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Remote Sensing Applications
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Geosciences

7.1. Geological Mapping

7.1.1. Introduction

Remote Sensing is broadly defined as collecting and interpreting information about a target without being in physical contact with the object. Aircraft and satellites are the common platforms for remote sensing data collection. In general, the data collected by remote sensing system is commonly presented in the form of an image. An image is any pictorial representation, irrespective of the wavelength of imaging device used to produce it. A photograph is an image that records wavelengths of 0.3 to 0.9 μm that have interacted with light sensitive chemicals in photographic film. In initial period of remote sensing applications, aerial photographs proved useful in mapping geological structures. Images derived from multispectral sensors showed tremendous potential as an important source of application in various branches of geology- specially in geomorphology, structure and lithological mapping. These maps proved useful in different applications like Geoenvironmental appraisal projects, mineral exploration projects, geotechnical projects. But, it is to understand remote sensing images will be of little use for geological mapping if terrain is covered with forest, soil or other land use cover. Moreover, many of the time geological mapping is accomplished from the rock exposures exposed at the road-cut, river or other vertical section. Therefore map prepared from the remote sensing images is needed to be validated in the field. With the advancement of sensor technology, the applications of remote sensing has increased manifold in the field of geological mapping. Hyperspectral images collected within narrow and continuous spectral channel can detect the spectral signatures characteristic to minerals and therefore help immensely in lithological mapping based on mineralogy. Microwave sensor, on the other hand, due to its side looking imaging capability enhances the geological structures by creating shadow etc.

7.1.2. Image Interpretation

Image interpretation is the act of examining images/photographs for the purpose of identifying objects and judging their significance. The interpretation is not restricted to identifying object on the image; it also usually includes determination of their relative locations and extents. Visual interpretation of satellite image is being applied successfully in many fields, including geology, geography, agriculture, water resources, forestry, etc. A systematic study of satellite images usually involves a consideration of two basic elements, namely image elements and terrain elements

Image interpretation of terrain elements and image elements with identification of geological features based on variations in spectral signatures help in satellite based geological mapping. A broad geological knowledge about the terrain is a prerequisite for interpretation and delineation of rocks, structures and other relevant geological features from satellite image. Collateral data such as existing regional geological maps, reports guide the interpretation of satellite image to derive updated, detailed or large scale geological map. Moreover, the synoptic coverage and multispectral information provided by the remotely sensed data have proved to be advantageous over conventional methods for geological mapping. The synoptic view helps in visualizing the terrain as a whole and comprehend to the spatial relationship between different features (Reddy, 1987). These geological maps can be used in varied applications like mineral exploration, engineering geological studies, environmental geology related studies, geohazard analysis, etc.

7.1.2.1. Image Elements

Following are the eight characteristic image elements that aid image interpretation. These are: Tone/colour, Texture, Pattern, Shape, Size, Shadows, Site and Association.

Tone/Colour: Refers to relative shades of gray on black and white images or colours on normal colour composite, False Colour Composite (FCC) or images. Tone is directly related to reflectance of light from terrain features. For example, water which absorbs nearly all incident light produces black tone, whereas, a dry sand reflects a high percentage of incident radiation. Consequently it produces very light tone on the image. Tone/colour is a fundamental property of an image and conveys more information to an interpreter than any other image elements. Without tonal differences, shapes, patterns and texture of objects described below, could not be discerned.

Some of the terms often used to describe relative tonal values are light, medium, dark etc. Absolute tonal values in terms of photo density have no physical significance for interpretation purposes and practically never used. The variation in gray tones can be transformed into corresponding colours of various shades/lines on FCC. Colour imagery normally provide better thematic information than single band B/W imagery, by virtue of the more spectral information it contains.

Texture: Refers to the frequency of tonal changes in an image. Texture is produced by an aggregate of unit features, which may be too small to be clearly discernible individually on the image. It is a product of their individual shape, size, pattern, shadow and tone. By definition, texture is dependent on the scale. As the scale of the photograph is reduced the texture of a given object becomes progressively finer and eventually disappears. Some of the terms often used to describe relative texture values qualitatively are coarse, fine, medium, smooth, rough, etc., it is rather easier to distinguish various textural classes visually than in the digital-oriented techniques.

Pattern: The pattern relates to the spatial arrangement of the objects. The repetition of certain general forms or relationships is characteristic of many objects, both natural and man made, and gives objects a pattern which aids the image interpreter in recognizing them. For example, interbedded sedimentary rocks typically gives an alternating tonal pattern which aids in their identification.

Shape: Relates to the general form, configuration or out line of an individual object. Shape is one of the most important single factor for recognizing objects from images. For example, a railway line is usually readily distinguished from a highway or a kuchha road because its shape consists of long straight tangents and gentle curves as opposed to the shape of a highway. The shape of an object viewed from above may quite different from its profile view. However, the plan view of object is more important and sometimes conclusive indication of their structure, composition and function is possible.

Size: The size of an objects can be important tool for its identification. Objects can be misinterpreted if their sizes are not evaluated properly. Although, the third dimension, i.e., height of the objects, is not readily measurable on satellite images, but valuable information can be derived from the shadows of the objects. Images with stereoscopic coverages, such as those from SPOT and CARTOSAT-1 & 2 provide information on third dimension (height). For planar objects, it is easier to calculate the areal dimensions on imagery, for example-alluvial fan, flood plain, etc.

Shadows: are of importance to photo interpreters in two opposing respects (1) The outline or shape of a shadow affords a profile view of objects, which aids interpretation, and (2) objects within shadow reflect little light and are difficult to discern on photographs, which hinders interpretation.

Association: It is one of the most helpful clues in identification of land forms. For example, a flood plain is associated with several fluvial features such as terraces, meanders, ox-bow lakes, abandoned channel, etc. Similarly, a sandy plain in a desert is associated with various types of sand dunes.

7.1.2.2. Terrain Elements

In addition to the image elements described above, the terrain elements listed below are also very useful for image interpretation. The terrain elements include drainage patterns, drainage density, topography/land form and erosion status.

Drainage pattern: The drainage patterns and texture seen on images are good indicators of landform and bedrock type and also suggest soil characteristics and drainage condition. For example, dendritic drainage pattern is the most common drainage pattern found in nature. It develops under many terrain conditions, including homogeneous unconsolidated materials, rocks with uniform resistance to erosion such as horizontally bedded sedimentary rocks and granitic gneissic terrains.

Drainage Density: Drainage density refers to the drainage lines within a given unit area. In a given climatic region, coarse-textured pattern would tend to develop where the soils and rocks have good internal drainage with little surface runoff, whereas fine textured pattern would tend to develop where the soils or rocks have poor internal drainage and high surface run-off.

The following three drainage density classes have been recognized:

Fine : Average spacing between tributaries and first-order streams is less than ¼ inch in 1:50.000 scale. Fine-textured drainage is indicative of high levels of runoff, suggesting impervious bedrock type and/or fine-textured soils of low permeability.

Medium: Average spacing between first-order streams is roughly ¼ to 2 inches in 1:50000 scale. Runoff is medium in relation to fine-and coarse-textured drainages. Soil textures and underlying rock are typically neither fine not coarse but contain mixtures of particle size.

Coarse: First-order streams are greater than 2 inches apart, and they carry little runoff. Such textures are indicative of resistant, permeable bedrock materials and coarse, permeable soil materials. Shale would tend to develop fine textured drainage patterns, whereas sandstone develops coarse textured drainage patterns.

Drainage analysis is an important parameter to understand the geomorphic and structural variants of a terrain indirectly. Drainage analysis includes the study of drainage pattern, drainage texture, individual stream pattern and drainage anomalies. It provides clues to the distribution and attitude of the underlying rock formations and geologic structures, such as bedding plane, joints, fractures, faults, folds, etc. The basic drainage patterns and their significance in geologic interpretation are summarized in Table 7.1.1. Drainage texture is also an important parameter for studying the rock type distribution as it indicates the infiltration capacity of the rocks. Higher the infiltration Capacity of the rocks, coarser is the drainage texture and vice versa. Drainage anomalies, i.e., the local deviation from the regional drainage/stream pattern in the form of linear stream segments, active stream courses, appearance/disappearance of braided and meandering streams, change in drainage texture, etc., also indicate a change in underlying rock types and geologic structures. (Reeves *et al.*, 1975 ; Pandey, 1987 ; Gupta, 1991). Significance of drainage patterns in geologic interpretation is summarized in following table 7.1.1.

Table 7.1.1: Drainage pattern and Geological significance

Drainage Pattern	Geologic Significance
Dendritic	Develops in regions of rock homogeneity, shows lack of structural control; indicates horizontal to sub-horizontal bedding and gentle regional slope. Example-shales and granitic gneisses.
Rectangular	Shows structural control, develops along joints/faulty intersecting at right angles. Example-sandstone
Trellis	Shows structural control; develops in • areas having parallel fractures/faults, • tilted interbedded sedimentary rocks having differences in rock resistance and • folded sedimentary sequence.
Parallel	Develops due to pronounced regional slope or in areas having elongated geomorphic features, such as homoclinal ridges of quartzites.
Radial	Associated with domes, doubly plunging folds, volcanoes, etc.
Deranged	Indicates limestones in humid climate

Topography/Land form: The size and shape of a landform are probably most important identifying characteristics. There is often a distinct topographic change at the boundary between two landforms as can be seen in several images. Identification of landforms can help deciphering the underlying geology. Often many of the rock types have distinct topographic expressions, for example, interbedded sedimentary rocks typically exposed in the form of alternating ridge and valley topography. Similarly, basaltic flows occur in the form of mesa hills, Granitic bodies typically form hummocky topography, etc.

Erosion: In general, the deformation status and overall erosion within a given area can be assessed from the image which aids interpretation, particularly for geological mapping. For Example, a highly deformed and eroded rock unit can be considered older than the surrounding less eroded rock units. It also implies the physical competence, chemical susceptibility of underlying rocks to the weathering process.

7.1.2.3. Collateral Data

In addition to the image and terrain elements described above, collateral data in the form of published maps such as geological, soil type, topographical maps, etc., are very useful in the process of image interpretation.

Particularly, topographical maps are of immense help to an image interpreter. For example, slope and aspect information readily available on topographic maps are of great help in geomorphological studies. Similarly, topographic maps also depicts man made objects and other cultural features often useful for base maps preparation and also for transferring the interpreted details from images.

7.1.3. Spectral Signature of Rocks

The spectral signatures of rocks depend mainly on the spectral characteristics of constituent cations, anions and internal molecular structure. Spectral measurements, made in the laboratory and field, of various minerals have indicated that spectral features in visible and near infrared region (0.4-1.0 µm) are dominated by transition metals, such as Fe, Mn, Cu, Ni, Cr etc., and in short wavelength infrared region (1.0-3.0 µm) are dominated by hydroxyl ions, carbonates and water molecules. Interestingly, silicates, oxides, nitrates, nitrites and phosphates which form abundant rock forming minerals, do not have diagnostic spectral features in the reflected region (0.4-3.0 µm) of electromagnetic spectrum. However, thermal infrared region (3-14 µm) has characteristic spectral features of these constituents (Gupta, 1991; Hunt, 1977, 1979, 1980; Salisbury and Hunt, 1974; Kahle *et al.*, 1986). The diagnostic spectral characteristics of various cations and anions in terms of wavelength at which the absorption peak occurs in different regions of electromagnetic spectrum are summarized in Table 7.1.2.

Table 7.1.2: Absorption peaks of various cations and anions in different regions of electromagnetic spectrum (Gupta, 2003).

Cations/Anions	Absorbtion peaks (µm)
Normal - Visible and near Infrared (VNIR) Region	
Ferric ion *	0.40, 0.50, 0.70 and 0.87
Ferrous ion*	0.43, 0.45, 0.57, 0.55, 1.00 and 1.80 – 2.00
Manganese	0.34, 0.37, 0.41, 0.45 and 0.55
Copper	0.80
Nickel	0.40, 0.74 and 1.25
Chromium	0.35, 0.45 and 0.55
Normal - Short Wavelength Infrared (SWIR) Region	
Hydroxyl ions	1.44 and 2.74 – 2.77
Al – OH	2.20
Mg – OH	2.30
Water molecules	1.40 and 1.90
Carbonates	1.90, 2.00, 2.16, 2.35 and 2.55
Thermal Infrared (TIR) Region	
Silicates	9.00 – 11.50 (depending upon the crystal structure)
Carbonates	7 (not used in remote sensing) and 11.30
Sulphates	9 and 16
Phosphates	9.25 and 10.30
Nitrates	7.20
Nitrites	8 and 11.8
Hydroxides	11

* The absorbtion features of 0.87 m (iron oxide), 1.00m (amphiboles and olivines), 0.70 m, 1.00 m and 1.80 m (pyroxenes) appear to be more common.

The spectral measurements suggest that mineral constituents display conspicuous spectral features at a particular wavelength or in a very narrow wavelength band, which require sensors having bandwidth of the order of about 10 nm or even lower. The present day multispectral sensors on-board various satellites, such as IRS-IA & IB, IRS-1C/1D, Landsat and SPOT provide data in much broader wavelength regions due to which direct identification of minerals/rocks is not possible.

7.1.4. Lithological Mapping using Remote Sensing

The important characteristics of common rock types manifested on the remotely sensed data are briefly discussed below (Reeves *et al.*, 1975; Lillesand and Kiefer, 1987; Pandey, 1987; Reddy, 1987; Gupta, 1991; Srivastav and Bhattacharya, 1991).

7.1.4.1. Sedimentary Rocks

The most conspicuous characteristic of sedimentary rocks is stratification, which exhibits banded appearance on the remotely sensed images/photographs. Commonly occurring sedimentary rocks are sandstones, shales and limestone. Horizontally bedded sandstones being resistant to weathering, form massive hills and hogback ridges. The drainage pattern varies from modified dendritic to rectangular and drainage texture is medium to coarse due to high porosity and permeability. Due to high permeability and elevation, sandstones support natural vegetation. Sandstones, if not covered with vegetation, give light tone on the image because of high silica content and less surface moisture. Tonal banding on the image indicates the bedding of sandstones. Typically, two or three sets of joints are present in sandstones, which control the stream segments.

Shales, being incompetent rocks, form subdued topography. In humid climate, they form gently rounded hills with very gentle slopes. The drainage in shales is external and is mainly dendritic. They have fine drainage texture and badland topography develops in arid regions. Cultivation is generally practiced over shales because of the presence of moisture in soils and their low lying nature. Shales show darker tone compared to sandstones because of more surface moisture.

Limestones in humid climate show karst topography, subsidence, sink holes, caverns, etc., due to chemical weathering by water. These rocks have coarse drainage density because mainly internal drainage is present. The drainage is mainly controlled by joints / fractures / bedding planes. Deranged pattern is characteristic of limestone in humid climate. They show light tone and mottled texture on the image. Dolomitic limestone have comparatively less solution activity compared to pure limestone. In arid climate, limestone form prominent hills and ridges with steep side slopes and appear similar to sandstones.

Horizontally bedded sedimentary rocks such as sandstones, shales and limestones form terraced landscape in both humid and arid climate. In sandstone-shale sequence, sandstones form the cap rock and in limestone-shale sequence, limestone form the cap rock because of their resistant nature. The hills occur at almost the same elevations. Sandstones and limestones have steeper slopes compared to shales.

In tilted interbedded sedimentary rocks, ridge and valley type of topography having trellis type of drainage pattern is developed. In humid climate, sandstones form strike ridges, and limestones due to chemical weathering by water. Wheer as Shales form valleys. In arid climate, sandstones and limestones form strike ridges and shales form valleys. Landforms like Cuesta is common for interbedded and gently tiled sedimentary rocks.

7.1.4.2. Igneous Rocks

Igneous rocks are divided into intrusive and extrusive igneous rocks. Plutonic igneous rocks are characterized by their massive and homogeneous nature, and their discordant relationship with the country rocks. Granitic rocks are more common in nature compared to other plutonic igneous rocks, and are characterized by the presence of hummocky topography. They form dome-like hills surrounded by vast undulating plains. The drainage is dendritic to modified dendritic, however, radial and annular type of drainage are also present locally. The streams have a tendency to curve around the domes. These rocks are also characterized by the presence of crisscross jointing. Granitic rocks give light tone due to their acidic composition in contrast to gabbroic rocks having basic composition. Dolerites, which generally occur as dykes form linear to curvilinear ridges and have discordant relationship with the country rocks. However, when the surrounding rocks are more resistant, dykes form depressions. Sills are difficult to identify on the images as they are intruded parallel to the bedding of sedimentary rocks and can be misinterpreted as one of the sedimentary layers. Extrusive igneous rocks can be easily identified with the presence of volcanic land forms e.g., lava cones, lava flow and also by the presence of landforms such as cuesta, mesa/butte. Terraced landscape develops when these rocks are inter layered with non-volcanic sediments, wherein basalts have steeper slopes compared to non-volcanic rocks. Acidic extrusive rocks, such as Rhyolite, have the similar topography as that of the basic extrusive rocks, however, they have limited areal extent as the acidic lava is highly viscous in nature. Radial and annular drainage is developed in central type of eruption associated with volcanic cones and fine dendritic drainage is common in lava flows. Basic extrusive rocks give darker tone than acidic extrusive rocks due to the presence of mafic minerals. Thick black soil is developed over highly weathered basalts, which is often cultivated.

