Pakistan Journal of Hydrocarbon Research
Vol.13, (June 2003), p.1-10, 5 Figs., 2 Table

Status and Prospects of Remote Sensing Data to Petroleum Exploration in Pakistan

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ABSTRACT

Remote sensing is a rapidly emerging geological data-supporting tool, which supplements conventional geophysical and geochemical methods in petroleum exploration. Pakistan where a large part of land is un-explored and outcrops are broad and mostly with less vegetation, offers good opportunity for application of remote sensing. It enables one to direct efforts to identify new leads and to support assessment of hydrocarbon potential. It is, therefore, imperative to enhance the application of modern satellite data into petroleum exploration in the country.

INTRODUCTION

Major part of our country on-shore un-explored due to a number of reasons like lack of infrastructure, poor geological database, and in-accessibility etc. Nevertheless, favorable geological settings, distally located unexplored basins of Pakistan and constant improvement in imaging technology, are the factors which improve the decisive role of remote sensing. Remote Sensing has a broad sphere of activities in diversified fields like forestry, soil survey, agriculture, hydrogeology, engineering, geologic mapping, geo-environmental sciences and petroleum exploration.

This paper is based on the review of the published literature. It focuses to define repeatedly used terms of remote sensing, its attributes, and its application in identification of structures favorable for hydrocarbon exploration. The scope, status and prospects of remote sensing in Pakistan is discussed and measures have been envisaged for its application into petroleum exploration within the country.

ATTRIBUTES OF REMOTE SENSING SYSTEM

Remote sensing usually is defined a science and art of acquiring information about an object without physical contact. Important attributes of remote sensing are given in figure 1. The first attribute is an environment through which the electromagnetic radiation interacts. From the remote sensing point of view for geological purposes the land cover area of the earth is taken as environment.

Another attribute is sensor system. A sensor is an electrical device, measures the amount of electromagnetic energy reflected from the surface to the instrument in a particular frequency range. A sensor carried by a platform operates on the environment and produces data. These data are to be transferred into information by a variety of operations, collectively called reduction and analysis. The information extracted from the data finally is applied for different purposes, depending upon the user's requirements (Meer, 1990). The system is thus a discipline oriented and the user may extract information of his interest from the same data.

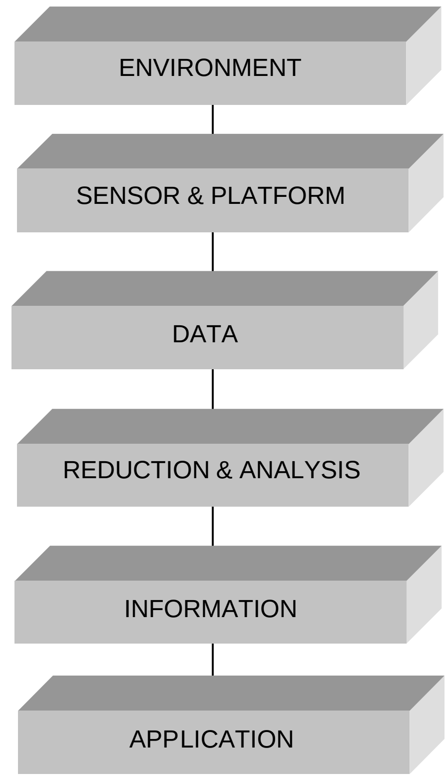

Figure 1- System overview of remote sensing methods (after Meer, 1990).

The platform may be an object, structure, vehicle or any base upon which a remote sensing system is mounted. Generally it may be (1) a ground, (2) Airborne, or (3) Space borne.

Sensor system works as (1) Active system or (2) Passive system.

Active system sends and receives back its own energy and does not need sun energy. This special wavelength is capable of penetrating rain, cloud, and haze, to provide a continually clear view of the earth. Thus it is all weathered system. (Example RADAR)

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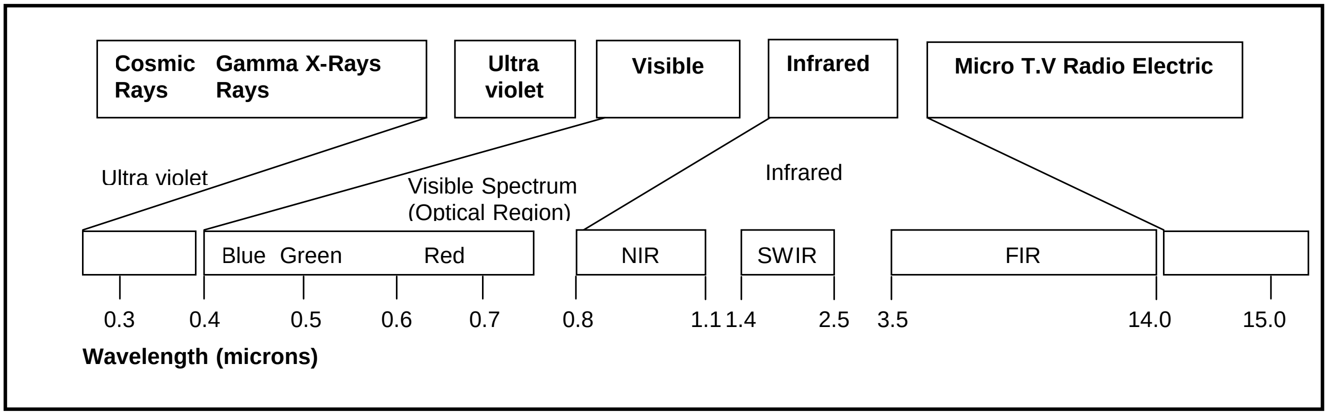


Figure 2- Electromagnetic spectrum.

