaments.

The isofracture, lineament incidence and the lineament intersection incidence maps show similar contour pattern and shape, and hence only the isofracture map is discussed here (Fig. 2). The contour values in isofracture map show wide variation in the area. The maximum values coincide with axis of the Jhalawar anticline and also along the axis of the complimentary syncline lying south west in Mandera area. The shapes of the isofracture contour are mostly elliptical. Their axes of elongation are drawn and reffered to as anomaly axes (Heman, 1961; Bakliwal, 1978; Ramasamy et al, 1983). In the Jalawar area a number of such anomaly axes are observed with an overall bimodal azimuthal distribution in NE-SW and NW-SE directions, the former parallel and the latter perpendicular to the axial

MAP SHOWING THE LITHOLOGY AND LINEAMENT OF JHALAWAR AREA

SCALE

FIG-1



(Prepared from landsat data)

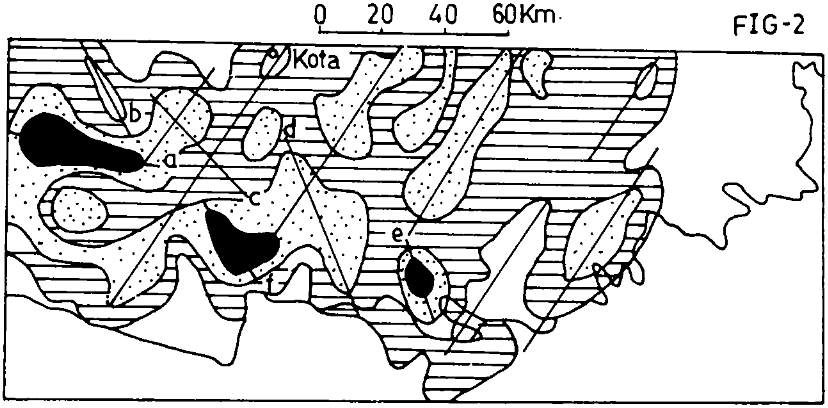
1· Lower vindhyans 2· kaimur 3· Rewa 4· Bhander (2-4 Upper Vindhyans)

5· Deccan trap --⁴⁴ Axial trace of fold ═ Lineaments ↻ Circular feature

ISO FRACTURE MAP OF JHALAWAR AREA

SCALE

FIG-2



● > 6

▒ 6 — 4

▤ 4 — 2

☐ < 2

No. of Lineaments per 100 sq. Km.

trace of the regional anticline. Though an overall bimodalism is observed in the azimuthal frequency of the anomaly axes, their minor scattering coincides with minor fold axes associated with regional anticline. For example amongst the NW-SE trending anomaly axes a to f (Fig.2) 'a' coincies with axial trace of Mandera syncline, 'b' with a minor synclinal flexure found at the north western closure of the Jhalawar anticline, 'c' with the axis of the major regional anticline, and 'd' with another flexure. The NE-SW trending system lie exactly perpendicular to the axial trace of the Jhalawar regional anticline. Bakliwal et al (1986) related these types lineament density with palaeostress envrionment and the anomaly axes to regional stress axes in proterozoic basins of Western India. The study made from space borne fracture system also indicates that the NE-SW and NW-SE trending anomaly axes could be related to compressive forces. However, to further confirm this and to evaluate the disposition of actual stress elipsoid the detailed study has been done with the aid of aerial photographs.

