BHARATHIDASAN UNIVERSITY
Tiruchirappalli - 620 024
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Programme : 6 year Integrated M.Tech in Geological Technology and Geoinformatics

Course title : Principles of Remote Sensing
Course code : MTIGT 0701

UNIT – IV
Remote Sensing and GIS for hydrocarbon exploration

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The key to the success of any hydrocarbon exploration is the integration of the database / thematic data. GIS is a particularly effective means of providing functionality for all of the disciplines represented on the team.

RS data has become a major source of the information required by decision-makers for petroleum exploration and exploitation. The various geological, geophysical, and geochemical data are now available from large scale exploration and laboratory analysis, with the provision of more detailed information about potential petroleum exploration targets.

On the other hand, the remotely sensed data, together with other geosciences datasets, need to be properly managed, analysed, retrieved, displayed, and maintained.

This could be accomplished through the introduction of geographic information systems (GIS) into the RS framework.

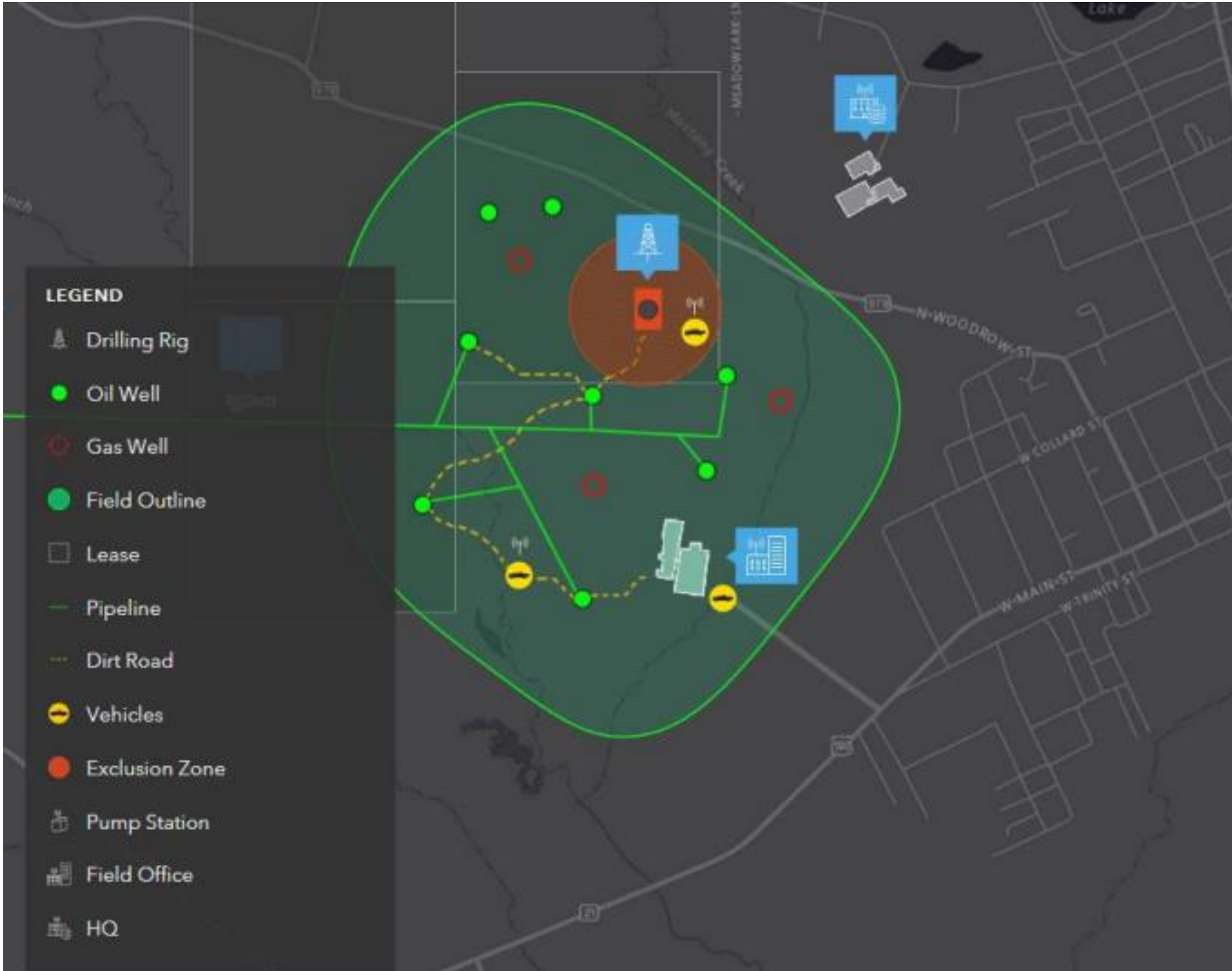
In recent years, although remotely sensed data, together with geological and geophysical information, have been applied to many projects of petroleum exploration and exploitation, few studies have been reported on integrated RS-GIS application.