A Passive system uses energy from external sources, such as the sun's energy. Since data is collected at frequencies roughly equivalent to the human eye (Visible or Optical region of the electromagnetic spectrum), these sensors unlike RADAR are unable to collect data in darkness or conditions such as cloud cover, fog, dust, hail or smoke prevail. (Example LANDAST Multi - Spectral Scanner (MSS), Thematic Mapper (TM) or SPOT–HRV etc.

The Electromagnetic Spectrum is the physical base of remote sensing. The continuum of electromagnetic energy is broken down into various wavelength bands or spectral regions (Figure 2). The longest of these waves are radio waves the shortest are cosmic waves.

The wavelength of primary interest from remote sensing point of view can be divided into the following regions.

1. Optical wavelengths, ranging from 0.4 to 0.7 um (um-6 = 10m)
2. Radar wavelengths, ranging from 0.1 to 30 centimeters and beyond.

Cameras and multi-spectral scanning systems operate in the optical NIR and SWIR wavelength region; therefore, this region will be of major concern to us.

The major portions of the optical region are

1. Reflective wavelengths
   a. Ultra-violet………………………. 0.3-0.4 um
   b. Visible……………………………. 0.4-0.7 um
   c. Reflective infrared……………….. 0.7-3.0 um
      c.1 near infrared (NIR)……………… 0.7-0.9 um
      c.2 middle infrared (SWIR)………… 0.9-3.0 um
2. Emissive wavelengths
   a. Emissive or thermal region. …… 3.0-16 um

In reality none of these regions have distinct boundaries and there is considerable overlap in the regions and the terminology applied.

The wavelengths of reflected energy used for remote sensing thus range from 0.4 to 3 micrometers, whereas the self-radiated or emitted energy for earthly objects generally predominates above 3 micrometers. Passive systems records energy which nature provides directly, and that both reflected energy and thermal energy, although coming from the earth's surface, is almost totally derived from solar radiation (Figure 3) with the exception of geothermal energy.

Resolution: Resolution is a broad term commonly used in remote sensing system. It describes:

- The area on the ground that a pixel represents in an image file.
- The number of pixels you can display on a display device.

Four distinct types of resolution are important (Figure 4A):

- Spectral--- the specific wavelength intervals that a sensor can record
- Spatial--- the area on the ground represented by each pixel (picture element)
- Radiometric--- the number of possible data file values in each band (indicated by the number of bits into which the recorded energy is divided)
- Temporal--- how often a sensor obtains imagery of a particular area.

The four domains contain separate information that can be extracted from the raw data.

Spectral Resolution: It refers to the specific wavelength intervals in the electromagnetic spectrum that a sensor can record. For example, band 1 of the LANDSAT TM sensor records energy between 0.45 and 0.52 um in the visible part of the spectrum. Wide intervals electromagnetic spectrum is referred to as coarse spectral resolution, and narrow intervals are referred as fine spectral resolution. For example, the SPOT panchromatic sensor is considered to have coarse spectral resolution because it records EMR between 0.51 and 0.73 um. On the other hand, band 3 of the LANDSAT TM sensor has fine spectral resolution because it records electromagnetic energy (EMR) between 0.63 and 0.69 um (Jensen 1996).