AERIAL PHOTOGRAPH DATA

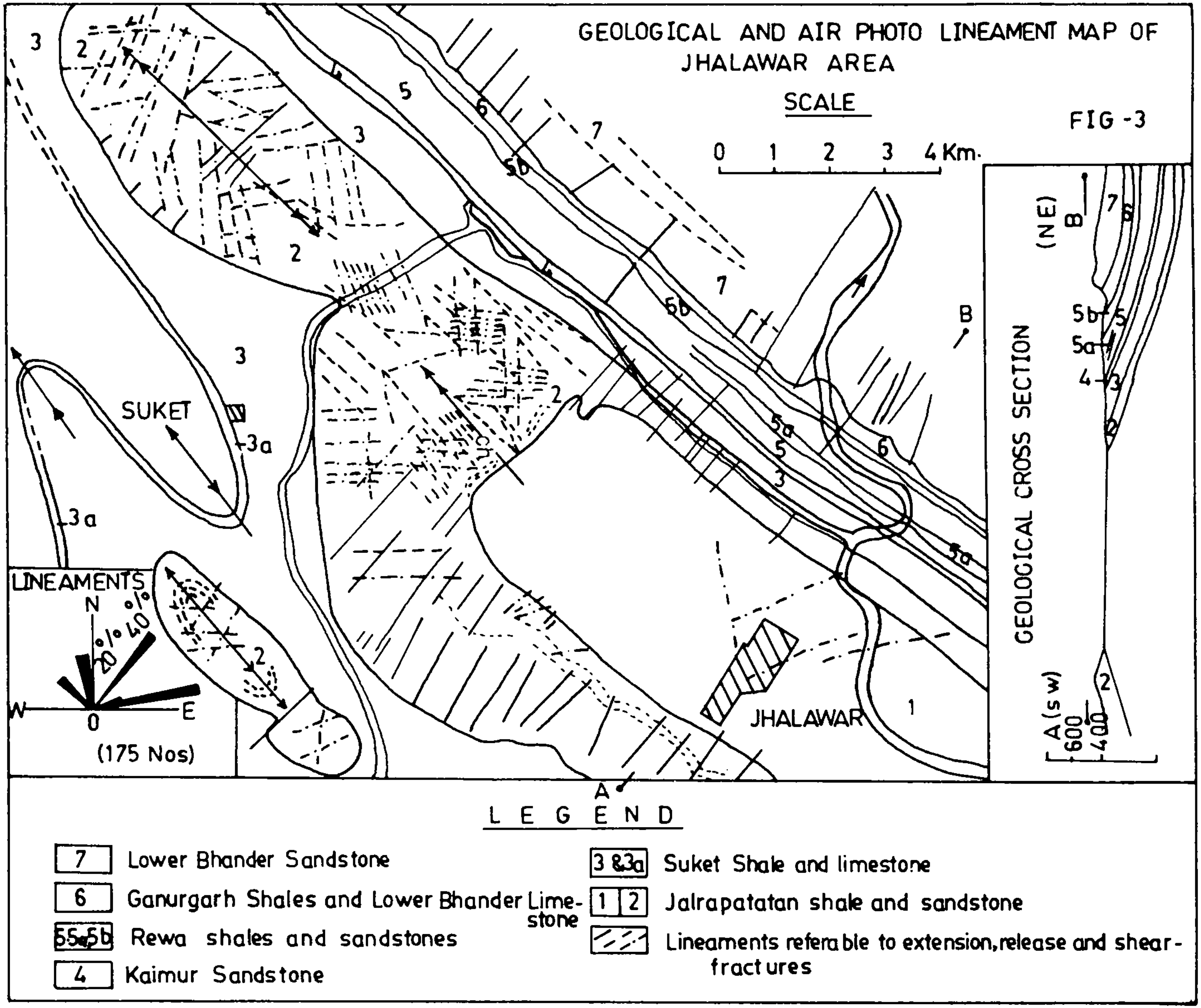
The aerial photographs study reveals that there are four well defined sets of lineaments (Fig 3). Amongst them the NE-SW trending set occurs as wide open linears, concentrated along the limbs forming pronounced wind gaps with prolific vegetation growth along them. Whereas the NW-SE trending set are frequent at the hinge portion of the regional fold and observed as comparatively less opened up linears. The core portion of the anticline exhibits closely spaced conjugate set of lineaments with their mean orientations in N 5° E - S 5° W and N80° E-S 80° W directions with thinly aligned vegetation along them. The cross cutting chronology of these lineament systems indicates that the NE-SW trending wide open linears are the first to form followed by the conjucate set of lineaments of the core which in turn is followed by the NW-SW trending comparatively less opened lineament systems.

GROUND TRUTH DATA

The ground truth shows that the NE-SW and NW-SE trending system of lineaments observed in space borne data and air borne data are observed as wide open and long fracture systems, with former more widely spaced and latter with more frequency. The former more widely spaced and latter with more frequency. The former set forms more pronounced wind gaps in the NW-SE trending ridges and promoting erosion along them. But in both the group no faulting or silicification is observed and exhibit occasional plumose marking along their fracture faces qualifying themselves as features of tensional origin (Parket in Badgley, 1965; Nadai in Badgley, 1965; Hodgson in Badgley, 1965), whereas the N 5°E-S 5° W and N 80° E-S 80° W set of lineaments observed in aerial photographs as thin vegetation linears are manifested at an outcrop level with pronounced silicification and frequent minor faulting with former showing dextral and the latter with sinistral slip geometries indicating their shear failure phenomenon (Desitter, 1956). These sets of lineaments show faint expression of faultings in aerial photographs also. All these NW-SE, NE-SW and the conjucate set of fracture systems/ lineaments are vertically disposed and thereby their intersection lineation is vertical.

TECTONIC EVOLUTION

The integration of space borne data, aerial photograph data and the data from ground truth clearly reveals the tectonic evolution of the Jhalawar anticline (Fig. 4). The Jhalawar anticline exhibits N 45°W-S 45° E trending axial trace and the structure followed the model of flexural slip fold mechanism which normally operates in near surface envoirnment where the shearing stresses will be zero (Four marrier in Whitten, 1968) and hence the $\sigma 1$ (the greatest principal stress) is horizontally disposed.