7.1.4.3. Metamorphic Rocks

Metamorphic rocks are comparatively more difficult to identify on the image/ photograph, since most of the primary features of the original rocks are lost because of the metamorphism. Commonly occurring metamorphic rocks are gneisses, schists, phyllites, slates and quartzites. These rocks, except quartzite, have subdued undulating topography and manifest regional foliation / schistosity / cleavage in the form of thin parallel lineations, called trend lines, on the images. Quartzites owing to their resistant nature form linear to curvilinear ridges. Metamorphic rocks give banded appearance on the image. However, the bandings in metamorphic rocks are short, irregular and numerous compared to long, sedimentary rocks. These rocks have trellis, rectangular, dendritic and mixed drainage pattern.

7.1.4.4. Steps in interpreting lithology from satellite image

Satellite data is preprocessed (co registered, mosaiced) and enhanced using different image processing techniques. Best image products in terms of delineation of all the lithological units are used for image processing. Figure 7.1.1 shows flow chart describing steps to be followed for updating/preparing lithological map through satellite data interpretation.

7.1.5. Criteria for Structural Mapping

The structural features that can be identified on remotely sensed imagery may be divided into two categories – (i) associated with or internal to specific rocks known as rock structures and (ii) those which cut, deform and otherwise affect the rock units themselves known as geologic structures (Reeves *et al.*, 1975). The basic criteria for the identification and mapping of geologic structures are given below (Reeves *et al.*, 1975; Pandey, 1987; Gupta, 1991; Srivastav and Bhattacharya, 1991).

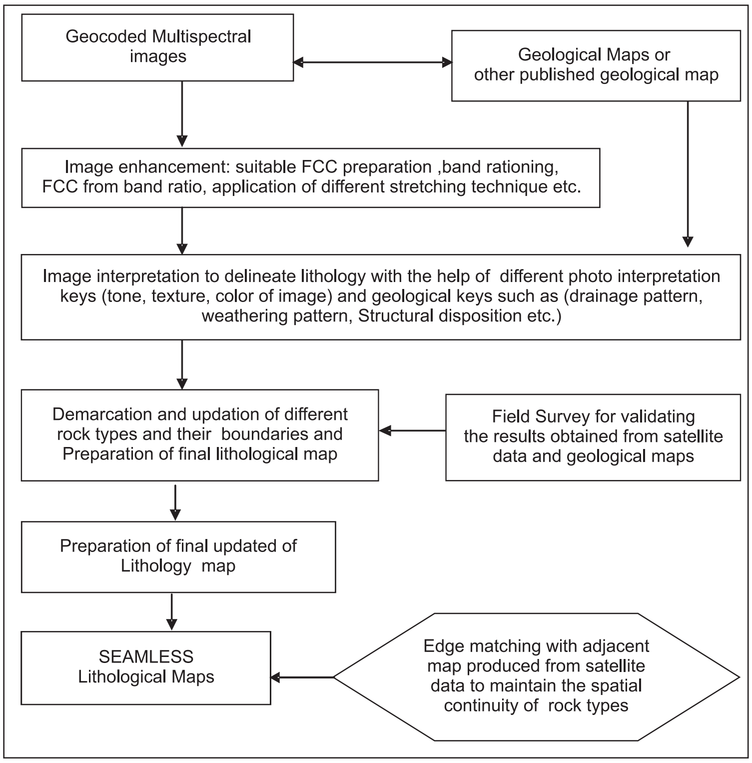

Figure 7.1.1: Flow chart describing steps for preparation/updation of Lithological map from Satellite image

7.1.5.1. Attitude of Beds

The strike and dip direction, and amount of dip constitute the attitude of beds. By visual interpretation of satellite image, amount of dip can be estimated broadly by studying the slope asymmenty (i.e., the amount of inclination of slopes on opposite sides), land form, drainage characteristics, etc., Some of the important characteristics of horizontal to sub-horizontal and inclined beds are the following:

A) **Horizontal and sub-Horizontal beds**

- Show tonal/colour bands parallel to contour
- Show mesa/butte type of landform
- Show dendritic drainage pattern

B) **Inclined beds**

- Show elongated ridges and valleys due to differential weathering
- Low dipping or gently dipping beds (5° to 25°) form cuesta hills having pronounced gentle dip slope and steep obsequent slope
- Moderately dipping beds (>25° and <35°) develop homoclinal ridges
- Steeply dipping beds (>35°) develop hogback ridges
- Vertical beds show narrow, long, continuous and evenly spaced narrow bands running parallel to the strike of the formation. Triangular dip facets develop wherever interbedding of hard and soft rocks exists. The open end of the dip facets points towards down-dip direction

7.1.5.2. Folds

Plunging, non-plunging and refolded folds can be identified on the aerospace data by mapping the marker horizons. The criteria for the recognition of folds are given below:

- Non-Plunging folds produce outcropping in parallel beds
- Plunging folds have v-or U-shaped outcrop pattern. Further classification into plunging anticline or syncline can be made on the basis of dip direction of beds. The nose of a plunging anticline is typically V-shaped

in outcrop pattern and the plunge is in the direction of outcrop convergence. Whereas, a plunging syncline generally shows U-shaped nose and plunge is towards the open end of the outcrop convergence

- Doubly plunging folds produce oval shaped outcrop patterns
- Major streams curve around the nose of the plunging folds

7.1.5.3. Linear Features

Remotely sensed data offer enough scope for the mapping of linear features of geological interest, called lineaments, representing joints, fractures, faults, etc., the lineaments on the remote sensing data can be identified mainly based on their linear nature, presence of moisture, alignment of vegetation, alignment of ponds, straight stream segments, etc., however, the interpretation of fault is complex, but a few general principles apply as given below:

- Rocks on opposite sides of a fault line fail to match each other in type or attitude or both
- Abrupt termination of geological structures, land forms, drainage pattern, etc.
- Lateral offset of the topographical features
- Modified drainage patterns and alignment of vegetation, alluvial fans, springs etc.
- Presence of scarps, nick points or local steepening of streams

7.1.5.4. Unconformities

Angular unconformity can be easily recognized on the image by seeing the angular disposition of rock types on opposite side of the contact. Similarly, non-confirmity in which the older rock is of plutonic origin is easily recognizable. Unconformable contacts are mainly irregular and can be easily differentiated from faulted contacts of straight or slightly curvilinear nature.

7.1.5.5. Methodology for extracting structural information

Several image processing methods are useful in enhancing geological structures. Various spatial domain filters especially Highpass, edge detector, etc., may be attempted for enhancing the structures. Most of the structures are highlighted in a standard FCC with a suitable radiometric enhancement. Microwave data also can be used in conjunction with visible data for highlighting the structures. High pass filters are generally suitable for enhancing linear geological structure;. During Fourier transformation, images are converted from spatial domain to frequency domain. A flow chart (figure 7.1.2) is given to show the steps demonstrating the sequential methods generally followed to delineate geological structure from satellite imageries.

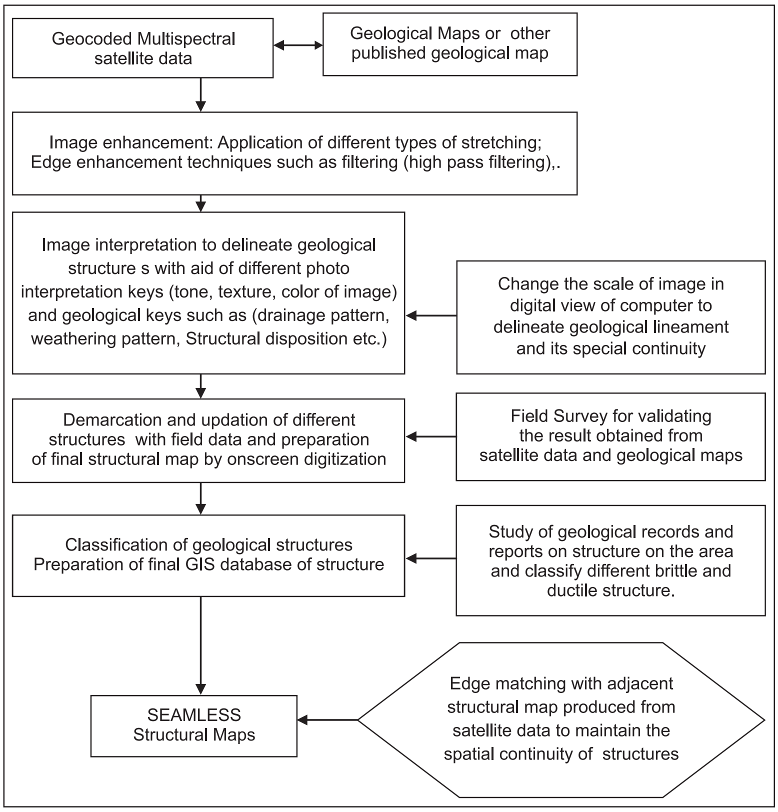

Figure 7.1.2: Flow chart describing steps for delineating Structural features from Satellite Image

7.1.6. Criteria for Geomorphological Mapping

Geomorphology is a complex subject with multiple approaches to its analysis and multiple scales of mapping. In earlier days, ground surveys were the only source of information for geomorphological mapping supplemented by information from topographic maps. But such type field based geomorphology mapping used to be local and demand more time. From the 1970s aerial photographs have played a key role in such surveys (van Zuidam 1985, 1986). But with arrival of digital photogrammetric technique and high computing facilities, the old aerial photographs are scanned and used to generate 3D for landform analysis (Schiefer and Gilbert, 2007). Areal photographs provide also an opportunity to view the terrain 3 dimensionally and thereby aid in landform interpretation. One has to analyse more number of aerial photographs (unlike few scenes in satellite imagery), when geomorphology mapping has to be carried out for a large area. Major drawback of aerial photographs are its high cost and non repetitive nature to capture the dynamic morphological changes.

Subsequently with advent of new satellites, geomorphology mapping has taken a new dimension as it provides direct perspective of large regions. Useful sources of satellite data for geomorphologic applications are images from the Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM), SPOT HRV, and other higher resolution sensors, such as IRS-LISS, MOMS, and the camera systems of KFA-200, KFA-1000, and SPOT HRV and other higher resolution sensors provide images with more spatial detail that may also allow stereoviewing of the terrain. Landsat TM and MSS data have been extensively used for geomorphology mapping by many workers because of narrower spectral bands, particularly suitable for the mapping of bathemetry (bands 1 and 2), vegetation (bands 2, 3, 4, and 5), soil (band 6) and rock (band 7). Microwave data such as ERS and Radarsat have cloud penetrating capability and are sometimes useful for geomorphological mapping. Van Zuidam *et al.*, (1994) used image fusion technique and GIS for mapping coastal landforms. They have used ERS-1 SAR, Landsat TM, SPOT XS and PAN and DTM to find out the tidal changes along the coast of The Netherlands.Use of Digital Elevation Model (DEM) in geomorphology study is not uncommon. Recently DEM has been derived from LiDAR, Stereoscopic satellite data is emerging as a new tool for both quantitative and qualitative geomorphological mapping. Terrain visualisation using DEM provides an opportunity to map the area 3 dimensionally. Mason *et al.*, (2006) have automatically extracted the tidal stream network from LiDAR data. Smith and Clark (2005) analysed different visualisation technique using DEM and observed that curvature visualisation is better than relief shaded visualisation as it provides a non illuminated image.

The nature of the geomorphic unit is controlled by the model of analysis chosen and the scale of mapping required. The basic geomorphic unit is not a single feature or entity, but must be carefully selected to be essentially homogeneous and indivisible at the scale chosen. Although all generally agree that the basic geomorphic unit should be a homogeneous entity, it can be defined in terms of genetic or structural pattern. The approach followed by the International Geomorphology Union (IGU) and most European geomorphologists are in terms of location and dimensions of geometric elements, along the lines of the British system. In India very few attempts have been made to bring out a regional classification system addressing all the aspect of the landform evolution. Of late with advent of remote sensing technology especially in the late 70, geomorphology has gained importance in the entire mapping project. Nevertheless all the study has been of local in coverage catering to theme-specific objectives. Most of the geomorphological mapping has been carried out for geo-environmental appraisal, mineral exploration, geo-engineering, geo-hazards and ground water targeting. Geological Survey of India has carried out geomorphological mapping for the entire country on 1:2,000,000 scale using Landsat MSS data. Department of Space has carried out many nationwide resource mapping projects in which geomorphology is one of the important inputs. Under Natural Resources Cencus(NRC) a renewed attempt has been made by Department of Space with National Remote Sensing Centre (NRSC) as the nodal agency for systematic classification and mapping of geomorphic units in a nation wide mission on 1:50,000 scale.

In nutshell, remote sensing data products (aerial photographs and satellite images) give direct information on the landscape-the surface features of the earth. Therefore geomorphological investigations are most easy to carry out based on such data. Moreover, landscape features can be better studied on regional scale using synoptic coverage provided by the remote sensing data, rather than in the field (Gupta, 2003).

7.1.6.1. Identification of different types of Landform/Geomorphic Units

Landforms are characteristic to the processes which operated to develop their sculpture. Landforms can be broadly subdivided in broad seven categories based on the processes or medium played role in their formations. These are: Aeolian Landform, Coastal Landform, Denudational Landform, Fluvial Landform, Glacier Landform, Tectonic Landform and Volcanic landform.

Aeolian Landform: Aeolian landform is a feature of the Earth's surface produced by either the erosive or constructive action of the wind. The word derives from Aeolus, the Greek god of the winds. Wind erosion processes consist of abrasion, the scouring of exposed surfaces by the sand-blasting action of wind-borne material; and deflation, the removal of sand-sized and smaller particles by the wind. Sand is transported short distances as individual grains or by saltation (a form of movement in short leaps) to form distinct constructional bed forms at various scales: aeolian ripple ridges (a few centimeters in width), meso-dune forms (a few meters in diameter), dunes (several tens to a hundred metres in size), and, finally, ergs (several square kilometers or more). The finer silt-sized particles are transported by airflow turbulence in suspension over much greater distances to form loess. Wind transportation causes attrition of the moving particles, which rub one another and develop characteristic surface frosting and pitting.

Coastal Landform: Coastal landforms are those which are influenced or controlled by the proximity to the Sea. There are two broad types of coastal Landforms: erosional coastal land forms and depositional coastal landform. Most prominent among erosional coastal landforms are those which are cliffs, terraces, benches, shelves, caves etc and significant depositional landforms are beaches ,spit, bars, tidal flats and deltas.

Denudational Landform: Denudational landforms are formed by the continued process of erosion of original landscapes by repeated action of denudational agents like river, wind and climate components like rainfall, temperature etc., Few major denudational landforms are pediplain, pediment, denudational hill etc.

Fluvial Landform: Fluvial landforms are created by the action of rivers or streams and the processes associated with them. This is one of most widely distributed landforms on the earth surface. The landform associated with fluvial erosions are gorges, canyons, V-shaped valleys, steep hill slopes, water falls etc. Typical depositional landforms include alluvial fans, cones, alluvial plain, flood plain, natural levees, river terraces, meander scars, channel fills, point bars and delta.

Glacial Landform: Glaciers are stream-like features of ice and snow, which move down slopes under gravity. Glaciers occur at high altitudes and latitudes and about 10% of earth surface is covered by ice. Areal extent of glacier is difficult to measure by field method and remote sensing data images provide information of much practical utility in this regard (Gupta,2003). Typical erosional landforms of glaciers are U shaped valley, hanging valleys, cirques etc. Main depositional landform of glaciers is moraine. Below streamline, glaciers melt down and form streams. Typical glacio-fluvial landforms are outwash plan, end morain, eskers, etc.

Tectonic Landform: Tectonic landform may be defined as structural landforms of regional extent. Davis in 1899 considered that structure, processes and time constitute the three most significant factors shaping the morphology of a land. Scarp, shutter ridge, structural hill, monocline, etc are few noteworthy tectonic landform.

Volcanic Landform: Volcanic Landforms are mainly constructional and are resulted from extrusion of magma along the vents or fracture of the earth's surface. Cinder cones, crater lava ropes etc are few noteworthy volcanic landform. The definition of major landforms formed under all seven categories of landforms is appended as annexure at end of this chapter.

7.1.6.2. Methodology for extracting Geomorphological information

Satellite data /aerial photographs are most suitable to identify and demarcate the boundaries of different landform as it gives the synoptic coverages. Some times, collateral data like toposheet maps, digital elevation models (DEM) are used to pick up the subtle variations of landscape and also to detect the intraunit variations. All the landforms are demarcated with the help of onscreen digitization process to prepare the geomorphology map. Field work is carried out to validate the map produced from satellite image interpretation. A flow chart (figure 7.1.3) is given to show the steps demonstrating the sequential methods generally followed to prepare a geomorphological map by satellite based method.