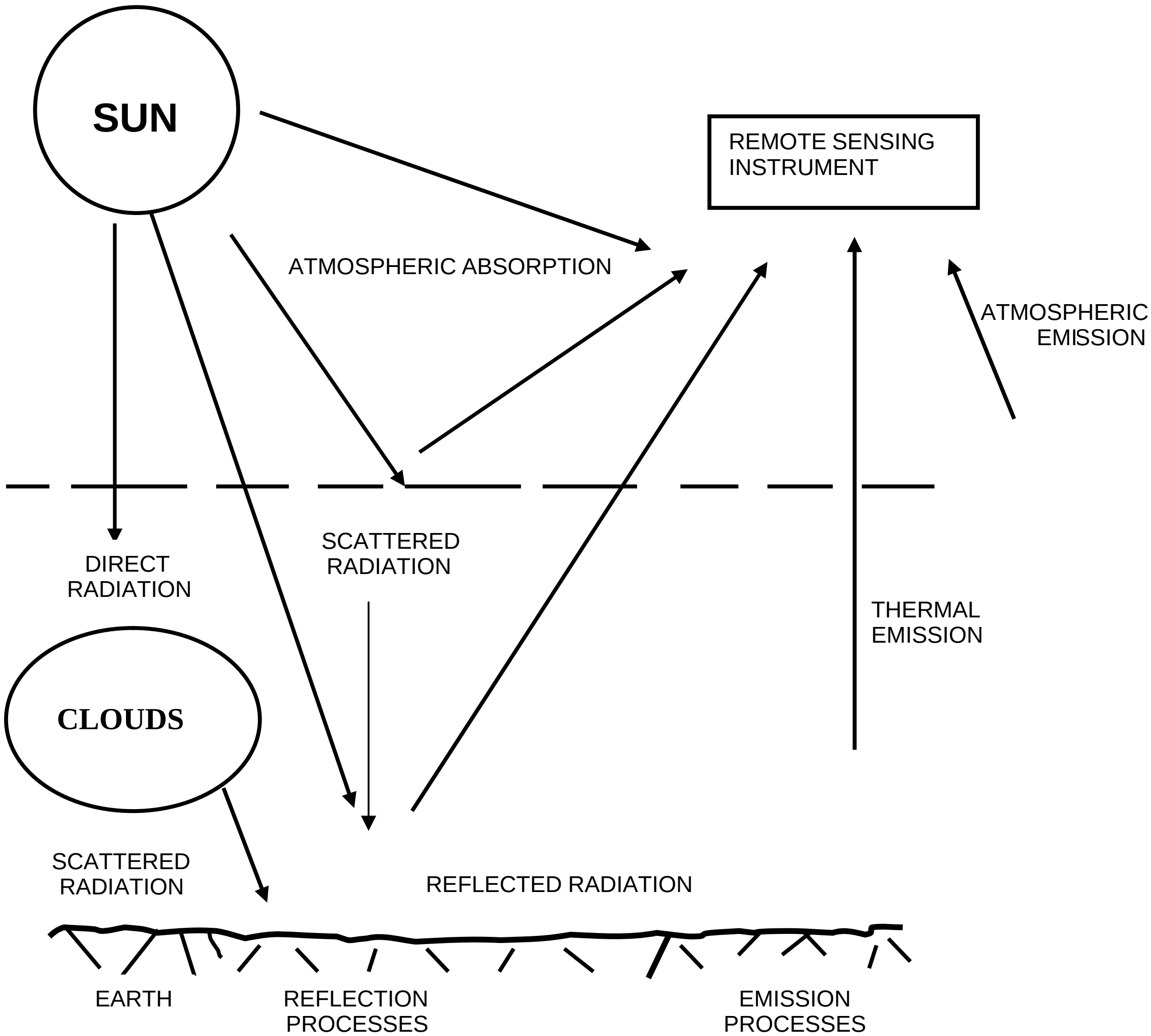


Figure 3- The remote sensing radiation system (after Meer, 1990).

Spatial Resolution: is measure of the smallest object that can be resolved by the sensor, or the area on the ground represented by each pixel (Simonett 1983). The fine the resolution, the lower the number. For instance, a spatial resolution of 79 meters is coarser than a spatial resolution of 10 meters.

Radimetric Resolution: It refers to the dynamic range, or number of possible data file values in each band. This is referred by the number of bits into which the recorded energy is divided. For instance, in 8 bit data the data file values range from 0 to 256 for each pixel, but in 7 bit data, the data file values for each pixel range from 0-128.In figure 4B, 8 bit and 7 bit data are illustrated. The sensor measures the EMR in its range. The tonal intensity of the energy from 0 to the maximum amount sensor measures is broken down into 256 brightness values for 8 bit data, and 128 brightness values for 7 bit data.

Temporal Resolution: It refers to how often a sensor obtains imagery of a particular area. For example, the LANDSAT satellite can view the same area of the globe once every 16 days. SPOT, on the other hand, can revisit the same area every three days by pointing the sensors.

Sensor can be classified according to spectral regions within which they operate. For example conventional photograph cameras, MSS, TM, SPOT operate in the visible and infrared portion of the EMS. The satellites are all equipped with a 4-band multi-spectral scanner (MSS), which records data from the visible and infrared portions of the electromagnetic spectrum. Spatial resolution of the MSS is 79 m. The recent LANDSAT platforms have been equipped with a powerful scanner, the Thematic Mapper (TM). This system has greater spectral and spatial resolutions that the MSS. The TM's 30 m resolution is suitable for viewing an image at a scale as large as 1:50,000, whereas retaining clarity. It is especially good for lithologic study.

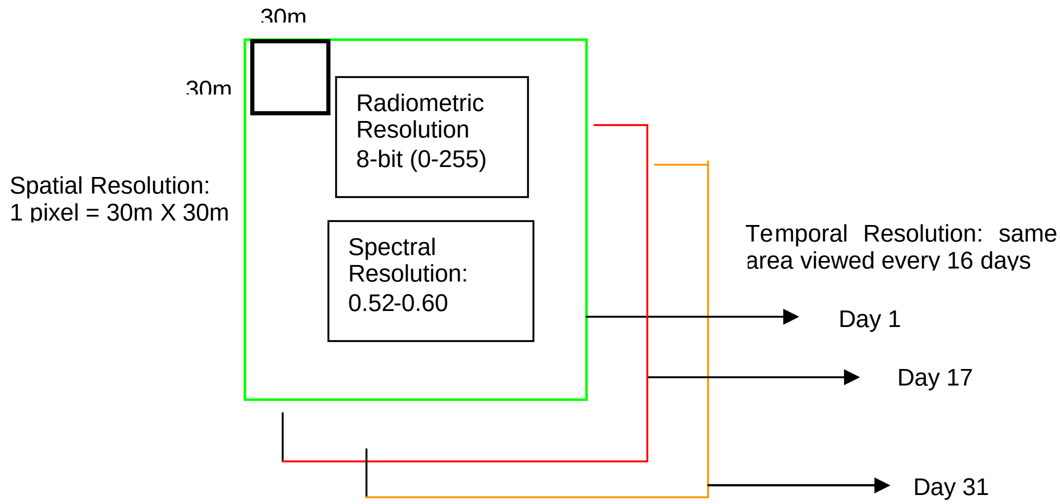
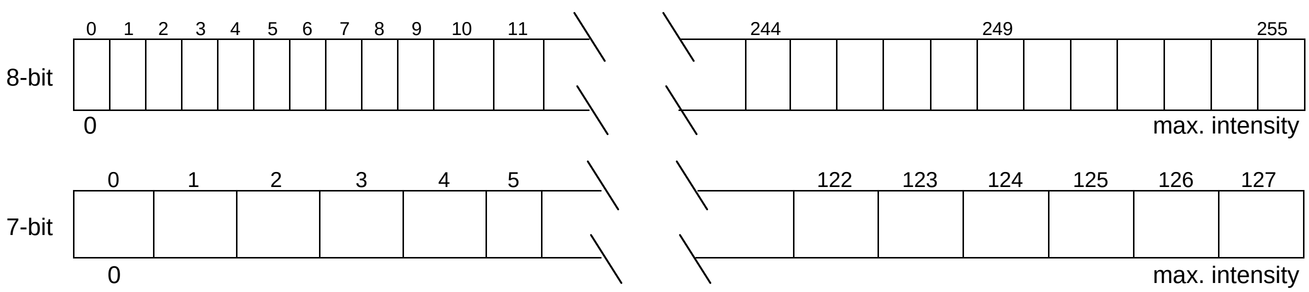