The petroleum is the most important and foundational energy in the world at present. It is also the most capital intensive. Revenues are large, as are the costs.

The petroleum business requires the handling and analysis of different types of data, which can be subdivided:

- *a) unstructured data such as reports inside a document management system.*

- *b) structured data in databases, and spatial data available from GIS.*


LEGEND
Drilling Rig
Oil Well
Gas Well
Field Outline
Lease
Pipeline
Dirt Road
Vehicles
Exclusion Zone
Pump Station
Field Office
HQ
N-WOODROW-ST
W-COLLARD ST
W-MAIN-ST
W-TRINITY ST

The Oil and Gas industry is driven by an estimated 80% data that has a spatial component.

- *This is the only industry that utilises spatial information at every stage of development, beginning with opportunity analysis and exploration, through appraisal and production, right up to the abandonment phase.*

- *So companies are beginning to understand the importance of geospatial to maximize production as well as minimize risks.*

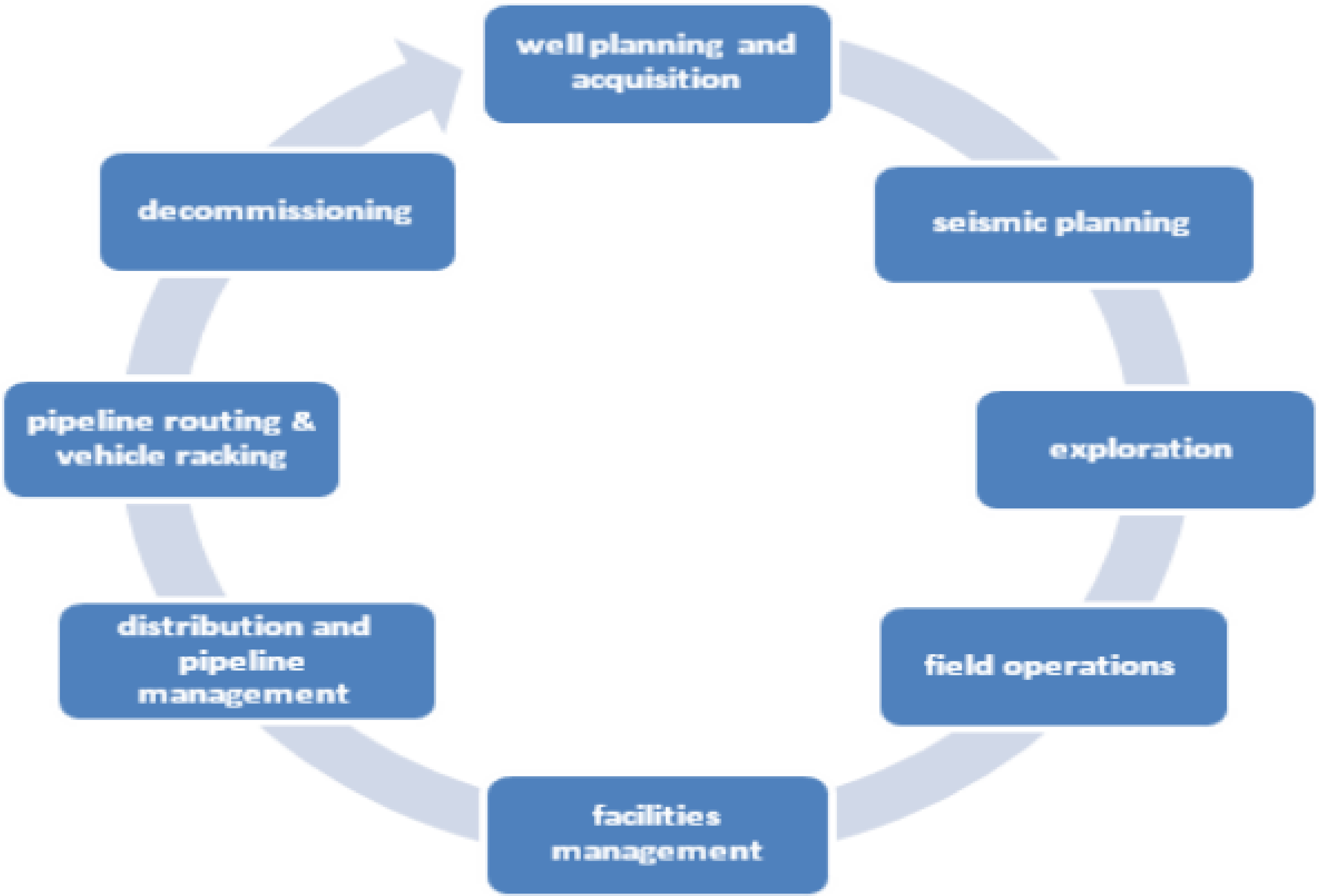
Discovering new sources of petroleum ahead of competitors is one of the key ways to stay successful in the petroleum industry.