7.1.7. Thermal and Microwave data in Geological Mapping

7.1.7.1. Thermal Remote sensing data in Geological Mapping

In thermal infrared (TIR) region, energy emitted by the objects is measured. This emitted energy depends upon the temperature and emissivity of the objects. For geological mapping, thermal response of the rocks to temperature changes is the fundamental property used for discrimination of rock types. Higher the thermal inertia of the rocks, warmer (or brighter) the signature in the night-time image and vice versa. For example, dolomite, which is difficult to distinguish from limestone on optical image, appears warmer (or brighter) on the

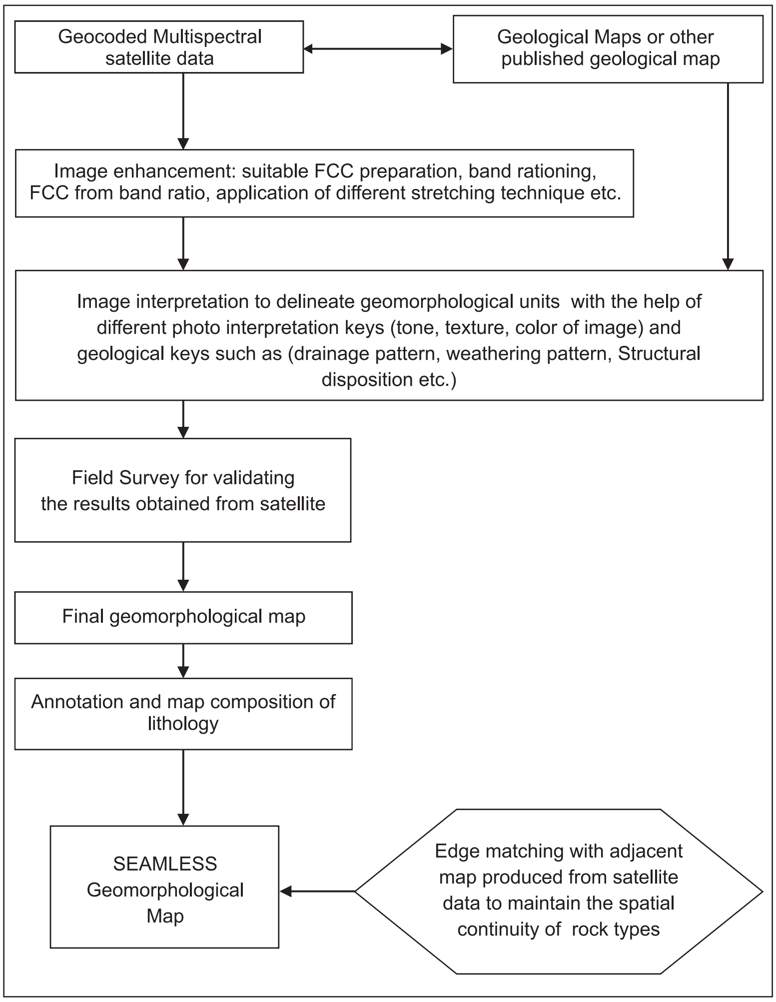

Figure 7.1.3: Flow chart showing steps followed in preparation of Geomorphological Map from satellite Imag

night- time thermal image because of higher thermal inertia. Geological structures such as plunging anticlines and synclines show a distinctive pattern of warmer and cooler signatures due to differences in thermal inertia of rocks. The weak zones, such as faults and fractures give cool linear anomalies in both the day-and night-time thermal images (Sabins, 1987).

7.1.7.2 Microwave remote sensing data in Geological Mapping

Imaging radars are operated in the microwave range of the electromagnetic spectrum at wavelengths from about 1 cm to 1m (Henderson, 1998). The Synthetic Aperture Radar (SAR) has unique capabilities to provide information on surface geometry i.e., shape, orientation, surface roughness and complex dielectric constant. Therefore SAR provides valuable information on surface roughness, soil moisture, topography, and drainage pattern of geologic terrain (Gupta, 1991). SAR also has the limited capabilities to penetrate through the soil cover and thereby can provide valuable information about in-situ rock type and sub-surface structure and SAR techniques have the efficiency to provide relatively coarser resolution where minor details and variations are suppressed. Owing to this fact, SAR images are very helpful in regional landform studies, especially if the variations in landform units are manifested in terms of differences in surface roughness, relief, moisture, etc. Lineaments are well manifested in radar images. Lineaments give the information about the strikes or trends of geological structures like fault, joints, shear planes, fractures, gneissosity plane etc. It must be emphasized that often geological features are better observed on SAR images than on corresponding VNIR or photograph images (Gupta, 1998). Singhroy *et al.*, (1993) have given a brief account of applications of microwave remote sensing in geological applications. Rivard *et al.*, (1999) demonstrated how radar data could be used with Landsat TM images for structural reconnaissance study of deep structural organs. The detailed work of Sharma *et al.*, (in Greenville Greenstone belt, Canada) has manifested the capabilities of radar data in enhancing regional geological structure. In this study, it has been demonstrated as to how radar data helped in the identification of structural dome and nappe in Greenville Province. In a sedimentary terrain, morphological characteristics such as dip slope-asymmetry, flatiron and v shaped pattern of outcrops develops on the images. The manifestation and patterns of these features depends on illumination geometry of microwave sensor (Henderson, 1998).

SAR is also useful in delineating different lithologies based on indirect criteria like surface roughness, soil moisture, drainage, relief, geomorphological features like sink holes, solution ridge, etc., Texture of SAR image is another important criterion as investigations have revealed appreciable correlation between radar return and surface roughness of different types of lithologies, which produce distinct texture in image. Further there is also a possibility of distinguishing various lithologies using multi-channel, cross and like polarized radar images (Daily, 1978, Dellwig, 1969, Bloom *et al.*, 1987). Their study revealed that the shorter wavelengths and small incident angle are best for Lava flows while for the sedimentary rocks the longer wavelengths and somewhat larger incident angle are preferred.

7.1.8. Review of Literature

Remote sensing has been effectively used for broad lithological mapping primarily based on principle and techniques of photo interpretation. Faults, fractures and contacts often provide a conduit for depositional environment for hydrothermal or magmatic fluids in regions of known mineralization, and thus make excellent targets for further investigation. Landsat ETM has been used to map large scale lithological information in different parts of world (Macias, 1995; Rencz *et al.*, 1996; Glikson & Creasey, 1995). With the advancement in sensor technology, new sensors with better spectral resolution like ASTER (12 channels covering visible, SWIR and TIR), Hyperion (242 channels covering visible and SWIR) are being used for lithological mapping. A significant increase in the spectral resolution has led to increase in narrow spectral band to generate hyperspectral images. The narrow spectral channels of an imaging spectrometer forms a continuous reflectance spectrum of the earth surface in comparison to the narrow channels of multi-spectral. In particular, images that represent the effects of diagnostic absorption bands can be produced to show specific variability of certain material features. Absorption bands play a key role in defining the spectral curves of the different terrain parameters. There are various issues in the processing of such sensor data especially calibrating for reflectance with suitable atmospheric correction models, improving the Signal to Noise Ratio (SNR), reducing the redundancy, separating the spectrally pure end member and finally mapping using pixel and sub-pixel techniques. Airborne /satellite hyperspectral data has been used for mapping mineral abundance by various researchers (Boardman *et al.*, 1994; Kruse *et al.*, 2003; Vinod, 2006). This technique is rapidly gaining importance for lithological discrimination.

Satellite based remote sensing approach is best suited for geomorphological mapping. Philip *et al.*, (1989) used aerial photographs and Landsat MSS and TM imagery for the detection of palaeofeatures that have helped to establish the migratory trend of the Ganga and Burhi Gandak rivers. Jones (1986) demonstrated the applicability of suitably processed TM imagery for geomorphologic investigations in arid and semi-arid environments. Updation of geomorphological maps is of great importance for environmental monitoring and sustainable development. Yang *et al.*, 1999 have demonstrated the use of satellite image in deltaic environment updating the dynamic landforms. Sgavetti and Ferrari (1988) used TM data to study the deltaic depositional systems of the Po and Adige rivers.

The ability of radar polarimetry to obtain information about physical properties of the surface has led to many innovative applications in Geoscientific research and concerning environmental issues. Dierking and Haack (1998) demonstrated the capability of polarimetric L-band data acquired by the Danish airborne sensor EMISAR in August, 1997 in delineating the different lava flow and surrounding terrain as well as the identification of different lava facies within one flow. Singhroy *et al.*,(2004) has provided interesting information of polarimetric signatures collected from CV-80 high resolution airborne SAR data. It is found that copolarised polarimetric signatures are significantly different for different surface material type such as sand-silt alluvium, clayey till, deltaic sediment and sedimentary textures played important role in generating different polarimetric signatures. Evan's *et al.*,(1998) described an interesting account of how polarimetric signatures changes with the flow age in consistent with the physical mechanism of lava flow weathering in arid region. These processes, such as rubbling and filling, smoothen the surface of lava flows over time. The important visible difference was in the height of the pedestal, which seems to generally decrease with age, which is consistent with decreasing roughness with age. Guha *et al.*,(2007) evaluated the role of look angle, look direction, microwave frequency and polarisation in enhancing geological element of Kurnool Super Group of rocks, Andhra Pradesh. The future of geological microwave remote sensing would emphasize more on evaluating the role of polarimetry in delineating geological element and also to successfully use the satellite based microwave data in geodynamics. The future missions, namely first Indian microwave remote sensing satellite RISAT scheduled to be launched in 2009 and Radarsat-2 by Canadian space agency would enable detection of certain geological features otherwise indiscernible by virtue of polarimetric observation fulfill the requirement of satellite based polarimetric microwave data for such applications.

7.1.9. Gap Areas

Remote sensing sensors only helps in deriving the geological information impressed on the surface of the earth. Moreover, broadband multispectral sensors are, generally not suitable for delineation of different rocks type based on spectral signatures as no rock has characteristic spectral signatures under broad spectral band. Therefore, geological mapping from satellite data entirely depends on indirect criteria like geomorphic, weathering and geotectonic signatures. Moreover, geological structure specially brittle tectonic structures are only mappable on surface. Low angle brittle structures or ductile structures which do not have characteristic surface information such as recumbent fold, non plunging fold are difficult to be delineated from satellite data. It is therefore always difficult to prepare a conclusive geological map based on satellite data. However, satellite data can be used to prepare detail and updated geological map if satellite data analysis is compounded with the informations from existing regional geological map in small scale and complementary field work.

7.1.10. Case Study

Geological mapping was carried out in parts of Jaipur area in Rajasthan for preparation of geological database for urban information system of Jaipur city. The informations on geology and geomorphology and geological structures are important element for any urban information system because these components guide the urban planner to get the answers of many questions like where one would get better groundwater or what are the places that would be more suitable for rain water harvesting or which are the places with compact basement rock suitable for large scale engineering structures or what are the places that can be used for amusement park or tourist place etc.

7.1.10.1. Geological Description

The relevant information on aforesaid themes are discussed below:

Lithology: The geological sequence of the area is highly varied and complex, revealing the co-existence of the most ancient rocks of Proterozoic age and the most recent alluvium as well as wind- blown sand. Delhi super group are older rocks and are deposited at the central portion of Aravalli range and deposited in synclorium. The exposures of Delhi super group of rocks are restricted in eastern, north-eastern and south-eastern part of the area but in the west and the south-west, they are often engulfed in sandy alluvium and desert sands.

Delhi super group is divided into lower Ralio group, middle Alwar group and upper Ajabgarh group. Ralio group is rich in crystalline limestone, grits, schistose rocks and quartzites. The famous marble of Makrana (Nagaur district) belongs to this group. Alwar group and Ajabgarh group consist mostly of calc-silicates, quartzites, grits and schistose rocks. Thick-bedded quartzite, shiest/phyllite and other lower grade metasediments are exposed here (Figure 7.1.4). In the western part, recent wind blown deposits have covered the metamorphics of Delhi super group. Thickness of the wind blown deposit varies from few centimeters to few meters and at places stabilized dunes are formed. Stabilized dunes are formed if sand is deposited in a depression and moisture and vegetation around the sand body have restricted its further transportation. In places, especially at the margin of drainages or along a trend where palaeo channels existed early, sand and cohesive of alluvial origin are deposited.

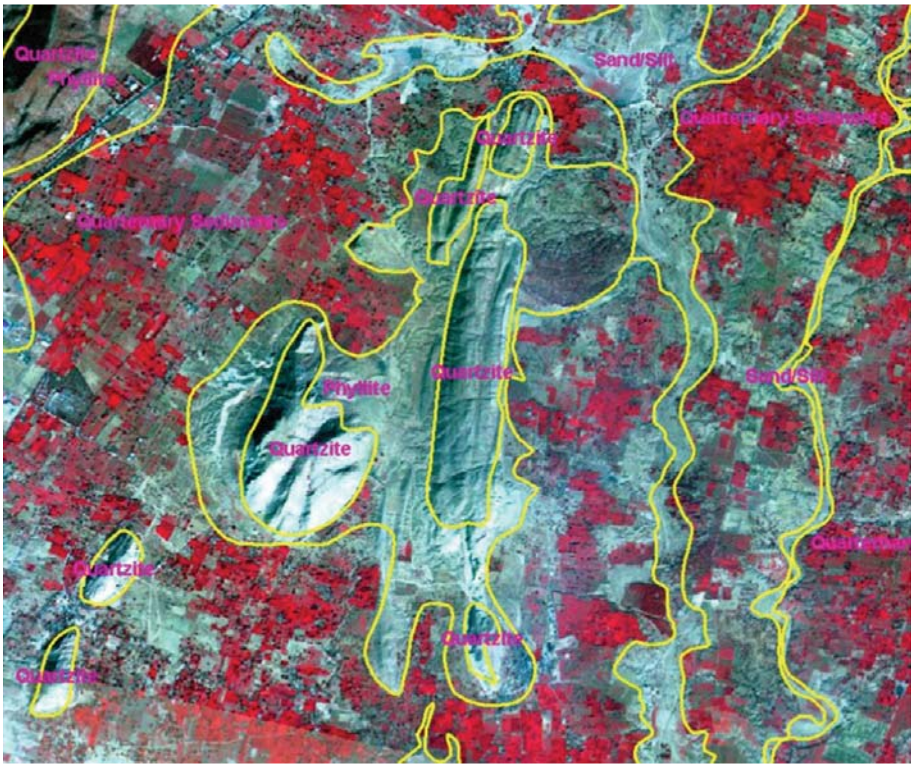

Figure 7.1.4: Lithological map of parts of Jaipur

Structures: The Delhi super groups of rocks are deposited in a synclorium and the trend of Delhi fold belt is NW-SE. The fold axis or orogeny of Delhi fold belt or Delhi orogeny is well depicted in the satellite data. Moreover, many fault and fractures are also delineated in Delhi group of rocks; which represent the pattern of brittle deformation in the area (Figure 7.1.5).

Geomorphology: The geomorphology of this area is very conspicuous and guided by the competence of the rocks. There are four major divisions in geomorphology. These are structural hill, denudation hill, pediment, alluvial plain and aeolian plan (Figure 7.1.6). Structural hills are formed as the result of regional deformation and their pattern and trend is guided by the regional deformation. These hills are very useful to map the regional fold belt of the Delhi Super group with the help of satellite data. Structural hill is subdivided in four categories e.g., highly dissected, moderately dissected, least dissected and linear ridge. These divisions are based on the trend of the structural hill and the amount of dissections is made by the fault, fracture and drainages. Similar subdivisions are possible in denudational hills but only two categories - least dissected denudational hill and moderately dissected denudational hills are present in this area. Denudational hills are remnant hills; which may be formed by the same orogeny; which has created the structural hill but amount of denudation is more over these hills. Aeolian plain has been divided into two categories based on the thickness of accumulated sand and its pattern. Isolated thick patches of sands are mapped as stabilsed sand dunes whereas the remaining area where veneer of thin sand deposition has taken place has been categorized as aeolian plain. In geology, any relatively flat surface of bedrock (exposed or veneered with alluvial soil or gravel) that occurs at the base of a mountain or as a plain having no associated mountain. Pediments are erosional surface of weaker rocks and inundated by lower order drainages and the weathered material of gully erosion of these lower order drainages moves downward and a thin or moderately thick weathered materials are accumulated at the base of pediment. Sometime weathered residue of each lower order drainages coalesces to form Bajada. Pediments are developed on lower grade metamorphic rocks like phyllite and schist. Alluvial plain are formed in the vicinity of present day drainage systems and also along the trend of older and buried drainage course.