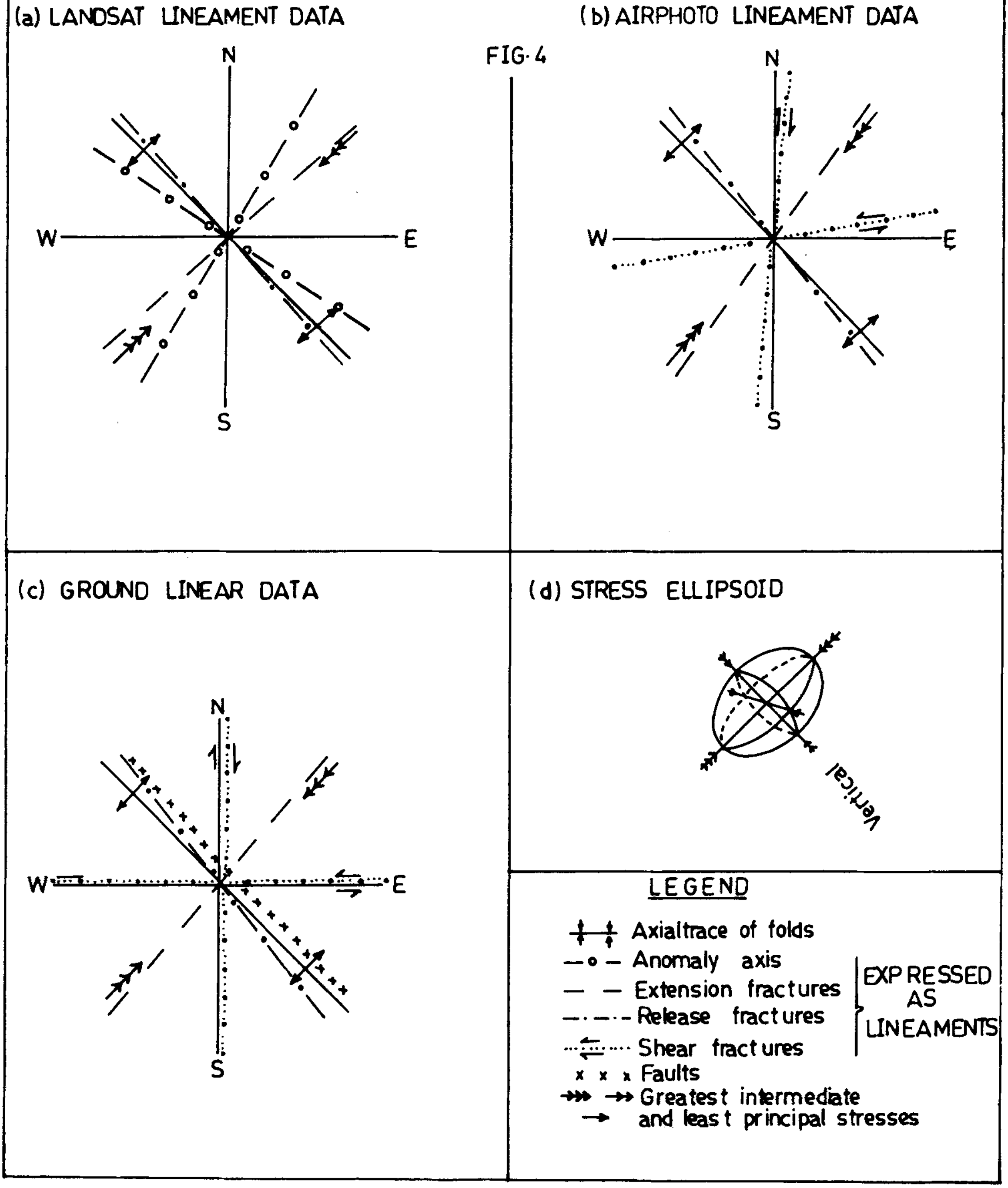


GEOLOGICAL AND AIR PHOTO LINEAMENT MAP OF JHALAWAR AREA

FIG -3

CONCEPTUAL KINEMATIC MODEL FOR THE STRUCTURAL EVOLUTION OF JHALAWAR ANTICLINE, RAJASTHAN

FIG·4



(a) LANDSAT LINEAMENT DATA

(b) AIRPHOTO LINEAMENT DATA

(c) GROUND LINEAR DATA

(d) STRESS ELLIPSOID

The conjugate set of shear fractures observed as lineaments in aerial photographs with their mean orientation inh N 5°E-S5°W and N 80° E-S 80° W directions and dextral and sinistral geometries respectively show that their acute bisector, which is referable to $\sigma 1$(the greatest principal stress) lies in NE-SW direction (Anderson, 1951). The $\sigma 1$ thus deduced also falls orthogonal to the axial trace of the regional anticline and further coincides with NE-SW trending wide open lineaments which are exhibiting signatures of extensional origin. The vertical disposition of the intersection lineation of the fracture sustems indicates the vertically disposed $\sigma 2$ (the intermediate principal stress). Hence, obviously, the $\sigma 3$ (the least principal stress) is also horizontally disposed and lies in NW-SE direction parellel to the axial trace of the regional anticline and also coinciding with comparatively less opened up fractures manifested as lineaments in aerial photographs at the hinge portion of the structure. The cross cutting chronology deduced from the air borne data shows that tectonically the NE-SW trending extension fractures were formed first followed by the shear fractures and post tectonic to which the release fractures were formed at the core portion of the fold. The deduced stress pattern and distribution exhibits good correlation with the anomaly axes derived from Landsat lineament analysis suggesting that NE-SW trending anomaly axes are referable to $\sigma 1$ and NW-SE trending to $\sigma 3$. Hence the NW-SE and NE-SW trending lineaments showing darker tone in Landsat images are also referable to release and extension fractures respectively. The poor manifestation of shear fracture system in Landsat data is attributed to less resolution when compared to aerial data.

Thus the kinematics of Jhalawar antcline is regionally controlled by the NE-SW trending $\sigma 1$, $\sigma 2$ NW-SE oreinted 3 and vertically disposed 2σ stress trejectories. Iqbaluddin (1979) suggested that the centrifugal stress field geneated from the axial portion of the basin radially directed on all sides and acted with rigid basement lying at the basin margins and caused peri-basinal deformation in the Vindhyans. The present study also shows that the greatest principal stressis $\sigma 1$ oriented in NE-SW direction indicating its origin from the axial portion of the basin which lies in the northeast of Jhalawar anticline. But to cause such a regional anticline of this much magnitude, there must have been a rigid basement lying southwest of Jhalawar anticline but for which equal and complimentary force towards northeast would not have been possible. Thus the NE-SW oriented $\sigma 1$ is resolved into two components one in NE-SW $\sigma 1$ and the other in NW-SE $\sigma 3$ directions, the former caused the regional NW-SE trending