Figure 4A- LANDSAT TM-Band 2 (four types of resolution).



Source: EOSAT

Figure 4B- Brightness values.

SPOT-1 system is a French satellite, which is providing panchromatic and multi-spectral images with a ground resolution of 10 m and 20 m, respectively. Since it has off-nadir looking ability, therefore stereoscopic coverage is possible.

RADAR scanners operate in the microwave portion of EMS. RADARSAT's Scan SAR Narrow beam mode offers 50 m resolution and a 300 by 300 km coverage, which supports the identification of structural trends and features. The standard beam mode (25 meter resolution) helps optimize mapping, geophysical and drilling program. Airborne radar systems also have been used extensively in geologic exploration work. Digital merging of data sets by combining tonal and textural information from MSS and RADAR sensors respectively have led to a number of geological studies.

POTENTIAL OF REMOTE SENSING SYSTEM IN PETROLEUM EXPLORATION

There are several remote sensing systems in operation. Many of these are of direct interest to exploration geologists. Aerial photography is a part of remote sensing techniques, which is extensively used, in geological programs. However satellite data is now rapidly substituting conventional aerial photography. Obviously an image covers relatively a large area and inherent technical problems associated with aerial photographs (for example tilt, drift, illumination and scale etc.) and complex mechanism of security clearance is not there.

Remote sensing techniques is useful for study of geological features such as lineaments, their intersection, fault zones, its lateral extent, folds, its vergence unconformity, lithology discrimination and identification of oil seepages.

Images can also give information about buried structures. Their existence can be linear features buried beneath deep, unconsolidated sediments, which have geomorphic expression visible at the ground surface. Such information is of great significance for any petroleum explorationist. Bannert et al, (1992,1993) working with LANDSAT MSS images in the western foldbet of Pakistan, analyzed the structural style of Zindapir and Shah Gudro anticlines, suggest similar structures beneath the alluvial cover along the western margin of the Indus Fore deep.

Yatabe & Fabbri (1986) mention the following pioneer research work conducted in early eighties based on application of remotely sensed data in the field of petroleum exploration. LANDSAT has been used to map accurately exposed and buried folds, faults, and fractures in the Qaidam Basin of China. These data have been corroborated by gravity and magnetic data that give the expression of basement tectonic activity that have propagated upwards into the younger rocks. Drilling targets were selected from interpretation of a structural high on aerial photographs. Amurskii and Bondareva (1981) located zones of concentrated faults on imagery, which correlated with the presence of gas-derived sulfur on the crests of anticlines in central Russia. The zones where lineaments and faults intersect, give rise to fractures. Reservoirs as a result are fractured controlled which are considered to act as conduits for migration of hydrocarbons. Presently there is special interest among geologists in fractured reservoirs. Such features can be identifying through interpretation of image using geological criteria. Bannert 1986, and subsequently Iqbal and Ali, 2001 conducted LANDSAT MSS Image interpretation for the oil and gas producing Potwar sub-basin of Pakistan and derived several sets of lineaments. It was established that 67 % of producing oil and gas fields in the mentioned basin are falling along the predominant northeast trending lineament set. Which is assumed to be the zone with fracture controlled reservoir rocks. Another set of lineaments are running in north-south direction and might have fractured the reservoir rocks.

Much of the work in the field of remote sensing so far conducted has involved the location of hydrocarbon macro and micro-seepages through either structural or geo-botanical anomalies derived from remotely sensed imagery. Berger (1982) located buried faults and topographic highs in the East Texas Basin through their effects on drainage, vegetation, and soil characteristics. Existing surface structural pattern may be used to infer stress and strain conditions and subsurface architecture. Staskowski (1985) located a number of structural anomalies on LANDSAT imagery which followed trends of subsurface anticlines known to control hydrocarbon migration and accumulation; 150 areas of unusual reflectance, which indicated a thinning of the vegetation canopy, were defined on enhanced LANDSAT imagery and color infrared aerial photographs. All were associated with lineaments or intersection of lineaments derived from the imagery; the anomalies were visible on images. Several anomalies were drilled later and producing gas wells were established on them. It is assumed that these tonal anomalies are the result of vegetation stress due to seepage from the underlying reservoirs. A soil-gas survey revealed that methane; ethane, propane, and butane anomaly coincided with these anomalies (Rock, 1984). The highest propane concentrations occurred along an anticlinal crest, and the lineaments derived from the imagery were to have greater concentrations than the rest of the area over the field (Mathews, Jones, and Richers, 1984).