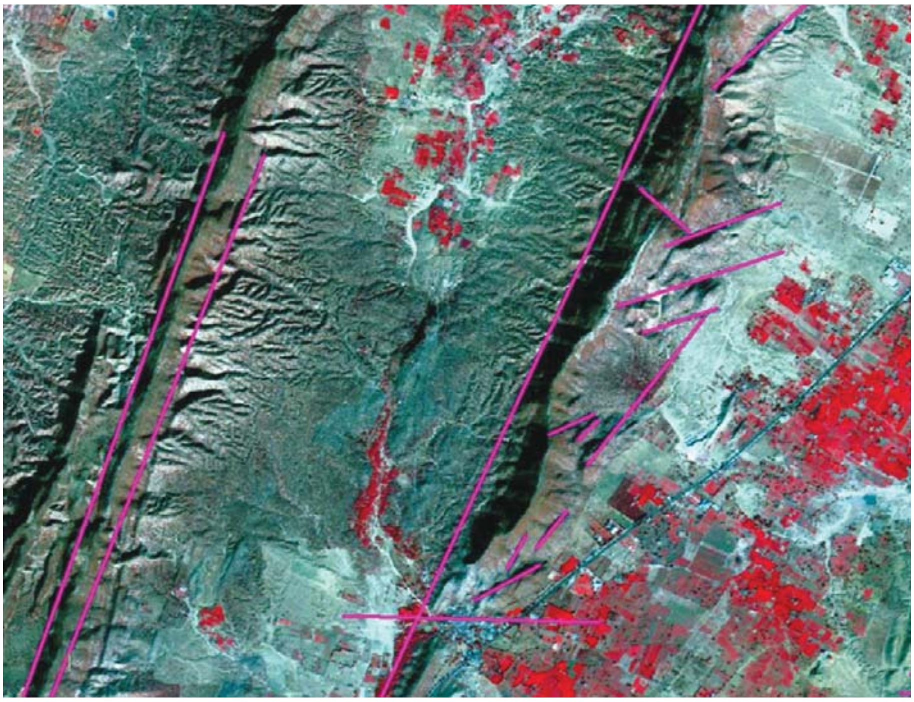

Figure 7.1.5: Lineament map of parts of Jaipur

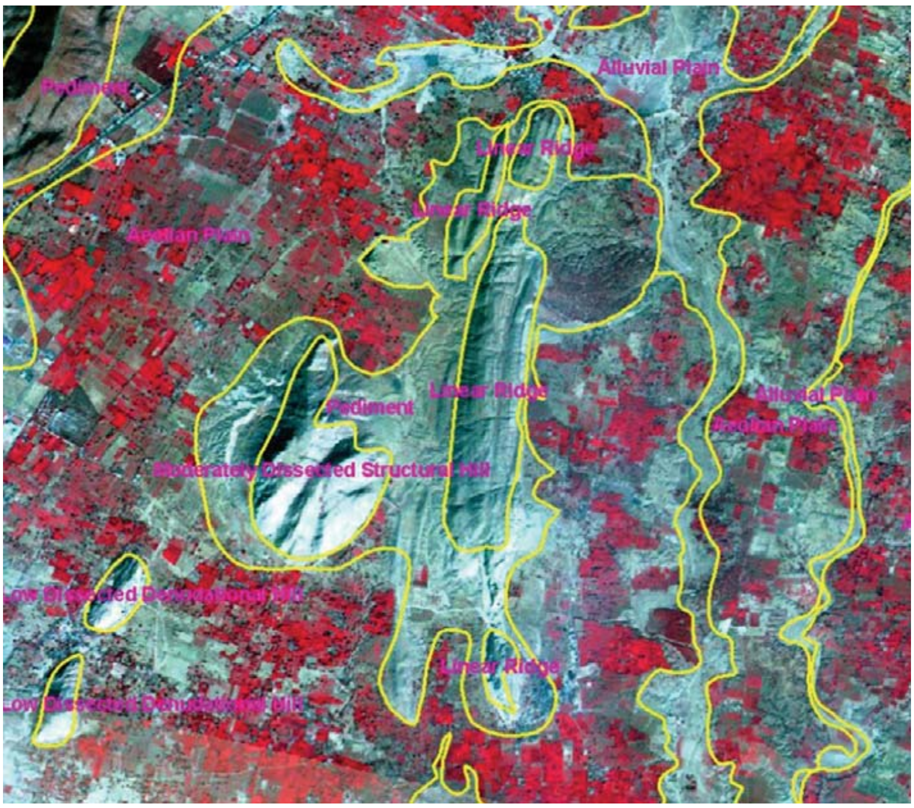

Figure 7.1.6: Geomorphological map of parts of Jaipur

7.1.10.2 Methodology

The geological informations were derived by on-screen or heads up interpretation followed by onscreen digitization process. IRS P6 LISS-IV data is used for the purpose of geological mapping. Geological map of the area at 1:250,000 scale was used as a reference for onscreen interpretation of units for lithology and structure. Geomorphological map on the other hand is entirely based on onscreen interpretation of landform. Photo-geologic elements and terrain elements were used to delineate various geological elements namely lithology, structure and geomorphology.

7.1.11. Summary

Remote sensing has given a big thrust to field of mapping. Remote sensing data analysis helped in updating the field-based lithological maps of regional structural analysis and geomorphological mapping. Synoptic coverage of satellite data facilitates faster and accurate mapping of landforms and therefore allowed to give better understanding between landform and processes.

7.2. Mineral Exploration

7.2.1. Introduction

The various mineral deposits occur in a vast variety of genetic associations. However, the commercial deposits of minerals are limited in genetic type and mode of occurrence (Gupta, 2003). This forms basic concept of mineral prospecting. Mineral exploration is the process; which is an endeavour of finding ore (commercially viable concentrations of minerals) to mine. Mineral exploration is a much more intensive, organized and professional form of mineral prospecting, though it frequently uses the services of prospecting, the process of mineral exploration on the whole is much more involved. Remote sensing data, by virtue of its synoptic overview, multispectral and multi-temporal coverage, can help in rapidly delineating the metallogenic province/belts/sites thereby cutting down the cost.

Remote sensing enables mapping the location of altered areas and regions of hydrothermal upwelling and outflow zones related to mineralization. The increased spatial and spectral resolution of satellite and airborne sensors provide powerful tool to exploration, evaluation and understanding of the genesis of mineral deposits. The use of remote sensing in mineral exploration began some 60 years ago with hand-held cameras being pointed out of aircraft windows and has since evolved through stereoscopic aerial photography to sophisticated space age technology, with satellite and airborne multispectral and hyperspectral digital imaging systems. The advent of sensor technology facilitates the generation of spectral signatures within very narrow spectral bands. These signatures help in identifying alternation minerals associated with significant mineral deposits. Moreover, the narrow spectral channels of an imaging spectrometer form a continuous reflectance spectrum of the earth surface in comparison to the broad channels of multi-spectral data. The critical aspect of the hyperspectral data processing lies in separating diagnostic spectral feature components from the background both in the pixel and sub-pixel domain and in assigning a meaningful class. There are various issues in the processing of such sensor data especially calibrating for reflectance with suitable atmospheric correction models, improving the Signal to Noise Ratio (SNR), reducing the redundancy, separating the spectrally pure end member and finally mapping them using pixel and sub-pixel based techniques. Spatial zones, relative abundances and assemblages of these minerals allow geologists to reconstruct the mineralogical, chemical and sometimes thermal disposition of ancient hydrothermal systems in their search for optimal drilling targets. Airborne hyperpspectral data has been successfully used for mapping mineral abundance in arid terrain (Boardman *et al.*,1995).

To maintain our economic growth we must continue mining for minerals, which requires rigorous exploration strategies for new deposits of all types. Mineral exploration is like looking for a needle in a haystack, so it is important to keep on exploring by integrating various technologies. New mineral prognosis models need to be developed with the emphasis on mineral paragenesis rather than its spatial occurrences.

7.2.2. Global, National Issues, Scenario Development

When the Landsat multispectral scanner (MSS) began operations in the early 1970's, remote sensing mineral exploration took an enormous leap forward but still functioned largely by way of photogeological interpretation of hard copy. Since then, the Landsat Thematic Mapper (TM) has provided the geologists with information relating to specific groups of minerals, specifically the iron oxides and clays.

In the 1980's, airborne remote sensing began with the development of the Airborne Thematic Mapper by Daedalus, the Geoscan instruments (MKI and MKII) by Australian Carr Boyd Minerals Ltd., the Collins' imaging spectrometers developed by Geophysical and Environmental Research Corporation of Millbrook, New York and the Airborne Visible Infrared Imaging Spectrometer (AVIRIS) developed by the Jet Propulsion Laboratory, Pasadena, California. All the instruments offered improved spectral and spatial resolution over their satellite borne predecessors and the AVIRIS instrument in particular, provided geologists with a means of discriminating and mapping individual mineral species and alteration assemblages. However, in the 1990's that the means of processing this data has become available to the average geologists through the development of low cost, commercial image processing and analysis software for desktop computer. The rapid growth in computing power and storage capacity in desktop computer has allowed the very large data files captured by the airborne instruments to be handled in a time frame compatible with the needs of mineral exploration.

The biggest challenge before geoscientists today is to locate new mineral deposits. Remote sensing techniques have emerged as powerful tools in recent times for isolating the favourable areas from unfavorable areas at regional level. Remote sensing data are mainly used to provide the reconnaissance level lithological, geomorphic and structural guide for any exploration programme. Geographic Information System (GIS) on the other hand, is used to integrate and analyze different types of spatial datasets, such as geological, geophysical and geochemical maps to derive mineral potential maps based on knowledge based integration of themes.

In India, several mineral exploration projects using remote sensing technology have been taken up in isolation. Mineral targeting has been attempted under the project like Vasundhara for southern Indian peninsular shield, Pur-Banera and Rajpura area for base metals, Diamond Exploration in Chattisgarh, Gold Exploration in Hutti- Maski Schist belt, Uranium Exploration in Umra area in Rajashthan, etc., (Krishnamurthy, 1999). In all these projects remote sensing data was integrated with the ground and geophysical data for narrowing down the target zones. Suitable prognostic models were developed for interpolating the results from know to unknown. A significant finding was the discovery of new kimberlite pipe in Tokapal, Chattisgarh using this technique. Faults, fractures and contacts often provide a conduit for depositional environment for hydrothermal or magmatic fluids in regions of known mineralization, and thus make excellent targets for further investigation. NASA's GRACE mission improved our knowledge of Earth's gravity field by more than 100 times and is helping to revolutionize our understanding of Earth's climate The unique design of the satellite-based GRACE mission, launched in the year 2002 with twin-satellites flying in formation is expected to lead to an improvement of several orders of magnitude in these gravity measurements and allow much improved resolution of the broad to finer-scale features of Earth's gravitational field over both land and sea. The Magsat project is another important satellite mission by NASA/USGS effort to measure near-earth magnetic fields on a global basis. Objectives include obtaining an accurate description of the earth's magnetic field, obtaining data for use in the update and refinement of world magnetic models. All these satellite-based geophysical observation would contribute to geoscientifc data pool and would form important scientific data sets for future exploration strategies. The synopticity of these satellite observations would provide the first hand information in hitherto unexplored zones.

7.2.3. Conventional and Scientific Methods in Practice

7.2.3.1. Methods/approaches for utilization of Remote Sensing data for Mineral Exploration

Primary rock-forming minerals as well as many secondary weathering and alteration minerals exhibit wavelength dependent (spectral) absorption features throughout the visible and infrared wavelength ranges of the electromagnetic spectrum. These features result from the selective absorption of photons with discrete energy levels and are dependent on the elemental composition, crystal structure, and chemical bonding characteristics of a mineral, and are therefore diagnostic of mineralogy (Burns, 1993; Clark, 1999;). In silicate, carbonate and sulfate minerals fundamental molecular vibrations cause strong spectral features that appear as emissivity minima (reflectance maxima) in the 8–12 µm region (Hook *et al.*, 1999; Salisbury *et al.*, 1991). This region coincides with a window where Earth's atmosphere is relatively transparent to TIR (Thermal infrared radiation) and is also the region of maximum emission from a 300 K temperature bearing body (e.g., Earth), making it ideal for terrestrial geologic remote sensing applications (Kahle *et al.*,1993). For silicate minerals the wavelength position of the emissivity minima (''reststrahlen bands'') shifts to longer wavelengths with the increasing isolation (decreasing polymerization) of tetrahedral SiO_4 molecules in the crystal structure (Hook *et al.*, 1999).

The steps involved in mineral exploration include area selection, target definition, resource evaluation, reserve definition and extraction. Remote sensing plays an important role in the first two stages of mineral exploration.

Spaceborne multispectral sensors/ hyperspectral sensors can detect the spectral signatures characteristic to the alternation zone associated with a mineral deposit. These features can easily be detected specially in airborne hyperspectral scanner. The detection of alteration zone, favourable geological structures prospective for mineral deposits or suitable host rock of any particular mineral helps in area selection and target delineation phase of the mineral exploration. Other collateral data, namely geological map, geochemical data, and geophysical data is required along with remote sensing data to model the reserve potential. Since remote sensing helps deriving information on surface feature, it is not suitable for modeling a target for exploring a deep seated mineral deposit. A schematic diagram at Figure 7.2.1 is given below to show the steps generally followed when remote sensing data is used in integrated manner with other geoscientific data.

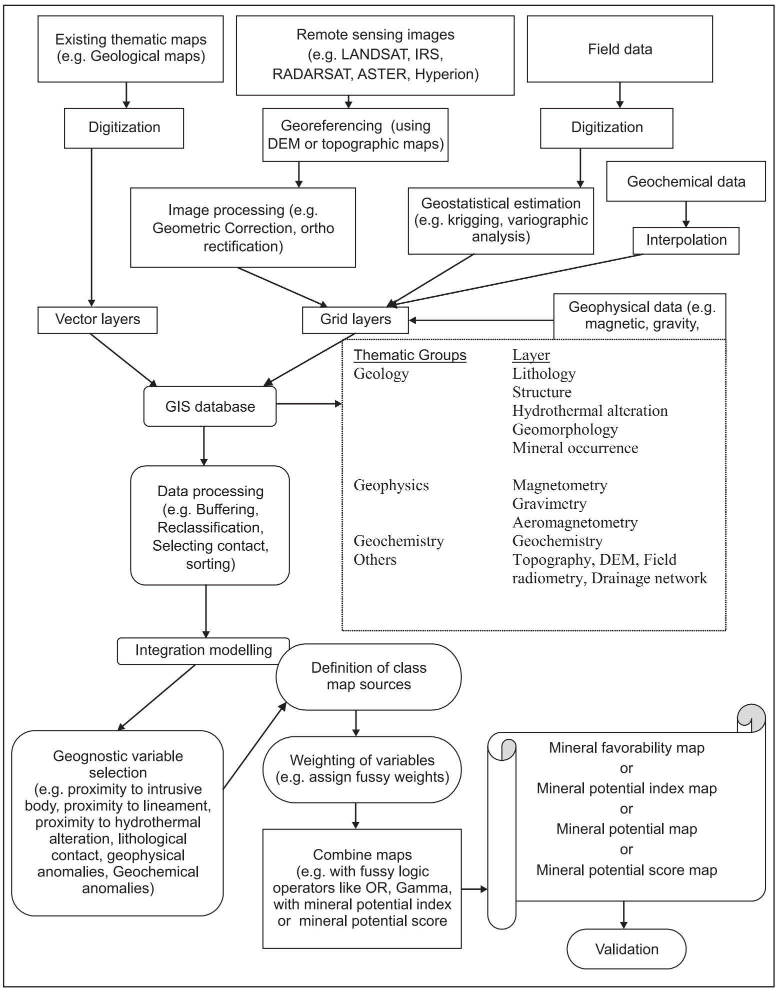

Figure 7.2.1: Steps used in Integration of Remote Sensing data with other Geoscientific data for Minaral Exploration

7.2.3.2. Methods for Oil field Detection through Remote Sensing

The primary source material for the origin of petroleum is generally considered as organic but theories on inorganic origin also exist. Early ideas and theories leaned towards the inorganic source whereas the modern theories consider organic matter as the only potential source, which occurs in a wide variety of both animals and plants. Petroleum occurs at considerable depths below the surface in sedimentary basins. It is formed in specific geological environment represented by source rock for the formation of oil from organic debris under particular pressure and temperature conditions, ultimately migrated, entrapped and accumulated in reservoir rock. A petroleum bearing basin must exhibit several important characteristics including-

- Source rock from which petroleum is generated and a thermal history which provides suitable thermodynamic conditions for the evaluation and release of the petroleum from rock
- Rocks with adequate porosity and permeability to allow migration and become a reservoir and a cap rock to seal further migration
- Structural and stratigraphic traps in which petroleum can accumulate
- Timing factors, which bring all of the geological and geochemical factors together at the right time in such a way that generated hydrocarbons are entrapped and preserved

The other factors that control petroleum accumulation is the sequence of the earth’s movements, release of internal pressure and compaction of source rocks, all taking place over geological time scale. Thus, petroleum accumulation is controlled by structural changes which at any given time can be visualized by the study of folds, faults, domes, unconformities, etc.

7.2.3.2.2. State of the-art techniques for Petroleum Exploration

Remote Sensing: The remote sensing plays a major role in regional geological mapping. It is the basis for reconstructing the geologic history of a region and for locating areas having the greatest promise for buried petroleum deposits. Remote sensing data helps in identifying the following four basic terrain elements important for oil exploration.

- Structural Mapping: Folds, faults, fractures and joints

- Rock type mapping : Rock types can be recognized on the basis of colour, texture, landform pattern, thermal inertia etc
- Geomorphic Analysis: In areas where the bedrock is obscured by surfacial deposits or vegetation, evidences of underlying geologic conditions are reflected at the surface but are only suggestively revealed through detailed geomorphic analysis. Drainage patterns, landforms, fracture patterns, and tonal or colour anomalies are valuable clues in this analysis
- Surface indications of hydrocarbons: The hydrocarbons escaping from the traps can alter the surface rocks to produce colour, mineralogic and vegetation anomalies, which can be detected by remote sensing techniques. The primary objective of using remote sensing technique for onshore exploration is to detect anomalies indicating possible presence of petroleum bearing structures at depth. Some of the anomalies which manifest on remote sensing data include:
  - High heat flow associated with hydrocarbon bearing structure (thermal IR data)
  - Vegetation or soil anomalies and subtle tonal anomalies resulting due to interaction between soil/ vegetation (SWIR) and
  - Chemical alteration zones caused by vertical migration (thermal inertia mapping)

7.2.4. Literature Review

Several noteworthy works have been carried out on mineral exploration at global level. Several examples of this type of application are known in the literature. For example, using Landsat MSS data and supervised classification, Halbouty (1976) located the likely extension of strata-bound copper deposits in the Tertiary Totra sandstones of Bolivia, into adjoining territory of Peru. Guild (1972) reviewed the relationship between mineral exploration and global tectonics. Offield *et al.*,(1977) using satellite data discovered a significant ore controlling linear feature in South America. Bowers (1996) integrated lineament structures derived from Landsat TM and SAR data with a database for known occurrences in GIS for more fruitful interpretation of lineaments for mineral exploration.