A GIS system can help oil companies evaluate the potential for oil in promising locations. Exploration often requires analysis of satellite images, digital aerial photomosaics, seismic surveys, surface geology studies, subsurface and cross section interpretations, well locations, and existing infrastructure information.

A GIS can relate these data elements to the location in question in map form and allow you to overlay, view and manipulate the data to analyze and understand its potential.

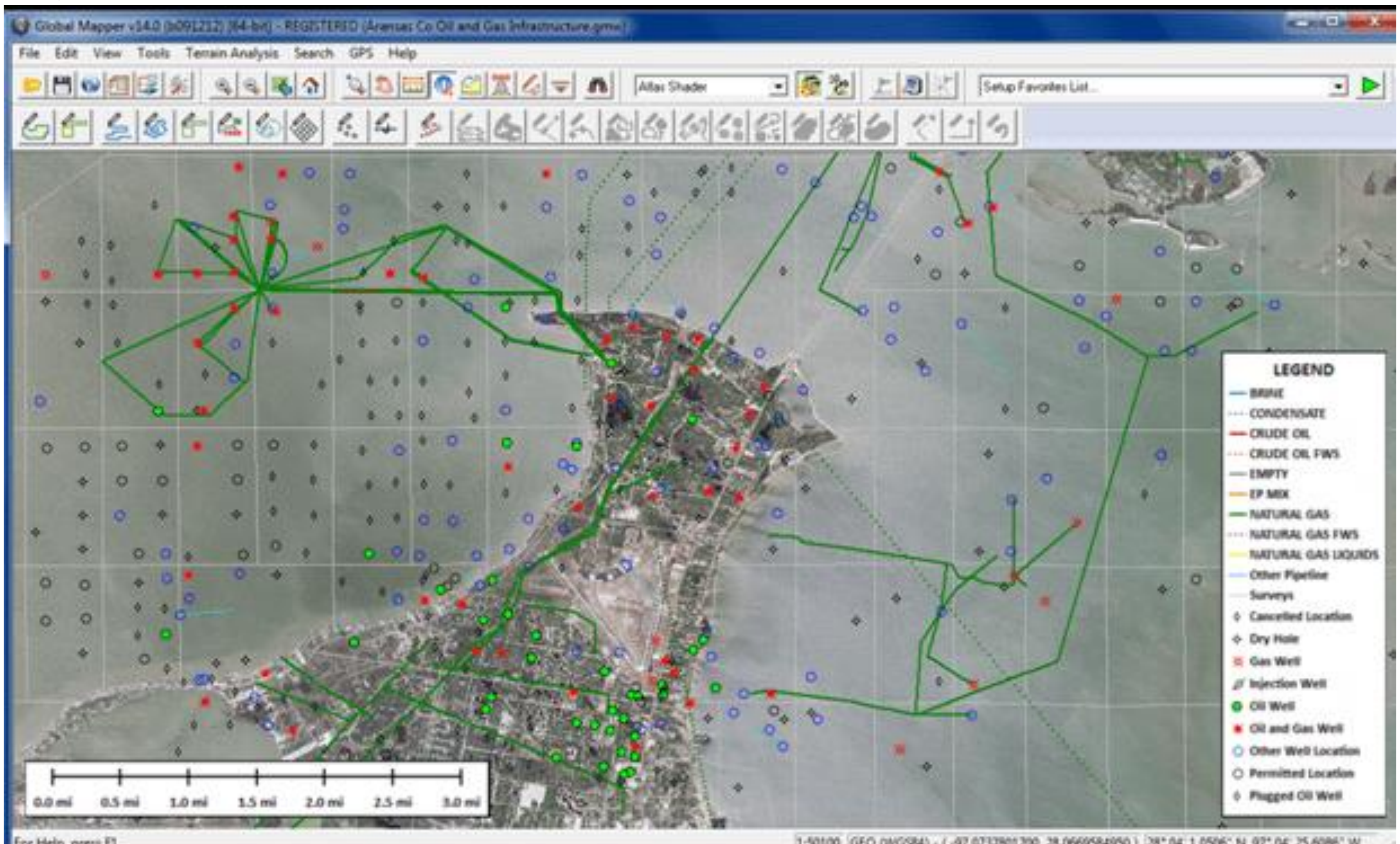
GIS technology today allows you to manage the spatial components of these everyday petroleum business objects, such as leases, wells, pipelines, environmental concerns, facilities, and retail outlets, in the corporate database and apply appropriate geographic analysis efficiently across the enterprise.