Hydrocarbon micro-seepages were detected through soil analysis near the Hugoton Gas Field of southwestern Kansas (Patton and Manwaring, 1984). These areas of seepage were associated with LANDSAT lineaments and circular features, sinkhole alignments, and a tonal anomaly recognized on LANDSAT imagery. The mentioned examples show the vitality of remote sensing even in its initial phase but now its application is spectacular in every geological expedition.

STATUS OF REMOTE SENSING IN PAKISTAN

The history of application of remote sensing data for geological investigations in Pakistan goes back to 1960, when aerial photographs were used for reconnaissance mapping of a large part of the country under Colombo Project. As a result Hunting Survey Corporation (1960) conducted excellent mapping for an extensive area of the western part of the country, which provides foundation for the geology of the area with special reference to the stratigraphy. Subsequently the following organizations have contributed in the discipline of remote sensing system.

Survey of Pakistan is a national organization mainly responsible for acquiring aerial photographs and preparing topographic maps for the country. It has prepared aerial photographs on different scales nearly for the entire country. It has its own training institute.

Geological Survey of Pakistan (GSP) is one of the leading organizations, which is mainly conducting geological mapping. It has established Photo-Geology Lab. at Quetta and in its regional offices throughout the country. It undertakes interpretation of aerial photographs. GSP with the collaboration of USGS has carried out interpretation for a large area of the country and produced excellent maps from images.

Space & Upper Atomosphere Research Commission (SUPARCO) with its ground station near Islamabad acquires data from satellites since 1989 and digitally processes the data according to user's requirements. It provides data both as hard copy and on CD's to users. SUPARCO has established Remote Sensing Application Center at Karachi.

Oil and Gas Development Company Ltd. (OGDCL) is a major exploration company of Pakistan. Its geological party conducts visual interpretation of aerial photographs and images, which is making its job quite comfortable but it lacks digital image processing system. OGDCL can save time and minimize unnecessary field problems if its geological party is equipped with modern satellite image processing software and its interpretation capability.

Exploration and production (E & P) companies in the country being well aware of the importance of satellite data into petroleum exploration. They have carried out more than 80 studies through foreign firms and thus pay substantial amount probably due to non-availability of expert's facilities in the mentioned discipline within the country.

Few universities and some private firms have installed digital image processing software but they are facing problems like paucity of funds and lacking skilled personals of the discipline.

Hydrocarbon Development Institute of Pakistan (HDIP) with the collaboration of Federal German Institute for Geosciences and Natural Resources (BGR), Hannover carried out detail structural interpretation of the western foldbelt and Potwar region of the country through satellite images. BGR assisted HDIP's scientists in interpretation of satellite data and provided an opportunity to undertake training of the mentioned discipline from International Institute of Aerospace Survey and Earth Sciences (ITC), Enschede, the Netherlands. Additionally HDIP with the assistance of BGR established its own digital image-processing unit, with modern image processing software (ERDAS IMAGINE 8.4), where image processing and structural interpretation from imagery could be made.

Since research and development of frontier basins of the country is one of the top priorities of HDIP R & D program, therefore, using modern satellite images an interpretation of the Pishin Frontier Basin, Balochistan was conducted in 1999, followed by fieldwork to cross check the ground truth. Figure 5 shows interpretation job carried out in HDIP for the northeastern part of the Pishin frontier basin. The mentioned part of the basin has been awarded as (Murgha Faqirzai block) for petroleum reconnaissance / exploration.

Previously HDIP and BGR / IGDL (Institute for Geology and Geodynamics of the Lithosphere George August University Gottingen, Germany) carried out a project; “Petroleum Evaluation of the Zindapir Anticlinorium, Pakistan (1995-1997)”. Widespread application of images and aerial photographs was made and extensive geological fieldwork during three years was undertaken. Exploration and production companies reviewed their exploration strategy and these blocks have been awarded for exploration. Recently HDIP carried out a comprehensive study for Pakistan Petroleum Limited (PPL) in Jhamat EL and surroundings. Geological mapping of the mentioned block was made. During the mapping and structural interpretation SPOT images were used. Its results were quite helpful.

The imaging software installed in HDIP has the capability to incorporate additional information (scale, attitude of beds etc) to interpret images. Skilled interpreter through the use of the software can provide substantial information at initial stage of exploration both for under explored and mature basins. Structural information, regional trend, folds (antiforms or synforms), and many, much other such information, are of great importance from petroleum exploration point of view, particularly in inaccessible areas. HDIP facilitated from this capability in fieldwork of Duki – Balochistan.

METHODOLOGY

Yatabe and Fabbri (1986) presented a sequential procedure (Table 1 & 2) for application of remote sensing system in petroleum exploration both in frontier and mature basins, respectively.

In both situations, remotely sensed data is recommended at initial stages of exploration prior to conduct detailed fieldwork and geochemical & geophysical investigation. Interpretation of images should be carried out using standard geological criteria (tone, texture, drainage, pattern, shape etc), targeting not only regional geological structures and mapping but also locating fracture intersections, fracture density, circular features, and tonal anomalies. In frontier areas, integration of existing data sets, at a reconnaissance scale, will enable geologists to pin point prospective areas.