Alteration zones often accompany mineral deposits and constitute one of the most important guides for mineral exploration. These are very important for hydrothermal deposits, which include metals such as copper, lead, zinc, cobalt, molybdenum, etc. This type of alteration zones with phyllosilicates has been delineated in satellite based mineral exploration study (Abrams *et al.*, 1977). Spectral characteristics of limonite have been successfully used for mapping and exploration of hydrothermal deposits (Conradson and Harpoth,1984). Fraser (1991) adopted Directed Principle Component Technique (DPCT) for discriminating ferric oxide (hematite and goethite) from vegetation. Rowan *et al.*,(1974) demonstrated the utility of ASTER data for mapping the hydrothermally altered areas from regional rocks and soil units in Pakistan.

Suitable sites for placer deposits i.e., diamond, gold, monazite, etc., also can be better located on the remote sensing data. For example fluvial placers also can be identified by delineating buried channels, abandoned meander scars, scrolls etc (Gupta, 2003). Geological structure plays a major role in locating an ore deposits in metallogenic provinces.

In geobotanical remote sensing, several contributions have been made to demonstrate the capability of spectral behaviour of geobotanical elements in mineral exploration. For the purposes of mineral exploration, the geobotanical changes are of three types: structural, taxonomic and spectral (Mouat, 1982). These changes can easily be studied using remote sensing data. It is reported that the red band absorption (0.67 micrometer) is more characteristics of concentrated heavy metals in soil, rather than red edge, the absorption band being regularly shallower and narrower over mineralized areas (Singhroy and Kruse, 1991). Mathematically, modeling for mineral exploration was attempted in Rajpura- Dariba – Lunera mineralized belt. A number of favorability index maps based on unweighted, weighted and logical models were generated (Bhattacharya *et al.*,1993). Nasipuri *et al.*,2006 has shown the utility of day and consecutive nighttime Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data over a part of the Cambay basin, Gujarat, India in generating thermal inertia images. The thermal inertia map has been utilized for exploration of petroliferous basins.

A significant improvements in the spectral resolution has led to increase in narrow spectral band to generate hyperspectral images. The narrow spectral channels of an imaging spectrometer forms a continuous reflectance spectrum of the earth surface in comparison to the narrow channels of multi-spectral. Imaging spectroscopy resolves the narrow absorption bands in the spectrum which can be used to identify specific parameters. In particular, images that represent the effects of diagnostic absorption bands can be produced to show specific variability of certain material features. Absorption bands play a key role in defining the spectral curves of the different terrain parameters. The critical aspect of the data processing involves separating this component from the background both in the pixel and sub-pixel domain and assigns a meaningful class. There are various issues in the processing of such sensor data especially calibrating for reflectance with suitable atmospheric correction models, improving the Signal to Noise ratio (SNR), reducing the redundancy, separating the spectrally pure end member and finally mapping them using pixel and sub-pixel techniques Spatial zones, relative abundances and assemblages of these minerals allow geologists to reconstruct the mineralogical, chemical and sometimes thermal disposition of ancient hydrothermal systems in their search for optimal drilling targets. Airborne hyperpsectral data has been used for mapping mineral abundance in arid terrain (Boardman *et al.*,1995). The EO-1 Hyperion sensor launched by NASA covers the 0.4 to 2.5 microns spectral range with 242 spectral bands with 10 nm band width.

Aeromagnetic surveys are widely used to aid in the production of geological maps and are also commonly used during mineral exploration (Bhan *et al.*,1991, Hegde *et al.*,1983). Some mineral deposits are associated with an increase in the abundance of magnetic minerals. The integration of remote sensing data with aeromagnetic data seems as important tool for mineral exploration. Regional aeromagnetic surveys have been undertaken by National Remote Sensing Centre (NRSC) since 1981 under National Aeromagnetic Project sponsored by Airborne Mineral Surveys and Exploration Wing (AMSE) of the Geological Survey of India (GSI). Under this programme states of Tamil Nadu, Karnataka, Kerala and parts of Andhra Pradesh, Maharashtra, Madhya Pradesh, Orissa, Bihar and Gujarat, Upper Assam shelf covering parts of Arunachal Pradesh, Assam, Meghalaya & Nagaland and the entire Vindhyan basin was covered. So far, NRSC(National Remote sensing Centre) has acquired, the aeromagnetic data for about 5.00 lakh line kms and prepared about 2, 200 maps on 1:50,000, 1:250,000 and 1:500,000 scales.. These maps and the data are being utilized in the ongoing exploration programmes of GSI, ONGC and DGH for planning detailed ground geoscientific investigations and also utilized in the project Vasundhara (geoscientific database creation for mineral exploration), which was taken up jointly by the Department of Mines and the Department of Space, GOI. Recently High Resolution Aeromagnetic (HRAM) surveys was carried over Ganga basin for Directorate of Hydrocarbon with the state-of-the-art survey and data processing procedures for identifying oil bearing structures in the basement as well as within the sediments.

7.2.5. Gap Areas

Since many of the unexplored mineral deposits occur at considerable depths below the surface, exploration techniques for those minerals is geologically more complex and uncertain. In such cases, for mineral target delineation would not be possible by remote sensing method unless indirect geologic signatures indicative of mineral deposit are present on the surface. Hence, the detection of mineral zones depends mainly on the geological, geophysical, geothermal, geochemical and geobotanical parameters of the area. An integrated approach utilizing a wide range of remote sensing devices which measure spectral signature from the space and aerial platforms and the geophysical techniques; which measure various physical properties of the subsurface rocks would certainly define potential target areas. Aerogeophysical data can provide supplementary information that is useful for targeting shallow subsurface deposits. Aeromagnetic survey is a potential reconnaissance tool in mapping the regional surface and subsurface structures. Measurements of variations in the earth's magnetic field are used to determine the configuration of crystalline basement rocks that commonly influence the development of hydrocarbon trapping structures in overlying sedimentary rocks. Another important geophysical technique is gamma ray spectrometer survey. Uranium, thorium and potassium concentrations have been found to be related to gamma field intensity of surfacial geologic materials, and the measured concentrations being a product of radio-active mineral fixation. It can also help in oil field detection. The processes of fixation are known to be influenced by oil/gas habitat and, therefore can represent surface manifestation of possible hydrocarbon occurrence at depth. A low activity area, characterized by gamma field sink, and rimmed by 10-15% increased activity is observed generally over oil/gas bearing structures. These geophysical techniques are needed to be integrated with remotely sensed data to delineate potential zones for detailed exploration. Without such integration, remote sensing data would be of little use for mineral exploration surveys.

Availability of spaceborne sensors extracting different geophysical/geochemical signatures would be more useful in mineral exploration. For example, aerogeophysical/ aeromagnetic signatures and remote sensing based spectral informations, received from a mineral prospective terrain will help more realistic identification of mineral potential zone.

7.2.6. Case Study

Conjuctive use of remote sensing and geophysical data over parts of Deccan Syneclise for hydrocarbon exploration

7.2.6.1. Introduction

With the increase in demand for the petroleum products and diminishing indigenous production, it has become necessary to look for probable potential zones even in locales that were hitherto known as areas with bleak prospects. The study area consists of series of basaltic lava flows presumed to have been erupted on to the surface during Cretaceous – Tertiary period, blanketing all pre-existing rocks ranging in age from pre-Cambrian to Cretaceous. Deccan Syneclise is a super order negative platform structure with appreciable thickness of sediments below the Trap. The mesozoic sediments, throughout the world, are known sources for hydrocarbons and are potential source rocks for more than 50 % of the world's hydrocarbon reserves. These sediments are expected to be present below the northwestern, northeastern and middle parts of the Deccan Syneclise. The discovery of hydrocarbons in the Mesozoic sediments in Jaisalmer basin (Goru & Pariwar formations) and East Godawari sub-basin (Narsapur & Mandapeta structures) indicated the significance of looking for structures entrapping hydrocarbons in Mesozoic sediments in Cambay basin and adjoining trap covered areas. The hydrocarbon prospects of the Deccan Syneclise are still poorly understood, as the studies are based only on the sparse sedimentary exposures. The evaluation of the basin for the Mesozoic prospects is a challenging job in the absence of adequate geophysical data. The study area is bound between the 73º 00' to 75º 05' E and latitudes 20º 50' to 22º 00'N and covered by six topographic sheets (46 G, 46 H, 46 K, 46 L, 46 O and 46 P) of Survey of India on 1:250,000 scale and form north western parts of Deccan syneclise.

The study area of about 40,000 sq. km. has been covered by 6000 gravity stations and the gravity data was acquired along roads and tracks at approximately 2 km spacing using Lacoste Romberg G-type gravimeters (LRG) with an accuracy of 0.01mGals. The data was processed and modeled. Comparison of the elevation, free air and regional and residual Bouguer anomaly maps clearly indicate the crustal density distribution of the region. The broad gravity low over the Cambay basin is due to the known Tertiary filling. The residual gravity low over the Shirpur and the semi-circular Residual gravity low encompassing the Navapur may be interesting for the subtrappean Mesozoic sediments. The Bouguer anomaly map of the gravity data was interpreted for major regional faults. Magnetotelluric (MT) method is considered to be one of the effective techniques in delineation of sediments buried below the trap covered layers, since it has a marked resistivity contrast with the underlying basement and also with the overlying volcanic cover. This technique is one of the well-known geophysical techniques to probe the earth into much deeper crustal layers. This study provides a detailed electrical structure, which in turn could be interpreted in terms of lithology, and geological structure over a range of depths extending from very shallow levels to as deep as few tens of kms. A total of 511 MT soundings were carried out in the study area. A major sedimentary basin is delineated from this study between Narmada – Tapti rivers towards eastern part of the study area. The thickness of the Mesozoic sediments below Deccan traps is of the order of 2.5 to 3 km and also possesses relatively low resistivity as compared to the sediments delineated in other parts of the region. Over the study area 50 DRS stations were carried out, which could successfully delineate a major sedimentary basin covered under trap in the eastern part of the area. The DRS results are found to be very consistent with the results from other studies such as MT, Gravity and Seismics. The total thickness of the Tertiary and Quaternary sediments in the deepest part of the basin is expected to be of the order of 5000 m resting on the Deccan Trap floor. In the Narmada valley and adjoining areas, the trap thickness is about 700 – 800 m. In the area south of the Narmada River, a few gravity-magnetic computations did earlier indicate the traps to be thicker than 1500 m. Thus the older works have revealed that the Cambay – Narmada – Tapti rift zone holds potential Mesozoic sediments for hydrocarbon exploration. The geophysical investigations in the trap covered areas of Kutch and Saurashtra by NRSC and NGRI (NRSC, 1998; NGRI, 1998, 2000) respectively was a proved and fruitful effort in delineation of the structures. The gravity, DRS, MT and seismic data was acquired and processed by NGRI, Hyderabad .

7.2.6.2. Methodology

The IRS P6 - AWiFS geocoded digital data of the area was co-registered with the geophysical data. The profiles along which the geoelectrical sections have been constructed based on DRS stations and the gravity and resistivity profiles along which the actual field observations were collected, were scanned, digitized and registered on to the satellite image. The geo-referenced satellite data was interpreted for the geological structures namely faults /

lineaments based on the ‘length-based classification’ and ‘geomorphic anomalies’ using digital image processing techniques. Some of the required geophysical observations were coded as separate vectors into this attribute. This was used to understand the inter-layer relationship and also to confirm the satellite-derived information.

A regional geological structure assessment of the basin was carried out to understand the manifestation of any sub-surface geological structure for hydrocarbon exploration. The basic geological information like lithology and the stratigraphic details were taken from published geological quadrangle maps of Geological Survey of India on 1: 2 million scales. Figure 7.2.2 demonstrates the steps followed to prepare structural map and associated geomorphic anomaly to indicative of favorable zone of oil accumulation (Figure 7.2.3).

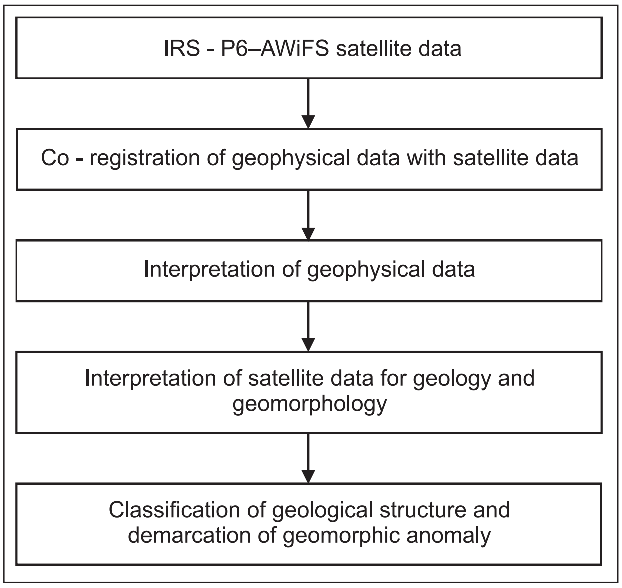

Figure 7.2.2: Schematic diagram of the approach

There are basically three major trends of lineaments and faults in this area i.e., NW-SE, NE-SW and ENE-WSW. The NW-SE trend is the oldest one corresponding to the Pre-cambrian trend. The mega fault has prominent ENE-WSW trend, which corresponds to the Mesozoic group. Prominent geomorphic anomalies are observed in the area, coinciding probably with the subsurface basement high. Two areas of tectonic activity, one in the north-western part around Dediapada village and the other in the eastern part around Shirpur village were also identified by the integrated analysis of remote sensing and geophysical data interpretation. These may be the potential zones for oil bearing formations.

7.3. Geoenvironmental Studies

7.3.1. Introduction

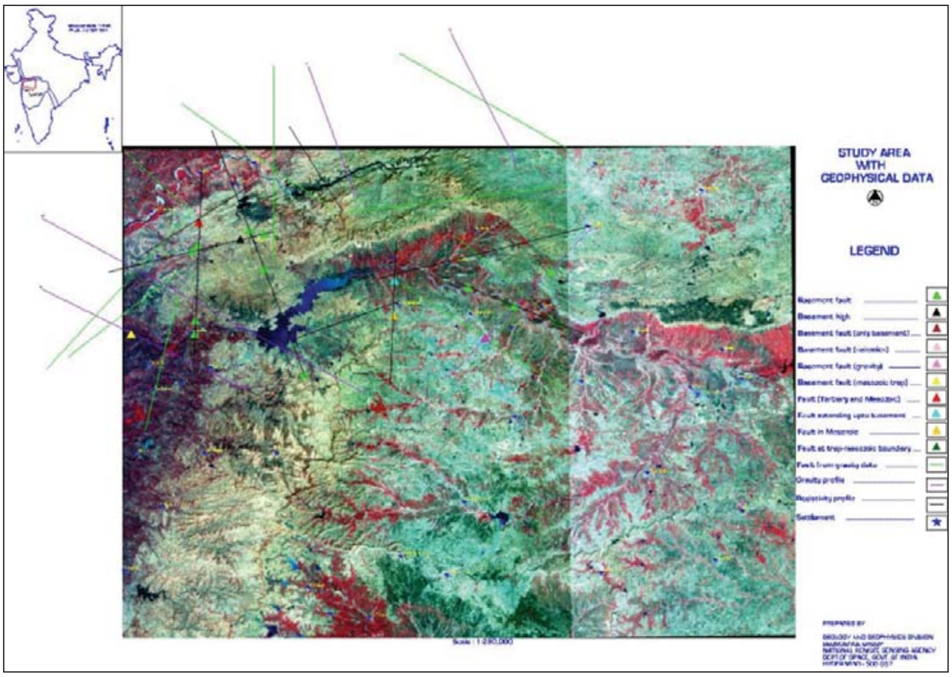

Figure 7.2.3: Geophysical interpreted map of Narmada Tapti Region

Environmental geoscience is a highly interdisciplinary in nature with offshoots extending to almost all scientific disciplines. The application potential of remote sensing techniques for environmental surveillance stem from their unique advantages: a multispectral approach, synoptic overview and repetitive coverage i.e., the possibility of examining objects in different spectral ranges, in the perspective of regional setting and repetitively at certain time intervals. Broadly, various genenvirornmental problems can be related to changes or degradation of land, water, air or vegetation resources. Following geoenvironmental studies can be taken up using remotely sensed data.

- Land-use changes associated with open – cast strip mining

- After-effects of underground mining, such as subsidence etc
- Evolution of dumping grounds
- Spread and dispersion of smoke plumes from industries and power plants
- Discharge of thermal plumes from power plants and industries in rivers and lakes
- Deforestation and erosion in river catchments and sediment load studies
- General warming of the environment in industrial areas
- Discharge from nuclear power plants and associated environmental hazards
- Degradation in quality of vegetation, due to atmospheric pollution in industrial areas and metropolitan cities

In addition, investigations into many other specific problems are also possible.

The presence of an oil film on a water surface leads to a lower emissivity. Although the kinetic temperature for a oil film and the clear water is same, the difference in the emissivity produces a differences in radiant temperature of the order of 1.5 ^{0} C. As most thermal detectors have a temperature sensitivity of the order of 0.1^0 C, this difference between oil slick and surrounding water can easily be measured. Coal fire is one of the major environmental problem specially in the coal field area in countries like China, India, South Africa, USA, Venezuela and other countries. Coal fires burn out valuable energy and also create environmental pollution. Satellite and airborne thermal infra red surveys play an important role in mapping coal fires in timely and cost-effective manner.