GIS Deployment through the Oil Field Life-cycle



Well Planning and Acquisition

Basin Analysis *: map of potential hydrocarbon accumulations; sub-surface secondary fluid migration network mapping; flow direction – flow accumulation mapping across DEM; potential migration pathways, etc.*



Seismic Planning

Terrain analysis; seismic survey maps and data; satellite image processing and spatial analysis; etc.

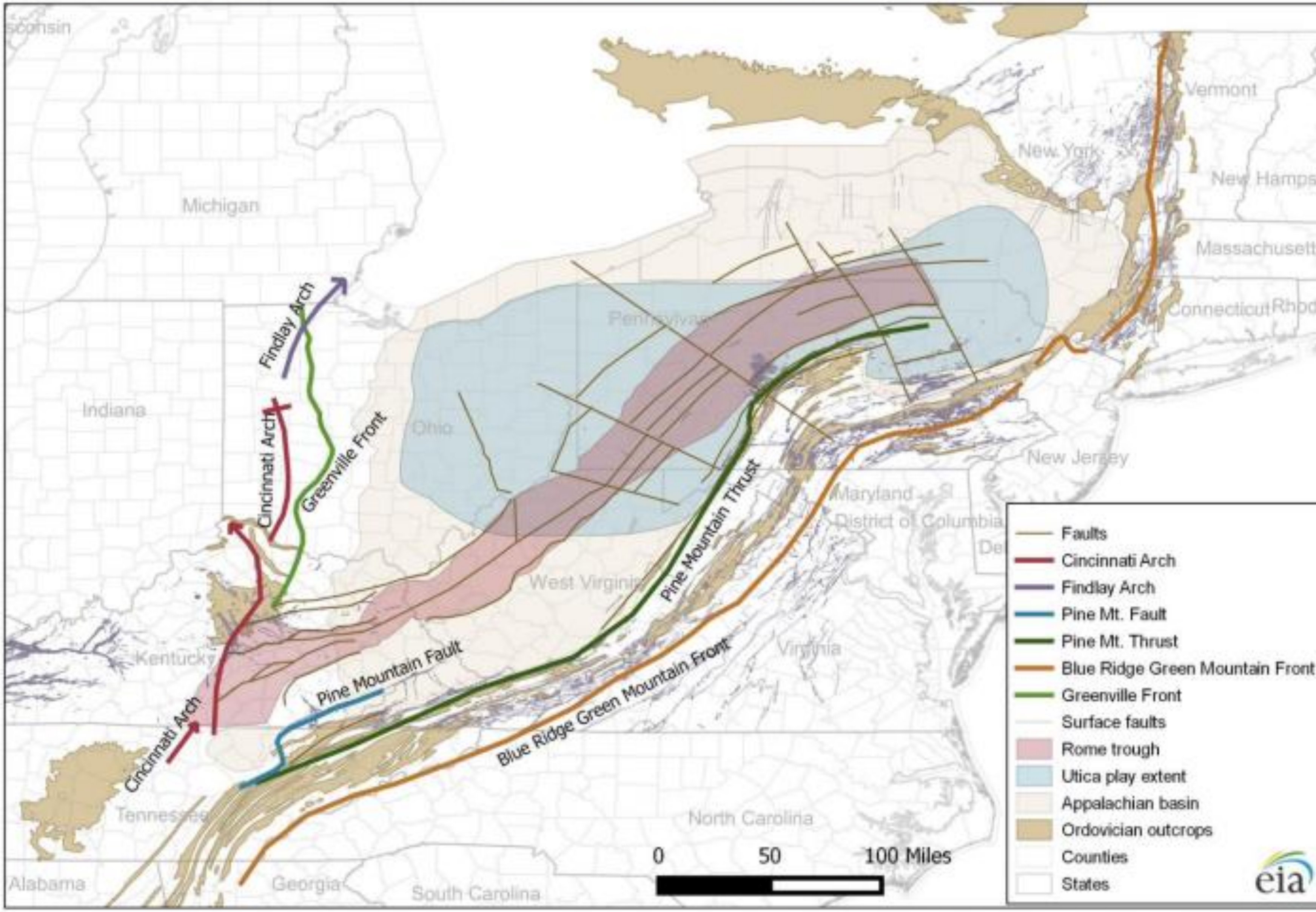
Exploration

- *Well Planning: well planning around multiple drilling constraints; GIS tools used in well pattern optimization workflows.*

  - *Drilling :spatial analysis within GIS for optimized well drilling patterns and efficient configurations.*

  - *Production : GIS allows data integration and visualization of production volumes, injection rates and recovery efficiency in near real-time.*

Major structural and tectonic features in the region of the Utica play



Source: U.S. Energy Information Administration, based on DrillingInfo Inc., IHS Inc., The Appalachian Oil and Natural Gas Research Consortium, and U.S. Geological Survey.