In areas of moderate to heavy exploration where abundant geologic and geophysical information already is available, the data should be integrated at a larger scale; the emphasis of image analysis in these areas should be on searching for subtle expressions of buried structures and seepages. Information available on established wells and the resulting subsurface contour and spacious maps can help to define the geologic model

LIMITATION OF REMOTE SENSING SYSTEM

Remote sensing techniques are used in petroleum industry within certain limits. To evaluate the performance and pitfalls of the remote sensing system, a survey conducted in 1986 in Canada reveals the following:

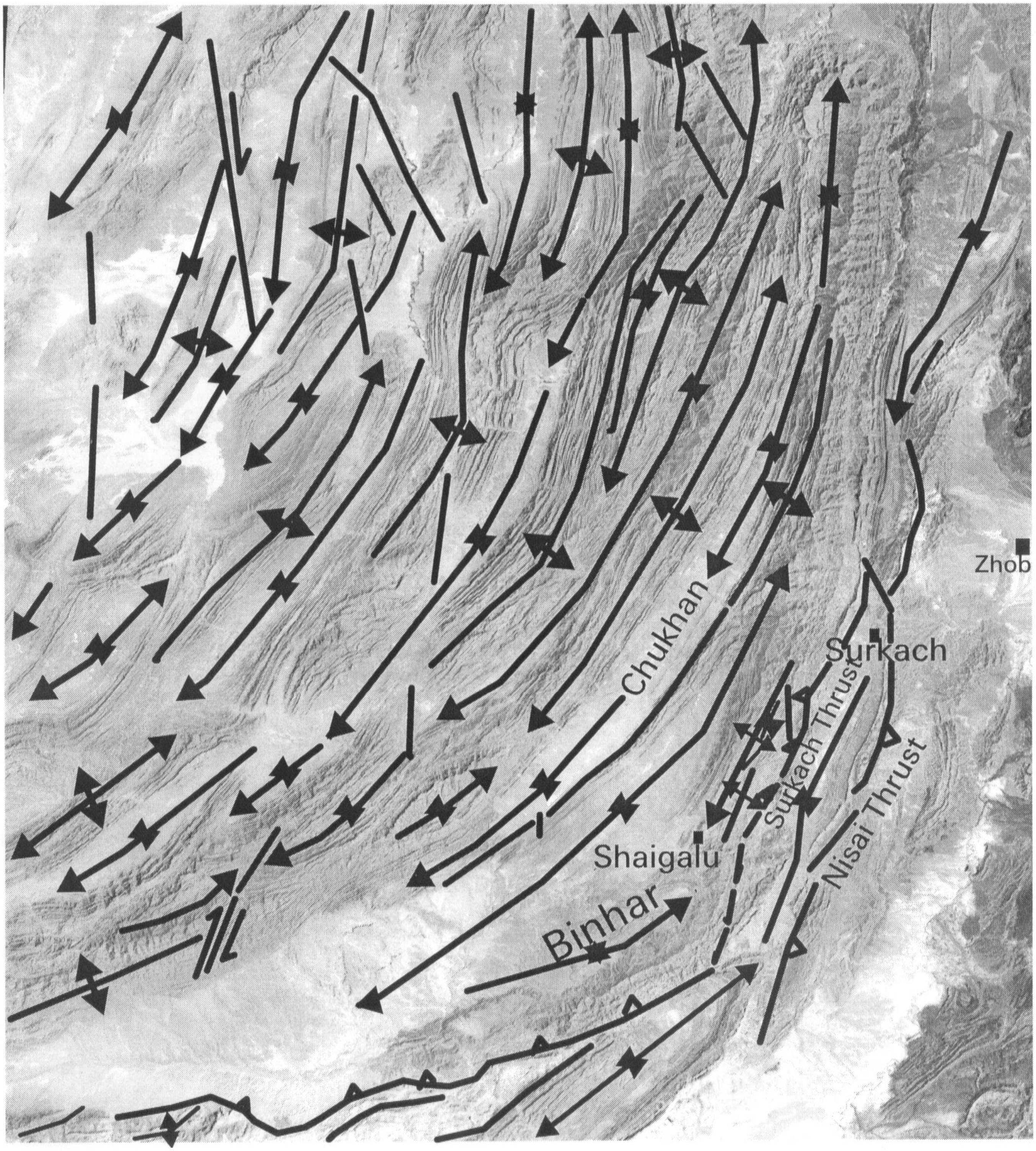
1. In heavily exploited areas, most of the remaining undiscovered reserves are buried beneath the surface. In fact, thick vegetation cover tends to obscure the structure in larger parts of the country.
2. The geology of some parts of the country has been well mapped at the surface and has been drilled extensively and seismically surveyed. It is felt that remote sensing will not provide any additional geologic information.
3. As exploration geologists are obligated to conduct costly seismic surveys, they have little incentive to use a tool such as LANDSAT or other sensors.
4. The resolution of the LANDSAT MSS is too coarse to pinpoint certain targets such as reefs.
5. Some exploration personals are unaware of the capabilities of remotely sensed data. Some experts receive the enhanced, interpreted product, but are not involved actively with image analysis.

Prior to have in-depth sight into the result of the mentioned survey, it is worth realizing that Canada has entirely different geological environment than Pakistan; with specific targets and priority. But in Pakistan geoscientists have problems of different nature and thus different targets. Some of the pitfalls pointed out in the mentioned survey are associated with every system at advanced stage. Usually such surveys are carried out for bringing improvement in a system. For example Pakistan has about 800,000 Km^2 area, i.e., 20% more than Alberta (600,000 Km^2) the main oil producing province of Canada but the latter is geologically and seismically well mapped and intensive drilling is in progress. But reverse situation exists in Pakistan; major part of our country is un-explored, proper detailed geological and seismic coverage is un-available, drilling rate is poor, new plays have been added to the petroleum geology map of Pakistan and major part of onshore land is having less vegetation. Such circumstances demand more use of remote sensing system.