7.3.2. National and Global Scenario

The applicability of remote sensing in monitoring the environmental impacts of human activity is immense. Several environmental hazards like coal-fire, subsidence due to mining activity are being monitored from satellite data. Satellite based thermal data from medium resolution thermal channel like ASTER can help in periodic monitoring of coal fires in coalfields on India, China, Africa. Microwave data (ERS data, Radarsat-2) with tandem acquisition can help in determining the subsidence associated with the mining activity. Moreover, in microwave data (ERS data, Envisat ASAR, Radarsat-1&2) are of great use in monitoring natural and artificial oil-slick mapping.

7.3.3. Literature Survey

Remote sensing is an important tool for understanding the dynamics of earth surface processes. Remote sensing technology is an important tool in delineating high temperature earth features such as coal mine fire, surface fire, volcano etc. In the electromagnetic (EM) spectrum the thermal infrared region with the wavelength domain 3-5 µm and 8-12 µm is actually used in remote sensing for delineating high temperature bodies because atmosphere acts almost transparent to the EM spectrum in above mentioned range. With the advent of thermal remote sensing several algorithms have been developed and proved to calculate the emissivity of thermal pixel in domain of thermal remote sensing with an effort to accurately calculate the temperature of thermal pixels. The major applications of thermal remote sensing was confined to delineating coal fires and estimating the spatial extent and temperatures of coal fires. During 1960s, when air borne thermal sensor data and later when satellite borne thermal scanner data became available, remote sensing-based coal fire detection and monitoring became operational (Gangopadhyay *et al.*, 2005). Most of the researchers used broadband thermal channel of Landsat TM/ETM+ to monitor and model the coal fire zones in earlier phase of geological thermal remote sensing (Reddy *et al.*, 1993). In these studies most researchers applied an average emissivity value (0.96) to represent all land cover. At the later stage of research, pixel integrated NDVI value obtained from medium to high resolution space borne sensors like TM/ETM, IRS/LISS, etc. have been found appropriate to derive average emissivity of land surface classes (Chatterjee,2006). It is found that NDVI has empirical relationship between average value of thermal emissivity and normalized difference vegetation index (NDVI) for different surface covers (Van de Griend and Owe,1993). This empirical relationship has been proved from the field measurement of the both the parameter.

Prakash *et al.*,(1995) and Saraf *et al.*,(1995) have contributed to the mapping coal fires and to estimate the depth of coal fires. But the depth modeling of subsurface hot features (such as subsurface coal fires) from satellite remote sensing data is still in infancy since many parameters are required for the depth of subsurface coal fires. Moreover, coarse spatial resolution of thermal satellite data precludes monitoring and mapping coal fires with very small spatial extent and moderate temperatures. In India, Landsat TM and ETM thermal data have been used to delineate the coal fire zones in coalfields in the last decade of twentieth century. The coal fires in Jharia coalfield were studied in detail and efforts also were made to map the subsurface coal fires with little success. Recently, NRSC has produced coal fire map of Jharia (October 2006) and Raniganj coal field (December, 2006) of India with the help of night time ASTER data. Guha (2007) delineated major coal fire zones in the western portion of the Raniganj coalfield and localized along the open cast mines of the coalfield. Vinod Kumar *et al.*,(2006) have evaluated the dynamics of the coal fire in Jharia coalfield . Another important utility of thermal remote sensing is monitoring very high temperature features such as volcano with the help of thermal channel of satellite data. Researchers are using the thermal data for monitoring the volcanic eruptions in different part of the world. Thermal channels of Landsat TM data have been used to monitor the Barren Island Volcanic eruption (Reddy *et al.*, 1993) Moreover, very high temperature phenomenon also can be monitored in visible domain of electromagnetic spectrum. Eruption in Barren Island was delineated using IRS P6 AWiFS sensor images (Vinodkumar *et al.*, 2006).

7.3.4. Case Study

7.3.4.1. Introduction

Coal fire is a serious problem in Indian coal field such as Jharia coal field, where high ranking coals are burning due to this hazard. The combined act of surface and sub-surface fires and subsidence has endangered the environmental stability of Jharia coal field. Coupled with the ecological damage done by open cast mining, this has made parts of Jharia resemble moonscapes with dark rolling hills and deep smoking ravines. Remote sensing data have immense potential in coal fire studies. In the present study, delineation of coal fire, which is a major environmental problem in coal mining areas, is addressed using Landsat-7 ETM+ (60 m resolution) and ASTER (90 m resolution) thermal infrared images to demarcate the coal mine fire areas from non fire areas. For this study, Landsat-7 ETM+ data of 29th March, 2003 and ASTER data of 9th October, 2006 were used. Landsat-7 ETM+ data have the best spatial resolution in thermal band among many of available commercial satellites operating in thermal region. The kinetic temperature was calculated from Landsat ETM+ satellite data using NDVI derived emissivity models whereas band 13 of ASTER nighttime data was used with fixed emissivity value to derive kinetic temperature. The study reflects that eastern part of the Jharia coalfield is most affected by the coalmine fire in comparison to western part. The collieries affected by coalmine fire are Kusunda, Kujama, Bararee, Ena etc. Amongst all the colliery areas, Kusunda area is most affected (29% of total area) by coalmine fire. It also shows significant increase (28%) in fire from 2003 to 2006. The coalmine fire and non-fire areas were further verified on the ground and fire temperature on the ground was measured using the handheld infrared thermometer. The final coal mine fire map of Jharia coalfield was prepared by using density-slicing techniques with the information collected from the ground. The surface features map prepared using IRS-P6 LISS-III data shows the distribution of land use / land cover units such as forest land, built-up area, agricultural land and mining area etc. An estimated 6.9% of the total area in Jharia coal field is occupied by mining related activities, which depicts the vulnerability of the area for environmental degradation.

7.3.4.2. Remote Sensing Data Analysis: Principles of thermal remote sensing

All matter at temperature above absolute zero (0º Kelvin) emits electromagnetic radiation continuously. The temperature of the earth materials and high temperature phenomena can be estimated based on the thermal emission from these materials. Max Planck, using his quantum theory, developed a relation between spectral radiance, wavelength of the emitted radiation and temperature for the blackbody. The Planck's equation for black body is given in equation -1.

$$L_\lambda = \frac{2\pi hc^2}{\lambda^5} * \frac{1}{e^{hc/\lambda \kappa T_{rad}} - 1} \qquad (1)$$

Where

L_λ = Spectral radiance in band-6 ($W/m^2/Sr$) of Landsat-TM
λ = Wavelength (μm) in band-6 of Landsat-TM
T_{rad} = Radiant Temperature (°K)
h = Planck's constant (6.63×10^{-34} joule sec)
c = Speed of light (3.0×10^{8} m/sec)
k = Boltzmann constant (1.38×10^{-23} joules/k)

Equation (1) can be rearranged as follows

$$T_{rad} = \frac{C_2}{\lambda \ln(\in C_1/\pi L_\lambda \lambda^5+1)} \qquad (2)$$

Where,
$C1 = 2\pi hc^2 = 3.742 \times 10^{-16}$ Wm^2
$C2 = hc/k = 0.0144$ mK
$\in$ = Emissivity

In equation - 2, wavelength may be considered as the mean wavelength of the spectral region under investigation. Once the corrected spectral radiance (L_λ) is known for a pixel, it can be substituted to equation – 2 to compute radiant temperature value. The radiant temperature is defined as the equivalent temperature of a black body which would give the same amount of radiation, as obtained from a real body. The radiant temperature (TR) depends on actual temperature of surface element i.e., kinetic temperature (TK), emissivity (ε) and transmissivity of atmosphere (Gupta, 2003). Emissivity (ε) for a blackbody is 1 and for most materials it is less than 1 ranging generally between 0.7 and 0.96. So the kinetic temperature of natural materials is always higher than the radiant temperature.

In the present study, coal fires were mapped on the basis of their temperature from the back ground non fire zone. Coal fires not only occurs due to different causes (man-made, lightning strike, accidental fire, forest fire or spontaneous combustion) worldwide, but also have a along history (Zhang 2004). Coal fires are very high temperature surface elements and emit high thermal flux. Coal fires are very close to black body in terms of their thermal behaviour but emissivity of fire zones are dependant on several factors such as presence of moisture in coal, the total carbon concentration in coal, etc. Coal fires with high thermal flux are restricted in terms of surface extent. Therefore total thermal flux of pixel area of 3600 m^2 (in case of Landsat-7 ETM+) and 8100m^2 (in case of ASTER Data) represent the average thermal flux emanating from both coal fire zones and non coal fire area of given pixel. The emissivity and radiant temperature of a pixel containing fire depends on the entire contributing element within the pixel. If pixel averaged radiant temperature remains quite higher than the pixel containing no fire, then only coal fire zones can be delineated.

7.3.4.3. Methodology

A. Processing of Landsat-7 ETM+ data

Landsat-7 ETM + thermal band (band no. 6). Landsat-7 ETM+ data is acquired in .hdf (hierarchical data format) format and scene specific radiance value is calculated from raw digital values by using by Markham and Barkar equation (Markham and Barkar, 1986).

$$L_\lambda = L_{min\,(\lambda)} + [(L_{max\,(\lambda)} - L_{min\,(\lambda)})/Q_{calmax}] * Q_{cal} \qquad (3)$$

Where

L_λ = spectral radiance,
$L_{min\,(\lambda)}$ = minimum detected spectral radiance for the scene,
$L_{max\,(\lambda)}$ = maximum detected spectral radiance for the scene,
Q_{cal} = Grey level for analysed pixel,
Q_{calmax} = Maximum grey level,

Once the spectral radiance (L_λ) for ETM+ band 6 data is computed, it is possible to calculate radiant temperature directly using equation – 4 provided in the Landsat-7 users' handbook.

$$T_R = K_2 / \ln((K_1 / L_\lambda) + 1) \qquad (4)$$

Where

T_R = Radiant temperature,
K_1 = Calibration constant (1260.56 K),
K_2 = Calibration constant (666.09 watts/(meter squared*ster*µm)),
L_λ = Spectral radiance

Once the radiant temperature is obtained it is possible to calculate kinetic temperature provided emissivity is known using equation - 6.

In the case of single band thermal data, a possible option to extract land surface emissivity could be a classified image, in which an emissivity value for each class is assumed (Gangopadhyay, 2003). The methodology to extract land surface emissivity from NDVI has already been described by many researchers (van de Griend and Owe, 1993). The method of NDVI gives three classes of emissivity.

- NDVI < 0.2 – bare soil
- NDVI > 0.5 - vegetation
- NDVI between 0.2 - 0.5 - comes under the pixel of category of mixed pixel, which contains combination of vegetation, soil and rock etc. An empirical relationship between the average values of thermal emissivity and normalized difference vegetation index (NDVI) for different surface covers was established from the field measurements of both parameters and the relationship is as follows

$$\varepsilon = a + b * \ln(NDVI) \qquad (5)$$

Where, ε and NDVI are average thermal emissivity and average normalized difference vegetation index for individual surface covers respectively, 'a' and 'b' are two constants (a=1.0094 and b= 0.047 for a correlation coefficient of 0.941 at 0.01 level of significance). Satellite-based measurements of NDVI have been found helpful in making close approximation of real estimates of thermal emissivity (van de Griend and Owe, 1993).

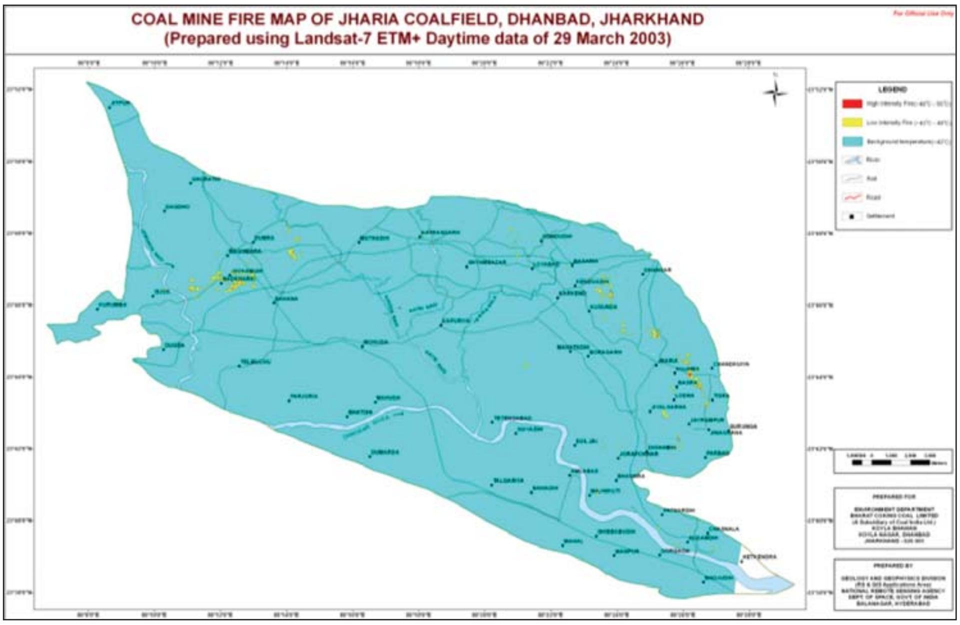

Figure 7.3.1: Coal mine fire map of Jharia coal field, Dhanbad, Jharkhand

Pixel-integrated NDVI values from medium resolution satellite sensors like Landsat-7 ETM+, MSS are appropriate for this purpose owing to their pixel size comparable with respect to thermal data (Chatterjee, 2005). In this work Landsat-7 ETM+ data was used to compute the NDVI.

Once the NDVI is derived, emissivity is calculated using equation - 5. The emissivity was subsequently resampled to the spatial resolution of thermal data i.e., 60 m. Once emissivity is derived, it is used to extract kinetic temperature using following equation.

$$T_K = T_R / \varepsilon^{1/4} \qquad (6)$$

The kinetic temperature computed from the satellite data by using above mentioned procedure was further classified into three classes as given in Table 7.3.1 to prepare the coal mine fire map of the Jharia Coal field (Figure 7.3.1).

Table 7.3.1: Temperature class used in the preparation of coal mine fire map from Landsat-7 ETM+ data

Sl No.	Temperature Class	Remark
1	< 43º C	Background temperature
2	43º C - 49º C	Low intensity coal mine fire
3	> 49º C - 55º C	High intensity coal mine fire

All the data are processed by using standard image processing softwares such as ERDAS 9.1 and ENVI 4.2 to generate the requisite outputs

B. Some vital aspects and limitations in calculation of fire temperature from landsat-7 ETM+ data

- Landsat-7 ETM+ Data is the best in thermal bands in terms of spatial resolution but by 31st May, 2003 a problem encountered in the sensor. So, ETM+ data was not available for mapping the latest coal fires
- Here NDVI approach was used to derive the emissivity of surface features in the study area. The role of topography for controlling the emissivity of surface features was subdued in present terrain, as the terrain is almost flat with some occasional monadnocks / undulation present sporadically in the area. Therefore, the assumption of deriving emissivity from NDVI values (van de Griend and Owe, 1993) holds good to get the kinetic temperature of surface pixel
- Atmosphere also plays a role in attenuating or enhancing the thermal wave emanating from surface. During daytime, upwelling thermal wave from the hot atmospheric layer also changes the kinetic temperature of the pixel. Path radiance of thermal wave is very less but has some effect, which also reduces the amount of thermal flux that reaches the sensor. The disturbance and movement at the upper part of atmosphere also play a dampening role in subduing the temperature of a pixel manifesting the coal fire
- From satellite-based study, kinetic temperature of a pixel, which could be a mixed pixel containing features from background earth surface as well as coal fire is measured. Coal fire generates very high temperature but it is sometimes spatially restricted to a smaller area (one third to one fourth pixel or even less) and the background subdues the fire temperature when temperature is measured for a pixel (60 m x 60 m) instead of smaller active coal fire area
- Thermal data for 6th channel is recorded in two gain setting e.g., low gain and high gain. For thermal band data, both low and high gain data are available by default in Landsat-7 ETM+ data. The low gain setting measures a greater radiance range but with decreased sensor sensitivity, while high gain measures a lesser radiance range but with increased sensitivity. Coal fire is a high temperature phenomenon, which gets subdued by adjacent background when pixel containing coal fire is measured for kinetic temperature. Low gain setting measures high radiances for coal fire and therefore it help to separate the pixel containing the coal fire from the adjacent pixel and makes coal fire demarcation better. The entire image processing methodology for extracting the coal fire for Landsat-7 ETM+ data is given below in the figure 7.3.2.