Field Operations

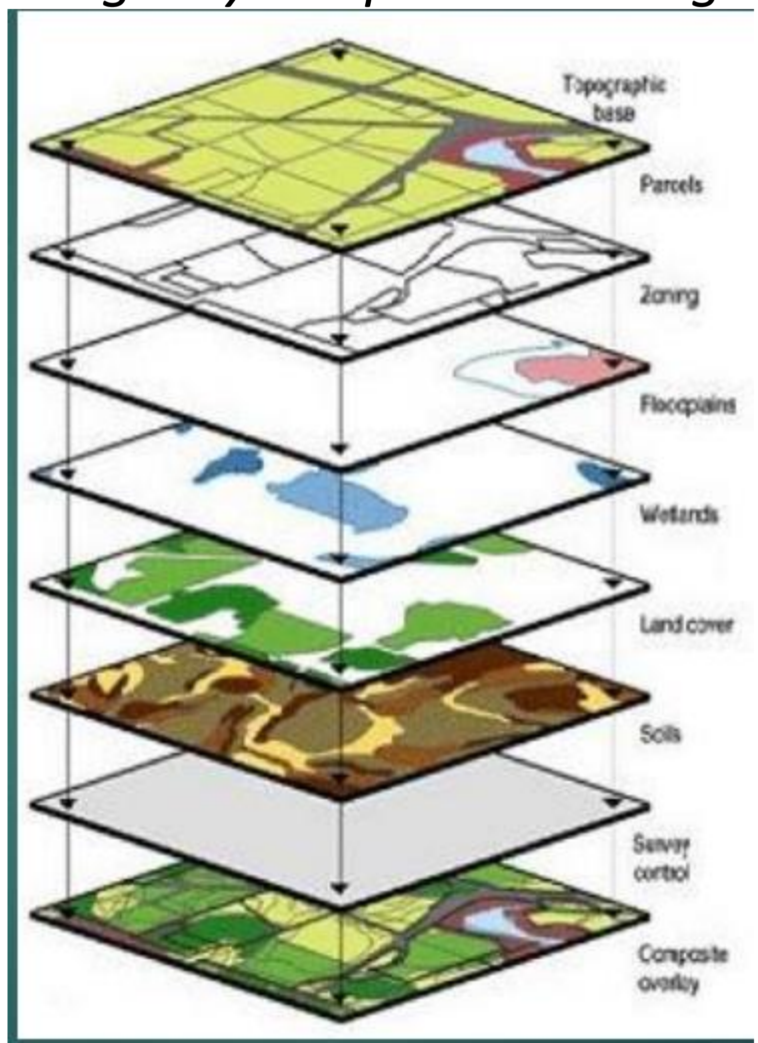
• GIS supports drilling around surface and geologic constraints; improved field production efficiencies for whole reservoirs /basins;

data integration and visualization in real time for production dashboards, coordinated workflows and personnel across rig sites;

Dynamic Hazard modeling for resource allocation; asset tracking in real time.

Facilities Management

- *3D GIS with field layout helps accurate monitoring of associated environmental changes in near real time for HSE (Health, Safety and Environment) and emergency response during oil spills, leaks or explosions*



Benefits of GIS in Oil and Gas

Empowers Decision-Making

• *Which acreage or play to enter, how to shorten workflows, how to plan the optimal pipeline route, integrate results of seismic survey, planning emergency response, better management of facilities, manage pipeline outage and leaks, etc.*

Supports future action and ongoing exploration activities

• *By standardizing processes and reducing technical uncertainty, GIS improves exploration efficiency. The GIS framework models a consistent exploration processes across all assets within the company. This supports a consistent, auditable corporate prospect portfolio, for ongoing portfolio decisions.*

Increased Efficiencies

• Multi disciplinary data integration for risk assessment and uncertainty, better access for cutting wasteful downtime, optimized maintenance schedules;

monitoring and analysis of daily fleet movements in real time, least cost path analysis for pipeline routing, standardized portfolio workflows, cutting down decision cycle times, etc.

Cost Saving

• An estimate of 10-30 per cent cut in operational costs, prevention and management of incidental or accidental costs, efficient pipeline and fleet management saves costs, optimized drilling and operation workflows enhances ROI, and so on.

Remote sensing images are highly useful for the oil and gas industry. Remote sensing has proven to be an integral tool for :

- *regional reconnaissance surveys*
- *downstream and upstream oil and gas operations*
- *evaluation of infrastructure for well-site planning etc.*

The process of determining hydrocarbon potential areas for exploration requires extensive studies of both surface and subsurface structures. Analysis and good understanding of these structures and surface expressions related to hydrocarbon formation provides a basis for identifying petroleum traps.

The existence of favorable subsurface conditions for petroleum accumulation is always dependent on surface manifestation of petroleum traps. Identifying these areas prior to exploration allows for proper planning of seismic works so as to focus exploration and resources on relatively small areas.