SCOPE OF REMOTE SENSING SYSTEM

Increase in speed, size, capabilities and decrease in cost of computers are some of those factors, which led to integration of data from various disciplines into remote sensing image (Yatabe and Fabbri, 1986). The final thematic format is better than conventional contour map, and which can be quickly process, display and may be use to disseminate information.

It is in practice that digitally merged gravity, magnetic, geologic, thermal infrared, and MSS/TM data have been studied which led to formulate regional and even global tectonic models. That is the reason that image-processing and interpretation is now considered as an integral part of



(Geometrically not correct LANDSAT TM-5 image)
Interpretation at HDIP Remote Sensing Lab. Islamabad

Figure 5- Shows general structural style in the west of Zhob (Fort Sandeman) Pishin Basin, Balochistan.

Table 1. Shows proposed exploration strategy for "Frontier area'' (after Yatabe and Fabbri, 1986).

	DATA	PROCEDURE	RESULTS
1.	LANDSAT MSS Space borne RADAR Reconnaissance scale Geology map	Select suitable reconnaissance scale Enhance Images Photo interpretation	Establish limits of sedimentary basin. Select structural and tonal elements for further targeting. Exclude areas of unfavorable lithology.
2.	Information obtained in 1 Published aero magnetic Maps Published gravity data	Integrate data digitally accordingly to conceptual model of petroleum favor ability.	Formulate model of surface, subsurface structure. Further target potentially favorable areas on reconnaissance scale.
3.	Airborne RADAR Thematic mapper Airborne MSS Low to mid. Altitude aerial photographs	Enhance images Examine areas targeted in 1 & 2 Repeat activities as per 1 Ground and initial field checking	Reduce number of targets. Obtain specific information on a few targets.
4.	Un-published geologic data, where available	Perform detailed field mapping Ground truth all anomalies derived in 3. Perform ground and aerial geophysic and geochemistry on targets of 3. Use remotely sensed data for logistics in areas of limited map control.	Reduce number of targets in preparation for drilling. Prepare detailed maps of prospective areas on a local scale.
5.		Drilling of targets established in 4.	

any geological exploration program. Data conversion and integration is one of the attributes of remote sensing and Geographic Information System (GIS). Its software is installed both in microcomputers and to large system supporting several users systems. Despite that the application of remote sensing for petroleum exploration in Pakistan is still at rudimentary stage.

Some of the possible reasons for this are:

1. Skilled personals with sound geological background are uncommon in the field of remote sensing within the country.
2. The discipline of Remote Sensing is not included as specialized subject at university level. Therefore, geoscientists are not well aware about its versatility and are deprived from the utilities of the system.
3. Organizations where there is dire need of image processing system lack the mentioned facilities.
4. Acquisition of data and its purchase (image and CD's) is difficult due to financial constraints. It is specially a big problem for R & D institutes.

CONCLUSIONS

Remote sensing is a tool to supplement the conventional geological exploration methods. Nevertheless, in some instances it has contributed directly to the location of producing oil and gas wells. The MSS images have been used to map geological structure on a variety of scales, but sensors of higher spectral and spatial resolution are providing data appropriate for more detailed work and the location of subtle features, including buried structures and areas of stressed vegetation and hydrocarbon bearing rocks. TM images are helpful to discriminate lithologic units. Thus interpretation of remotely sensed data is a pre requisite for prospectivity of large areas. In the case of Pakistan, where a major part of its on-shore land is un-explored and distally located, application of satellite data is more imperative. Barren rocks of Pakistan offer good opportunity for remote sensing interpretation.

In future the existing mature hydrocarbon producing basins may become exhausted, petroleum exploration activities will have to be diverted into frontier basins.

Table 2. Petroleum exploration strategy for well explored area (after Yatabe and Fabbri, 1986).

	DATA	PROCEDURE	RESULTS
1.	LANDSAT MSS Space borne RADAR Existing geologic maps Well information Reconnaissance scale aero magnetic Reconnaissance scale gravity	Select suitable Reconnaissance scale Enhance Images Map structure Photo interpretation	Add to existing knowledge of regional structure. Select structural and tonal elements for further targeting.
2.	Information obtained in 1 Airborne RADAR Thematic mapper Airborne MSS Low to mid altitude aerial Photographs Existing aeromagnetic, gravity and seismic data	Select suitable local mapping scale Enhance images Digital integration of suitable information according to conceptual model. Initial field checking	Study targets established in 1. Search for suitable structural and tonal anomalies. Further target potentially favorable areas on local scale.
3.	Un-published geologic data	Detailed field mapping Ground truth all anomalies derived in 2. Perform ground and aerial geophysics and geochemistry on targets found in 2.	Reduce number of targets in preparation for drilling. Prepare detailed maps of prospective areas on a local scale.
4.		Drilling of targets established in 3.	

Therefore, it is a high time to prepare for that challenging job. Substantial valuable data is scattered in degraded shape in various archieves. These data sets in combination with data from different sensors may be integrated which will lead to a thematic format. This information if use in initial exploration stage may systematically narrow down prospective targets.

RECOMMENDATIONS

To achieve meaningful results pertaining application of remote sensing in petroleum exploration in Pakistan, the following suggestions have been made.