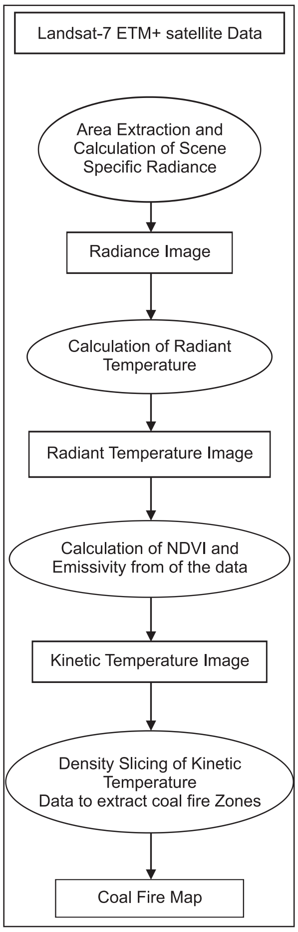

Figure 7.3.2: Steps for calculating Kinetic temperature from Landsat ETM data

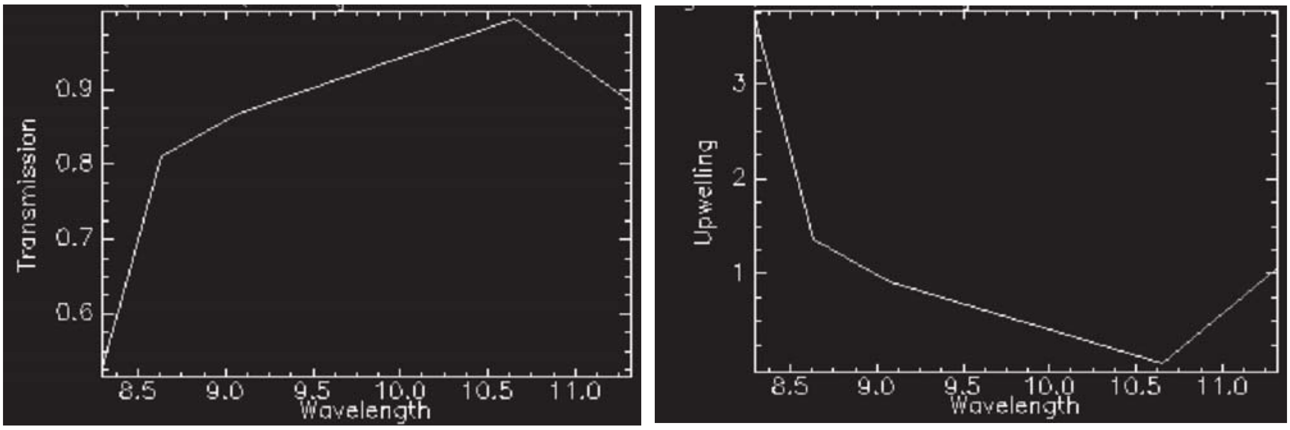

Figure 7.3.3 & 4: Transmission profile, welling Profile in ASTER thermal channel

C. Processing of ASTER data

In the present study, Multispectral Advanced Thermal Emission and Reflection Radiometer (ASTER) night time data dated 9th October, 2006 was acquired for coal fire mapping. ASTER provides five thermal channels in the thermal region within 8.125 -11.65 µm wavelength domain. Multi channel ASTER data is very useful to derive emissivity by using temperature emissivity algorithm and thereby allows to see the thermal anomaly within the range of entire thermal domain of ASTER. However, band 13 (10.25-10.95 µm) is considered here to delineate the coal mine fire zones as transmission of thermal wave is highest in this channel and upwelling (generated by the additive radiance of atmosphere) appear lowest in this particular thermal channel (Figures 7.3.3 & 4). Emissivity varies within the short range between 0.93 and 0.96 in this channel and therefore for present study, emissivity is assumed constant (0.96) to calculate the surface kinetic temperature from the radiant temperature. The emissivity of NDVI was not calculated from night time data since there was no channel in visible wavelength region for night time data.

Thermally emitted radiance from any surface depends on two major factors.

Table 7.3.2: Temperature class used in the preparation of coal mine fire map from ASTER data

Sl No.	Temperature Class	Remark
1	< 29^o C	Background temperature
2	29^o C – 32^o C	Coal mine fire
3	> 32^o C – 34^o C	
4	> 34^o C – 37^o C	
5	> 37^o C – 40^o C	

- Surface temperature, which is the expression of state of heat energy budget on the surface and also indicate the equilibrium thermodynamic state of incident and emitted thermal energy fluxes and
- The surface emissivity, which determines the efficiency of surface for transmitting the radiant energy (Schmugge, 2002)

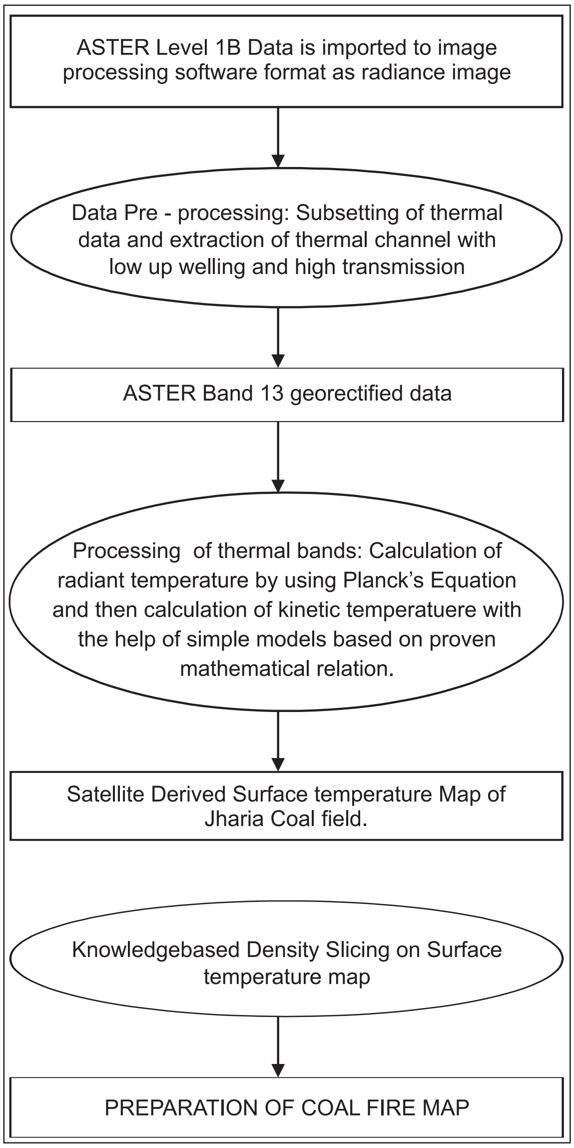

Figure 7.3.5: Steps for calculating Kinetic temperature (Coal fire map) from ASTER Data

Nighttime data provides better equilibrium state of surface heat energy budget as it has negligible solar flux contribution. Therefore nighttime band 13 data appears as the best available combination to derive the coal fire map for Jharia coalfield.

ASTER data was received as geocoded level 1B format from ERSDAC, Japan. This data was imported in ERDAS 9.1 software after converting in radiance by using facility module available for radiance conversion while importing. The georectified radiance data for 13^{th} thermal channel was then used in a model for calculating the radiant temperature from the radiance values using equation – 2. After deriving the radiant temperature image from the radiance image, kinetic temperature image was derived by simple model created in ERDAS platform implementing equation – 6. Procedure for calculating Kinetic Temperature from ASTER data is shown in figure 7.3.5.

Emissivity is assumed to be 0.96 in the thermal domain of 10.25-10.95 µm. Density slicing technique was used on the kinetic temperature image to differentiate the fire pixels from the background. The kinetic temperature computed from the satellite data by using above mentioned procedure was further grouped into five classes (Table 7.3.2) to prepare the coal mine fire map of the Jharia Coal field (Figure 7.3.6). Isothermal map is also prepared from kinetic temperature image using same methodology applied to Landsat – 7 ETM+ data (Figure 7.3.1).

D. Some vital aspects and limitations in calculation of fire temperature from aster night time data

- Determination of threshold temperature to delineate the fire from non-fire area is an important aspect of present study and appears critical. The satellite derived temperature of fire pixel is less as compared to

ETM+ data and hence, the threshold is fixed 29º C. The method of selection of the threshold temperature is fully based on knowledge-based iterative technique, which keeps on separating the non-fire zone where probability of fire is nil. In this case field information is very useful in iteratively isolating the fire pixel from non-fire pixel

- Satellite-derived temperature for fire pixel depends on the temperature of fire zone and the back ground. It is also influenced by the proportion of area of fire pixel occupied by the background
- Temperature of fire pixel derived from satellite data is dependant on the density of cracks emanating fire and the fire temperature. Increment in any of the variables increases the temperature of the fire pixel
- Nighttime data in the month of October keeps background temperature reasonably lower and the temperature of pixel containing fire does not seem to increase too much. Field study revealed that there are very few pixels where density of cracks with high fire temperature was present and back ground reasonably had a lower temperature. The month of September – October in 2006 received good rain in the area and this also reduced the temperature of fire cracks. These parameters contribute to the reduction in the satellite-derived temperature of a fire pixel

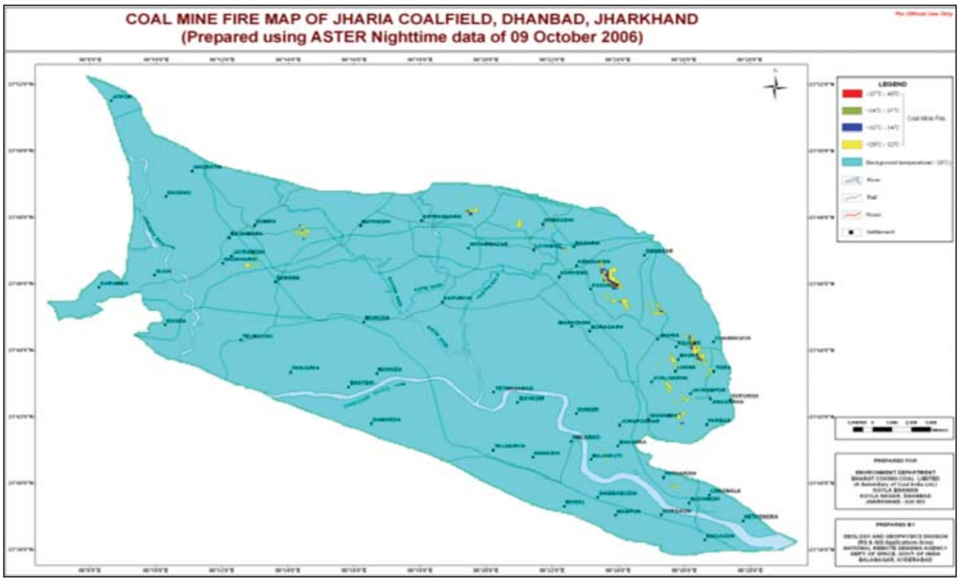

Figure 7.3.6: Coal mine fire map of Jharia coal field, Dhanbad, Jharkhand (prepared using ASTER Night time data of 09 October, 2006)

7.3.4.4. Results

The study was aimed at providing the status of coal fire in the Jharia coalfield in the period of 2003 and 2006. Landsat-7 ETM+ daytime data of 29th March 2003 was used to derive the coal mine fire map for the year 2003 (Figure 7.3.2). Similarly ASTER nighttime data of 9th October 2006 was used to prepare the coalmine fire map (Figure 7.3.6) for the year 2006. These data were used to prepare the coal fire maps on 1:50,000 scale. These two datasets are 60 m and 90 m spatial resolution in the thermal bands, respectively and they are the best thermal satellite data available on respective dates. The highest temperature computed for the year 2003 by Landsat-7 ETM+ is 55^0 C and for the year 2006 by ASTER is 40^0 C. The difference in the highest temperature is due to the time of satellite observation i.e., Daytime (March) for ETM+ and Nighttime (October) for ASTER and also for the difference in the spatial and spectral resolution between the two satellites. Coal fire map produced in different year depicts the pattern of dynamics of coal fire.

7.4. Geoengineering Studies

7.4.1. Introduction

Modern geology has been multi-disciplinary in nature since its origins more than 200 years ago. Multi-spectral remote sensing and Geographical Information Systems (GIS) together offer a new geological tool for different geological applications. Engineering geology is one of such disciplines where remote sensing has contributed significantly. Engineering geology is the application of the geologic sciences to engineering practice for the purpose of assuring that the geologic factors affecting the location, design, construction, operation and maintenance of engineering works are recognized and adequately addressed. Engineering geologists investigate and provide geologic and geotechnical recommendations, analysis, and design. Engineering geologic studies may be performed during the planning, environmental impact analysis, civil engineering design, value engineering and construction phases of public and private works projects, and during post-construction and forensic phases of projects.

Works completed by engineering geologists include; geologic hazards, geotechnical, material properties, landslide and slope stability, erosion, flooding, dewatering, and seismic investigations, etc.

Engineering geologic studies are performed by a geologist or engineering geologist educated, professionally trained and skilled at the recognition and analysis of geologic hazards and adverse geologic conditions. The overall objective of the study is the protection of life and property against damage and the solution of geologic problems. Analysis and interpretation of multi-spectral remote sensing data helps in delineating lithology, geological structures of a terrain .This information along with the information on topography, land use when integrated in GIS platform helps in identifying suitable area for dam or tunnel or any crucial engineering structure and also help in analyzing the feasibility of developing engineering structures in already identified area. High resolution stereo pair satellite data helps in generating DEM (digital elevation model) of higher accuracy for rugged terrain with the help of only few field-based point height collected by differential global positioning surveys (DGPS). These models are very useful to assess the stability of a engineering structure and also would help to simulate the effect of engineering structure such as dam over a terrain. The geological informations collected from satellite data also helps in modeling the impact of any large-scale engineering structure to surrounding natural resources.

7.4.2. National and Global Scenario

The advent of sensor technology especially high-resolution mono/stereo pair satellite data (such as Cartosat-1, Cartosat-2, Ikonos, etc.,) helps in mapping geological structures in details. Geological structure plays important role in governing the stability, environmental suitability of a large engineering structure. Moreover, stereo pair satellite data helps in constructing very accurate digital elevation model (DEM); which is important input information for finalizing the place for Dam or tunnel or similar engineering structure. Moreover, high-resolution operational multispectral satellite (ASTER, IRS P6-LISS-IV) help in lithological mapping more accurately helps that accurate identification of sites.

7.4.3. Cost- Benefit Analysis

Remote sensing based mapping of lithology, geological structure and topography reduces the time and cost for feasibility analysis for developing engineering structure in a particular area. Moreover, remote sensing based monitoring of engineering structure after its construction helps in understanding the impact of engineering structure.

7.4.4. Methodology

Building a hydropower station or stations in a rugged terrain such as in the Himalayas requires thorough understanding of geological lithologies, water drainage patterns, surface and subsurface structures. If hydropower is to be generated from dam water then selecting suitable dam sites requires careful consideration of environmental impacts. Image processing technology can play a vital role in the studies of the categories mentioned. Detailed field studies can be followed, once image processing accomplishes the initial stage of the studies. Processing of satellite data and its interpretation helps in identifying information on following themes; which are essential for feasibility analysis of any large engineering structure or monitoring the environmental impact of large-scale engineering structures.

In any geoengineering studies, the role of satellite data is reconniasnce mapping. Data like IRS/ASTER/LANDSAT ETM for liuthological contacts and classifying rocks as per rock mass strength. Following are the broad steps.

- Updation of existing geological map
- Preparation of structural map especially faults, lineaments, fractures, drainage etc for understanding the rock strength and vulnerability to tectonic forces
- Integrating all the above layers with field information for site suitability analysis
- Validation and report generation

Geomorphology map preparation using satellite data to understand ruggedness of terrain, weathering, landslides and any other terrain related information.

7.4.5. Summary

Remote sensing technology is a boon for suitability analysis studies for large engineering structures for its effectiveness in cost and time. Feasibility analysis projects for developing engineering structures are often time bound and the structures are made over rugged terrain. Therefore remote sensing has a bigger role in generate geological information required for site suitability analysis and impact analysis of such large engineering structure such as dam, tunnel, national highways within a fixed time period. Moreover, remote sensing also gives information on resource availability required for such large structures. For example, information on near source of exposures building material such as gneiss, quartzite, etc., helps in identifying the nearest resources for availing the raw materials for such projects.

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Glossary:

Alluvial fan: A low, outspread, relatively flat to gently sloping mass of loose rock material; shaped like an open fan or a segment of a cone, deposited by a stream (esp. in a semiarid region) at the place where it issues from a narrow mountain valley upon a plain or broad valley, or where a tributary stream is near or at its junction with the main stream, or wherever a constriction in a valley abruptly ceases or the gradient of the stream suddenly decreases.

Alluvial plain: A level or gently sloping tract or a slightly undulating land surface produced by extensive deposition of alluvium, usually adjacent to a river that periodically overflows its banks; it may be situated on a flood plain, a delta, or alluvial fan.

Alluvial terrace: A stream terrace composed of unconsolidated alluvium (including gravel), produced by renewed down cutting of the flood plain or the valley floor by a rejuvenated stream, or by the later covering of a terrace with alluvium.

Anticline: A fold, the core of which contains the stratigraphically older rocks.

Antiform / Anticline: A breached/unbreached uplift, where the structure is shown directly in the topography and perhaps by drainage pattern. In case of the presence of older rock in the core of the uplift the antiform is called as anticline.

Arete: The knife edge caused by the intersection of two adjacent cirque walls or indeed at sharp mountain ridge.

Avalanche Chute / Track: These are distinct channels in bedrock formed due to repeated debris avalanches.

Bajada: A broad, continuous alluvial slope or gently inclined detrital surface extending along and from the base of a mountain range out into and around an inland basin, formed by the lateral coalescence of a series of separate but confluent alluvial fans, and having an undulating character due to the convexities of the component fans; it occurs most commonly in semiarid and desert regions.

Barchan: A moving, isolated crescent shaped sand dune lying transverse to the direction of the prevailing wind, with a gently sloping convex side facing the wind so that the wings or horns of the crescent point downward (leeward) and an abrupt or steeply sloping concave or leeward side inside the horns.