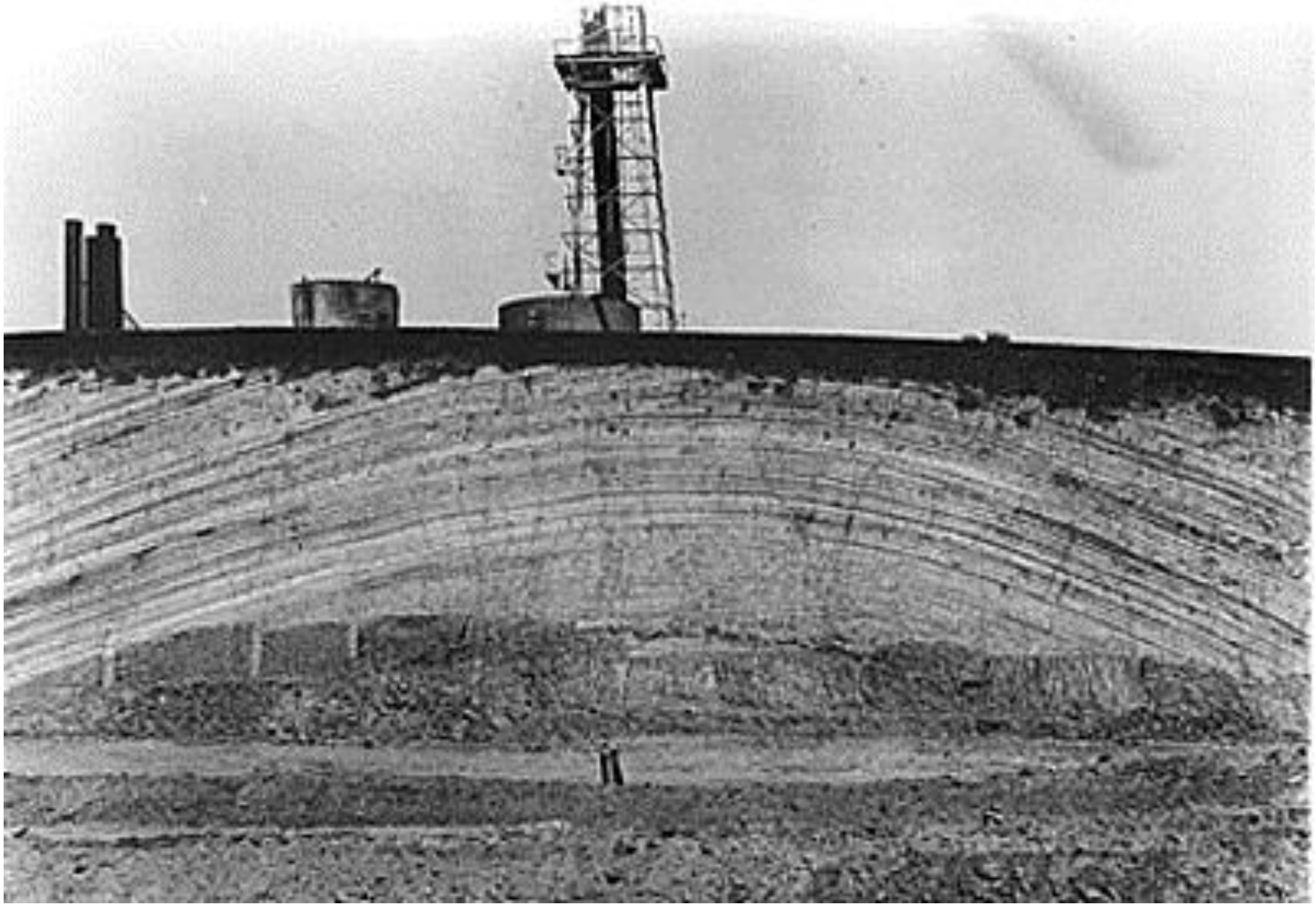
Remotely Sensed data have been heavily used in searching for surface indicators of "leaking" subsurface oil and gas. The general approach to petroleum exploration is:

One line of investigation looks at structural analysis of space images in search of subsurface traps. Another, approach seeks to find alteration at the surface caused by chemical changes related to surface-reaching oil or gas.

Exploration for oil and gas has always depended on surface maps of rock types and structures that point directly to, or at least hint at, subsurface conditions favorable to accumulating oil and gas.

Thus, looking at surfaces from satellites is a practical, cost-effective way to produce appropriate maps. But verifying the presence of hydrocarbons below surface requires two essential steps:

1) *doing geophysical surveys and*
2) *drilling into the subsurface to actually detect and extract oil or gas or both.*



Sedimentary basins are regions of prolonged subsidence on the earth surface and have huge accumulation of the sediments at places more than 20 kms.