1. The subject of Remote Sensing should be included in the syllabus at university level as a special subject.
2. Organizations related to petroleum research and exploration must establish their own digital processing lab and image archives. If these facilities already exist, it should be upgraded.
3. Satellite data related to geological investigation may be accessible, placed in a public domain and should be available free of cost to national organizations, R & D institutes, and academia and on subsidized rates to exploration and production companies. This exercise will enhance application of images in various disciplines and as result will expand a client- oriented market for remote sensing products.
4. Un-explored sedimentary basins of the country deserve extensive geological investigations. Any one of these basins must be targeted as pilot project for remote sensing system coupled with conventional geological methods.
5. An international institute parallel in all aspects to the regional institutes of the South Asian countries like Indian Institute of Remote Sensing Dehradun and Intl. Institute of Mountain Development Kathmandu, Nepal may be established in Pakistan where emphasis must be given to the applied aspects of remote sensing system.

ACKNOWLEDGEMENTS

The author is indebted to Mr. Hilal A. Raza, Director General, Hydrocarbon Development Institute of Pakistan, for permission of publication of this paper.

Mr. Wasim Ahmed, General Manager, HDIP Islamabad Operations, is acknowledged for his courageous efforts which materialized the establishment of Remote Sensing Lab at HDIP Islamabad and subsequently acquiring digital image processing software, one of the most user friendly software.

Professor Dr. D. Bannert, Former Head of Remote Sensing Section, Federal German Institute for Geosciences and Natural Resources, Hannover and Professor Dr. D. Helmcke, IGDL, Gottingen University, Germany, are appreciated for their technical guidance in interpretation of satellite data and discussions in extensive geological fieldwork /excursion, respectively in Pakistan (1986-1995) and Austrian Alps (1996). Special thanks to professor Dr. Bannert for critical review of the manuscript.

Suggestions, comments and criticism about the manuscript are welcome and may be sent to the author through Pakistan Journal of Hydrocarbon Research.

REFERENCES

Amurskii, G.I. and M.S. Bondareva, 1981, Application of space photography to structural studies of degassing zones of oil and gas basins: Soviet Jour. Remote Sensing, no.3, p.339-346.

Bannert, D., 1986, Stresses release in the Himalayan Foreland Arcs, Northern Pakistan inferred from LANDSAT images, HDIP BGR Technical Project.

Bannert, D., A. Cheema, and A. Ahmad 1992, The geology of the western foldbelt: Structural Interpretation of the LANDSAT MSS Satellite imager (1:500,000): Hannover Germany Federal Institute for Geoscience and Natural Resources, 3 sheets.

Bannert, D., H.A. Raza, M. Iqbal, A. Cheema and A. Ahmad, 1993, LANDSAT MSS Analysis of the west Pakistan foldbelt; Porce. Ninth Thematic Conference on Geologic Remote Sensing, Padadena, Cale: A nn Arbor, Michigan, p.751-752.

Berger, Z., 1982, The use of LANDSAT data for detection of buried and obscured geologic structures in the East Texas Basin. USA Proc. Intern Symposium on Remote Sensing of Environment, Second Thematic Conference, Remote Sensing for Exploration Geology, Fort Worth, Texas, p.579-589.

Iqbal, M., S.M. Ali, 2001, Correlation of structural lineaments with oil discoveries in Potwar sub basin, Pakistan; Pakistan Journal of Hydrocarbon Research, v.12, p.73-80.

Jensen, J. R., 1996, Introductory Digital Image Proce. Remote sensing perspective, Englewood Cliffs, New Jersey: Prentice-Hall.

Matthews, M.D., V.T. Jones and D.M. Richers, 1984, Remote sensing and surface hydrocarbon leakage: Proce. Intern. Symposium on Remote sensing of Environment. Third Thematic Conference, Remote Sensing for Exploration Geology, Colorado Springs, Colorado, p.663-670.

Meer, H. V. Mohr, 1990, Camera and Multispectral scanning systems in remote sensing as applied to geology. Part 1: Data Collection, International Institute for Aerospace Survey and Earth Sciences (ITC) Enshede, the Netherlands, Remote Sensing Course Handout (RSD 10).

Patton, K. H. and M.S. Manwaring, 1984, Evolution of a LANDSAT derived tonal anomaly for hydrocarbon micro seepage, southwest Kansas: Proce. Intern. Symposium on Remote Sensing of Environment, 3rd Thematic Conference, Remote Sensing for Exploration Geology, Colorado Springs Colorado, p.441-450.

Rock, B.N., 1984, Remote detection of geobotanical anomalies associated with hydrocarbon micro seepage: Proce. Intern. Symposium on Remote Sensing of Environment, 3rd Thematic Conference, Remote Sensing for Exploration Geology, Colorado Springs, Colorado, p.183-195.

Simonett, David S., et al. 1983, The development and principles of remote sensing, Chapter 1 in Manual of Remote Sensing, edited by Robert N. Colwel. Falls Church, Virginia American Society of Photogrammetry.

Staskowski, R.J., 1985, The leelanau, benzie and grand traverse, Michigan anomalies – structural and geobotanical indicators of hydrocarbon microseepage: Proce. Intern. Symposium on Remote Sensing of Environment, 3rd Thematic Conference, Remote Sensing for Exploration Geology, Colorado Springs Colorado, p.53-63.

Yatabe , S. M., and A.G. Fabbri, 1986, The application of remote sensing to Canadian petroleum exploration: Promising and Yet unexploited. in Computers / Geosciences v.12, no.4B, p. 597-609.