Barrier beach: A single, narrow, elongate sand ridge slightly above the high-tide level and extending generally parallel with the shore, but separated from it by a lagoon or marsh; it is extended by long shore drifting and is rarely more than several kilometres long.

Barrier island: A detached portion of a barrier beach between two inlets.

Basin: A general term for a depressed, sediment filled area. It may be an elongate, fault-bordered intermontane basin within an orogenic belt.

Beach: A gently sloping zone, typically with a concave profile, of unconsolidated material that extends landward from the low-water line to the place where there is a definite change in material or physiographic form (such as a cliff) or to the line of permanent vegetation (usually of the effective limit of the highest storm waves).

Beach ridge: A low, essentially continuous mound of beach or beach and dune material (sand, gravel, shingle) heaped up by the action of waves and currents on the backshore of a beach beyond the present limit of storm waves or the reach of ordinary tides, and occurring singly or as one of a series of approximately parallel deposits. The ridges are roughly parallel to the shoreline and represent successive positions of an advancing shoreline.

Bornhardt: A residual peak having the characteristics of an inselberg; specifically a large granite-gneiss inselberg associated with the second cycle of erosion in a rejuvenated desert region.

Braided stream: A stream that divides into or follows an interlacing or tangled network of several, small, branching and reuniting shallow channels separated from each other by branch islands or channel bars, resembling in plan the strands of a complex braid. Such a system is generally believed to indicate the inability to carry its entire load such as an overloaded and aggrading stream flowing in a wide channel on a flood plain. Syn: an anastomosing stream.

Buried / Palaeo Channel: Deep valleys cut in the bedrock terrain and today filled largely with alluvium, glacial otwash gravels and sands or with tills. These are good source for underground water.

Butte: A conspicuous, usually isolated generally flat-topped hill or small mountain with relatively steep slopes or precipitous cliffs, often capped with a resistant layer of rock and bordered by talus, and representing an erosion remnant carved from flat-lying rocks; the summit is smaller in extent than that of a mesa.

Channel bar: An elongate deposit of sand and gravel located in the course of a stream, especially of a braided stream.

Cirque: A deep, steep walled, flat or gently floored half bowl like recess or hollow, variously described as horseshoe or crescent shaped or semicircular in plan, situated high on the side of a mountain and commonly at the head of a glacial valley and produced by the erosive activity (frost action, nivation or ice plucking) of mountain glaciers. It often contains a small round lake, and it may or may not be occupied by ice or snow.

Coastal plain: A low, generally broad but sometimes narrow plain that has its margin on the shore of a large body of water (esp. the ocean) and its strata either horizontal or very gently sloping toward the water, and that generally represents a strip of recently emerged sea floor or continental shelf.

Colluvial fan: If the fan material consists of accumulation of heterogeneous material of ant particle size which accumulates on the lower part of the base of slopes. The material is mostly transported by gravity.

Complex dune: A dune formed by multidirectional winds resulting in the intersection of two or more dunes.

Crater: Any geological process that involves the effusion of materials from beneath the earth's surface via some sort of vertical pipe or vent usually develops a cone, collar or ring of deposits around the exit. This opening to the vent is the crater.

Cuesta: A hill or ridge with a gentle slope on one side and a steep slope on the other; specifically and asymmetric ridge with one face (dip slope) long and gentle and conforming with the dip of the resistant bed or beds that form it, and the opposite face (scarp slope) steep or even cliff-like and formed by the out crop of the resistant rocks, the formation of the ridge being controlled by the differential erosion of the gently inclined strata.

Deflation Plain: The planar surface in the desert exposed due to the removal of solid particles by wind action.

Delta: The low, nearly flat, alluvial tract of land deposited at or near the mouth of a river, commonly forming a triangular or fanshaped plain of considerable area enclosed and crossed by many distributaries of the main river, perhaps extending beyond the general trend of the coast, and resulting from the accumulation in a wider body of water (usually a sea or lake) of sediment supplied by a river in such quantities that it is not removed by tides, waves and currents.

Delta plain: The level or nearly level surface comprising the landward part of a large delta; strictly and alluvial plain characterized by repeated channel bifurcation and divergence, multiple distributary channels, and interdistributary flood basins.

Desert Pavement : It is a surface feature that may develop on the desert flat, on fans and bajadas and consist of rounded or sub-rounded angular pebbles. These are developed by the removal of fine sediments with resulting concentration of pebbles.

Dike: A tabular igneous intrusion that cuts across the planar structures of the surrounding rock. Also spelled as dyke.

Dissected Dune Complex : It is basically a dune complex which are dissected.

Dolines: Any basin or closed depression in a karst affected limesrone, of larger dimensions than a sinkhole, often enlarged by the collapse of caverns. The shape may vary from round to oval to elongate. Its floor is generally flat, often partly filled with alluvium.

Dome: A general term for any dome shaped landform or rock mass, such as a smoothly rounded rock-capped mountain summit, roughly resembling the dome of a building.

Dune: A low mound, ridge, bank, or hill of loose, wind blown granular material (generally sand, sometimes volcanic ash), either bare or covered with vegetation, capable of movement from place to place but always retaining its own characteristic shape.

Dune Complex: Two or more dune complex combined to form a large dune or dune field or a distinct group pattern.

Esker: An Esker is a sinuous low ridge composed of sand and gravel which formed by deposition from melt waters running through a channel way beneath glacial ice. Eskers vary in height from several feet to over 100 feet and vary in length from hundreds of feet up to many miles. The course of many eskers is similar to that of a stream. The cross lamination in eskers indicated downward flow.

Flood plain: The surface or strip of relatively smooth land adjacent to a river channel constructed (or in the process of being constructed) by the present river in its existing regimen and covered with water when the river overflows its banks at times of high water. It is built of alluvium carried by the river during floods and deposited in the sluggish water beyond the influence of the swiftest current.

Glacial valley: A 'U' shaped, steep sided valley showing signs of glacial erosion; a glacial valley, or one that has been modified by a glacier.

Glacial Stairway / Crevasse: Glaciers, ice shelves, snow fields and sea ice are subjected to stresses which are relieved by fissures and cracks called crevasses. In cross section crevasses are V shaped and often bridged by snow which makes them difficult to see on the surface.

Hanging valley (glacial): A glacial valley whose mouth is at a relatively high level on the steep side of a larger glacial valley. The larger valley was eroded by a trunk glacier and the smaller one by a tributary glacier and the discordance of level of their floors, as well as their difference in size is due to the greater erosive power of the trunk glacier.

Hanging valley (streams): A tributary valley whose floor at the lower end is notably higher than the floor of the main valley in the area of junction, produced where the more rapid depending of the main valley results in the creation of a cliff or steep slope over which a water fall may develop.

Highly Dissected Structural Hills and Valleys: Hills and valleys which are originated due to tectonic process and are highly dissected by the drainage lines. Here the drainage density is very high.

Hogback: It is a long narrow ridge or series of hills, structurally controlled by the presence of homoclinal sedimentary strata that dip steeply (over 50^0). Hogbacks develop best in sediments that are in hard and soft layers of marked contrast. Because of their steep dips, hogbacks remain more or less fixed in the landscape, and do not retreat as will a cuesta.

Homocline: Uniform regional tilting of the strata in the Physiography. The expression is a function, among other things, of the amount of tilt which is considered to be recorded in the dip of the rocks.

Horn: When more than two adjacent cirque walls intersect at a common point, it results in a sharp mountain peak called as horn.

Inselberg A prominent, isolated, steep-sided, usually smoothed and rounded, residual knob, hill or small mountain of circumdenudation rising abruptly form and surrounded by an extensive and nearly level, lowland erosion surface in a hot, dry region (as in the deserts of southern Africa or Arabia), generally bare and rocky although partly buried by the debris derived from and overlapping its slopes; it is characteristic of an arid or semiarid landscape in a late stage of the erosion cycle.

Interdunal Depression: The depression between the two consecutive dunes.

Intermontane Valley: The valley between the mountains.

Island: A tract of land, smaller than a continent, completely surrounded by water, under normal condition, in an ocean, sea, lake, or stream. An elevated piece of land surrounded by a swamp, marsh, or alluvial land, or isolated at high water or during floods.

Kame Terrace: Kames are mounds of poorly sorted sand and gravel deposited from running water in close association stagnant glacial ice. A kame terrace forms as an ice contact deposit when waters flowing from a glacier find a course between the ice mass and a valley wall. The character of the sediments within a kame terrace is intermediate in complexity between that of an esker and that of a kame.

Lake: Lakes formed by glacial action i.e., cirque lake formed at about snow line in glaciated valleys, lakes by glacial deposits.

Lapies: It refers to a rill like erosional form of lime stone solution in the karst landscape.

Lateral Moraine: This is debris shoved together or melted out from the advancing glacier along its sides.

Lava flow: The lava coming out from the vent during active volcanism and flowing down the flank of volcano.

Levee / Natural levee: An artificial embankment, usually of random earth fill, built along the bank of a watercourse or an arm of the sea and designed to protect land from inundation or to confine stream flow to its channel.

Loess: It is largely homogeneous, unstratified silt. It is usually permeable, porous, unconsolidated sediment apt to form vertical cliffs or bluffs. It is commonly yellow or buff in colour owing to its content of finely dispersed limonite, though sometimes it is grey.

Longitudinal dune: A long, narrow, usually symmetrical (in profile) sand dune oriented parallel with the direction of the prevailing wind responsible for its construction, being wider and steeper on the wind ward side but tapering to a point on the leeward side, and commonly forming behind obstacles in an area where sand is abundant and the wind is strong and constant.

Meander: One of a series of some what regular, sharp, freely developing, and sinuous curves, bends, loops, turns, or windings in the course of a stream.

Meander scar: A crescentic, concave mark on the face of a bluff or valley wall, produced by the lateral planation of a meandering stream which undercut the lateral planation of a meandering stream which undercut the bluff, and indicating the abandoned root of the stream. An abandoned meander often filled in by deposition and vegetation, but still discernible (esp. from the air).

Meander scroll: One of a series of long, closely fitting, arcuate ridges and troughs formed along the inner bank of a stream meander as the channel migrated laterally down-valley and toward the outer bank.

Medial Moraine: It lies between two ice streams and is formed upon intersection of two lateral moraines.

Mesa: An isolated nearly level land mass standing distinctly above the surrounding country bounded by abrupt or steeply sloping erosion scarps on all sided, and capped by layers of resistant, nearly horizontal rocks (usually lavas). Less strictly, a very broad, flat-topped, usually isolated hill or mountain of moderate height bounded on at least one side by a steep cliff or slope and representing an erosion remnant.

Monocline: A unit of strata that dips or flexes form the horizontal in one direction only, and is not part of an anticline or syncline. It is generally a large feature of gentle dip.

Monadnocks: A monadnock is an isolated mountain representing an erosional residual (peak or knob).

Nunatak: An isolated hill, knob, ridge, or peak of bedrock that projects prominently above the surface of a glacier and is completely surrounded by glacier ice.

Outwash Plain: These are proglacial landforms that are built by streams extending beyond an ice front. Outwash plains are produced by merging of a series of outwash fans.

Oxbow lake: The crescent-shaped, often ephemeral, body of standing water situated by the side of a stream in the abandoned channel (oxbow) of a meander after the stream formed a neck cutoff and the ends of the original bend were silted up.

Parabolic dune: A sand dune with a long, scoop-shaped form, convexly bend in the downwind direction so that its horns point upwind (windward), and whose ground plan (when perfectly developed) approximates the form of a parabola. It is characteristically covered with sparse vegetation and is often found along the coast where strong onshore winds are supplied with abundant sand.

Pediment: A broad, flat or gently sloping, rock floored erosion surface or plain of low relief, typically developed by sub aerial agents (including running water) in an arid or semiarid region at the base of an abrupt and receeding mountain front or plateau escarpment, and underlain by bedrock (occasionally by older alluvial deposits) that may be bare but more often partly mantled with a and discontinuous veneer of alluvium derived form the upland masses and in transit across the surface.

Pediment-Inselberg Complex: The pediments dotted by numerous inselbergs of small size, which makes it difficult to distinguish from the pediments. Hence it is called as a complex of pediment and inselbergs.

Pediplain: An extensive, multiconcave, thinly alluviate rockcut erosion surface formed in a desert region by the coalescence of two or more adjacent pediments and occasional desert domes, and representing the end result (the "peneplain") of the mature stage of the arid erosion cycle.

Piedmont slope: A small, low cliff occurring in alluvium on a piedmont slope at the foot of, and essentially parallel, to, a steep mountain range, resulting from dislocation of the surface, esp. by faulting.

Plateau: Broadly, any comparatively flat area of great extent and elevation specif. and extensive land region considerably elevated (more than 150-300m in altitude) above the adjacent country or above sea level and commonly limited on at least one side by and abrupt descent, having a flat or nearly smooth surface but often dissected by deep valleys or canyons and surmounted by ranges of high hills or mountains, and having a large part of its total surface at or near the summit level. A plateau is usually higher and has more noticeable relief than a plain (it often represents an elevated plain). And is usually higher and more extensive that a mesa; it may be tectonic, residual, or volcanic in origin.

Plateau Top: It is the flat or relatively flat portion of the Plateau on the topmost part.

Playa : It is essentially the dray lake remnant of a former base level of erosion which may be presently active. The name playa can be loosely applied to a dry lake filled periodically with a sheet of water regardless of whether or not the playa depression is a sedimentary/volcanic basin or a basement rock surface partially covered by a thin sheet of clastic sediments.

Point bar: One of a series of low, arcuate ridges of sand and gravel developed on the inside of a growing meander by the slow addition of sediments.

Residual Hill: A small remnant hill which has witnessed all forms of denudation.

Rift Valley: Valleys of subsidence with long steep parallel walls. The valley consists of a graben in the middle and horsts on both the sides. These are formed in regions of extension tectonics e.g., in East Africa.

Ridge: A long narrow naturally elevated topography. This created either by structural processes or due to the exposure of hard rock to erosion activities.

Sand dune: A dune consisting of loose sand piled or heaped up by the wind, commonly found along the low-lying seashores above high-tide level, more rarely on the border of a large lake or river valley, as well as in various desert regions and generally where there is abundant, dry surface sand during some part of the year.

Sand Sheet: Thin layer of sand spread over a horizon.

Scarp: Also known as escarpment is defined as a cliff or steep rock face of great length. The development of a scarp could be due to structural or erosional processes.

Scree: A heap of broken angular rock fragments greater than 10cm in diameter on the slope of a hill.

Seif Dune: Longitudinal dunes are also known as seif dunes.

Shield Volcano: These are very flat cones of moderate size with summit craters usually so small as not to interfere appreciably with conical shape.

Sinkhole: A general term for a closed depression in an area of karst topography that is formed either by solution of the surfacial limestone or by collapse of underlying caves.

Spit: A small point or low tongue or narrow embankment of land commonly consisting of sand or gravel deposited by longshore drifting and having one end attached to the mainland and the other terminating in open water usually the sea; a finger-like extension of the beach.

Star Dune : A dune with the shape of a star is called as star dune.

Strath Terrace: The terraces developed in wide flat floored valley because of the continuous deep cutting of the stream or crustal upliftment.

Strato Volcano: Symmetrical volcanic cone mountains with alternate layers of mixed ash and lava flows.

Structural origin: The landforms which are originated due to the structural/tectonic movements. The influence of geologic structures on the development and appearance of landscapes is prominent. The influence of geologic structures ranges from large features which exert a dominant influence on the form of an entire landscape, to small features which affect an individual landform and the geomorphic processes operating on it. The structural control could be active structures whose form is directly impressed on the modern landscape or ancient structural features whose influence on a modern landscape is due primarily to differential erosion.

Synform / Syncline: A breached/unbreached depression, where the structure is shown directly in the topography and perhaps by drainage pattern. In case of the presence of younger rock in the core of the depression the synform is called as syncline.

Talus cone: A small, cone shaped or apron like landform at the base of a cliff and consisting of poorly sorted talus that has accumulated episodically by mass-wasting.

Terminal moraine: An end moraine, extending across a glacial valley as an arcuate or crescentic ridge that marks the farthest advance or maximum extent of a glacier; the outermost end moraine of a glacier. It is formed at or near a more or less stationary edge, or at a place marking the cessation of an important glacial advance.

Tidal flat: An extensive, nearly horizontal, marshy or barren tract of land that is alternately covered and uncovered by the rise and fall of the tide, and consisting of unconsolidated sediment (mostly mud and sand). It may form the top surface of a deltaic deposit.

Till: It is glacial debris ranging from clay to large block size and of heterogeneous origin. By diagenesis or metamorphism tillites are formed from this.

Tor: A bare rock mass surmounted and surrounded by blocks and boulders. They display marked structural control and are delineated by joint planes, which are commonly near vertical and quasi horizontal.

Transverse Dune : Dunes that are developed across the direction of the wind.

Uvala: The uvala comprises a series of joined or coalescent dolines, often elongate and marking a former subterranean stream channel or series of collapsed sinkhole.

Valley: It is typically a low lying area of land surrounded by higher areas such as mountains or hills.

Valley fill: The unconsolidated sediment deposited by any agent so as to fill or partly fill a valley.

Volcanic cone: The cone shape mountain created due to volcanic eruption surrounding the vent. It has relatively homogeneous strata showing radial drainage pattern.

Wadies: Small tributaries.