Purpose of Basin analysis

The purpose of qualitative basin analysis methods are to provide

Estimates the possibility of hydrocarbon accumulation in a basin.

Estimates of the most likely locations in a basin where hydrocarbon is to be found.

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Satellite images provide large scale photos that depict large areas, within which clues to subsurface conditions may be evident. In general, most of the obvious structures that have surface expression had been discovered and mapped over much of the world.

Some regions, however, were not adequately mapped even in the 1970s, so that the advent of higher-resolution space images proved a boon to energy companies seeking new sources of fossil fuels. Sometimes the satellite images proved especially sensitive to subtle indications of interior structures. For instance, fractures around structures in known oil/gas fields may extend further, than suspected from field survey.

Structural and tectonic modelling of the subsurface / basement plays a major role in providing solutions in different phases and aspects of hydrocarbon exploration. Different tectonic phases and their associated structures play a significant role right from basin evolution up to prospect generation and exploitation/development strategies.

This influence of tectonics and structural analysis have more impact in case of basement exploration where different phases of Pre-Cambrian to Phanerozoic basement tectonics control various elements of exploration like prospective areas, well placement, reservoir capacity etc.

These elements are governed by the parameters of basement prospects like formation of basement highs, fracture pattern and densities, generation of secondary porosities by neotectonic deformations and reactivations of earlier structures.

Generally, satellite images can act as an excellent tool for detection and analysis of geological structures that are well exposed at the surface and display clear expressions of inclined bedrock strata and fault-line traces.

However, a large percentage of the world's onshore hydrocarbon reserves is either obscured by thick cover of vegetation and soil in areas of low topographic relief or is completely buried under younger and relatively undeformed rock units.

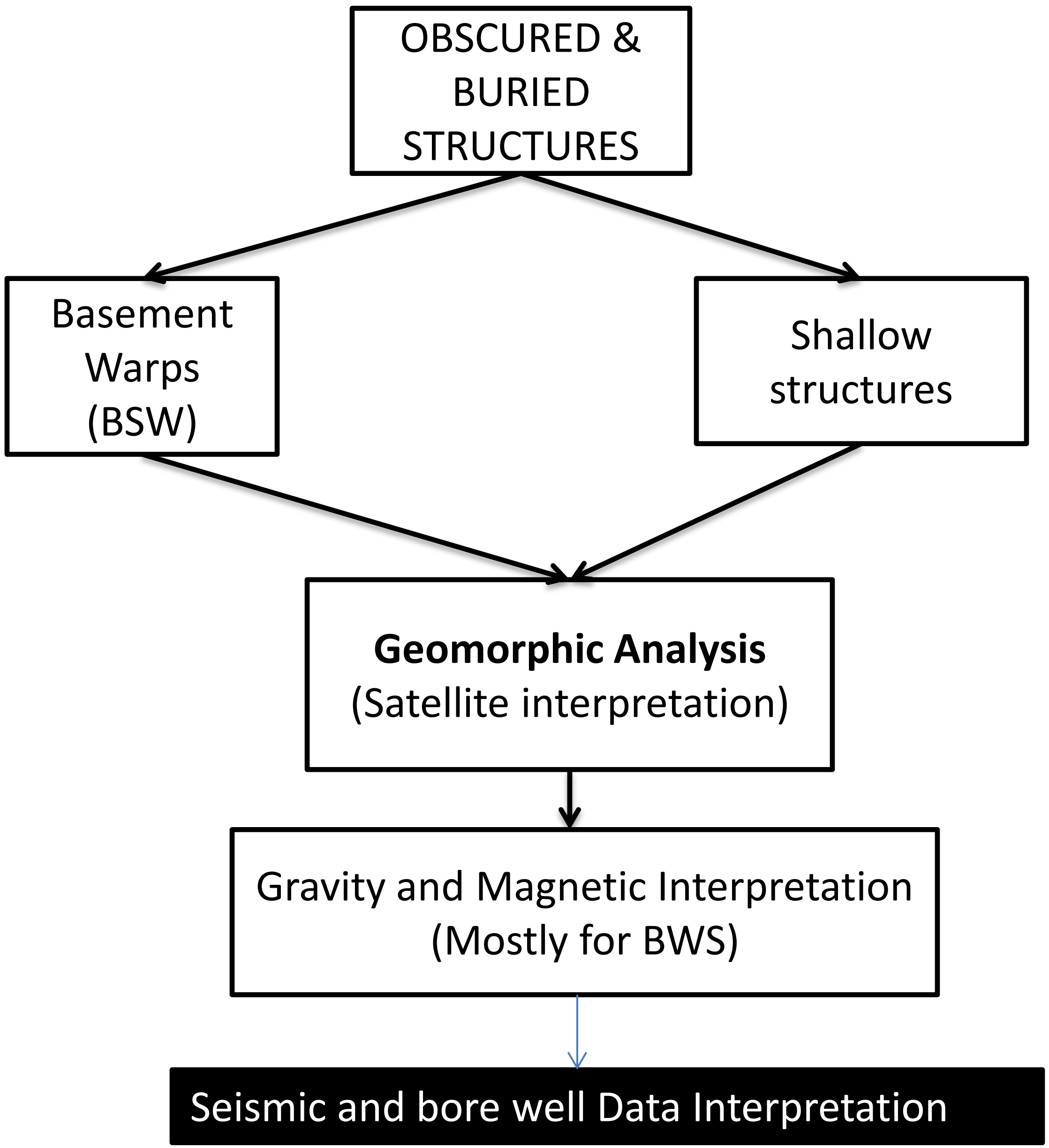
In these regions, the recognition of subtle topographic expression of structures can no longer be accomplished by measurement of exposed outcrops. Rather, the interpreter must rely on the recognition of local drainage, moisture and fracture patterns which indirectly reveal the presence of subsurface structures in the area.