anticline and the latter caused structural culmination on either ends of the anticline as evidenced by the doubly plunging anticlinal structures at the core portion of the regional anticline (Fig. 3). This study thus indicates the presence of a PreVindhyan basement high in the southwest of Jhalawar anticline under the thick cover of Deccan volcanics and the ENE-WSW trending major lineament observed south of Jhalawar (Fig. 1) must probably represent the northern limit of this basement high. The tectonic history helped in the identification target areas for the natural resources.

NATURAL RESOURCES

GROUND WATER

In Jhalawar region though the sandstone covers most of the area, overall the area forms an interlayered sequence of shales, sandstones and limestones, and hence the fractured zone of the rocks form favourable aquifers for the ground water. Hence the high isofracture value zones in general form favourable zones for groundwater (Fig. 2). A further narrowing down of the target area for ground water is made possible on the basis of this study. Among the different sets of lineaments/fractures the NE-SW trending set, owing its origin to the extensional phenomenon form the best tapping zones for ground water. The NW-SE trending fractures/lineaments in the area obtain only next priority as these are tectonically release fractures and hence taper down in depth. The N 5° E-S 5° W and N 80° E-S80° W or N-S and E-W oriented fractures are non potential zones for ground water as these are very thin and tight due to their development because of shear failure.

SILICA SAND

Numerous occurrence of silica sand is known for over a century in the study area but its control of occurrence is still vague. On the basis of the present study envisaged with the help of remotely sensed data the fractures trending in N-S (N 5° E- S 5° W) and E-W (N 80° E-S 80° W) directions are observed as shear fractures exhibiting faulting, slipping and silicification. Hence these fracture systems are responsible for silica sand formation and are favourable loci for search.

KIMBERLITE PIPE DIAMOND

In the area just northwest of Jhalawar town ship at the core portion of the anticline, a pronounced circular anomaly is observed to a radius of 5 to 7.5 kilometer in Landsat MSS data indicating a probable subsurface plug or pipe beneath the anticline. In Vindhyans of Rajasthan nowhere any subsurface magmatism is reported except in Chittorgarh area (Prasad, 1976). But in Vidhyans of son valley kimberlite pipes at Panna and Jungel in similar geogical set up is known for few decades. Hence this circular anomaly may probably prove a potential source of diamond.

CONCLUSION

The study of space borne and airborne remote sensing data exhibit their immence potential in the study of tectonic evolution, deducing lineament fabric, stress anomalies and thereby helping in targetting natural resources. Jhalawar area affirms a cratonic basin evolution of Vindhyans with rigid basement in the south of the area. Under this stress model the circular anomaly observed in Landsat imagery in the core of Jhalawar anticline is very significant.

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