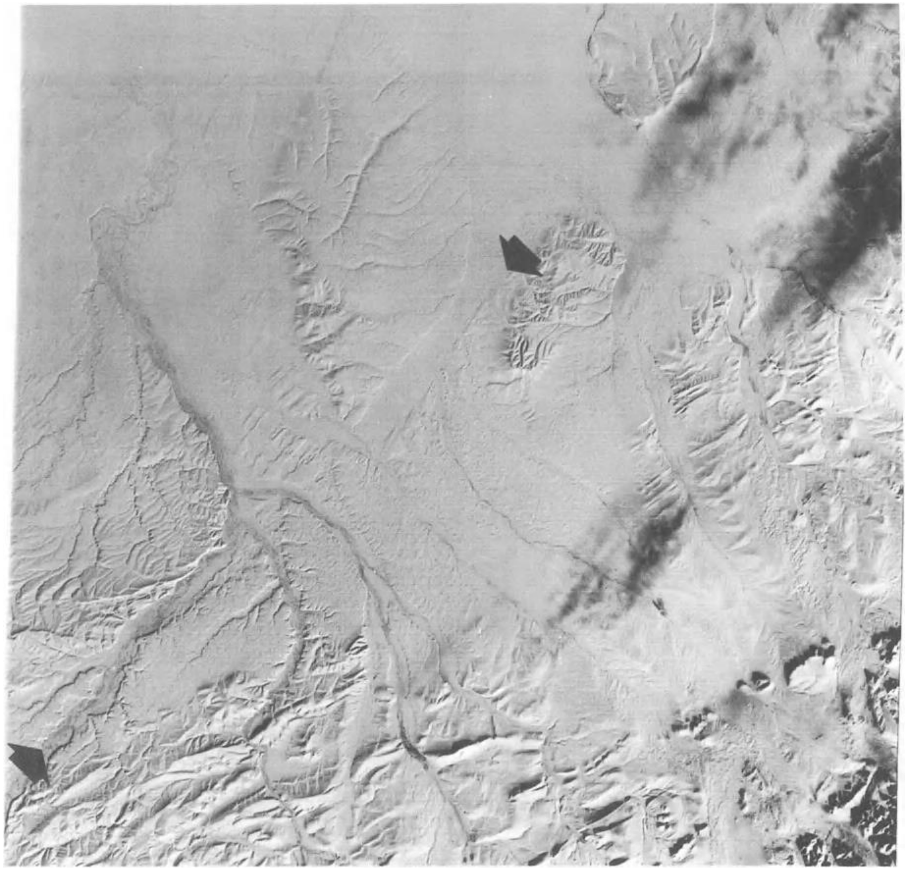
The ability to recognize and map geological structures from remote sensing data dependent primarily on two main factors: **the level of bedrock exposure of the mapped structures and their magnitude of deformation.**

These factors determine:

- the type of the satellite image (i.e. monoscopic vs stereoscopic) that is required for structural mapping
- the kind of interpretation techniques (i.e structural vs geomorphic) that must be employed and
- the level of integration with other data sets that is needed to improve the interpretation of the image.

Exposed structures are recognized and analyzed from the image by the unique expressions of their inclined bedrock strata and fault-line traces.


OBSCURED & BURIED STRUCTURES
Basement Warps (BSW)
Shallow structures
Geomorphic Analysis
(Satellite interpretation)
Gravity and Magnetic Interpretation
(Mostly for BWS)
Seismic and bore well Data Interpretation



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Basin analysis

1. *Geological*
2. *Geochemical*
3. *Geophysical*

Geological methods

Mapping basin boundary, establishing the lithological units, lithological succession, unconformities, identifying and mapping lineaments / faults.

In low relief areas, where such obscured and buried structures occur are divided into two categories.

- *Shallow but well-defined subsurface structures that, once recognized on images can be further studied in detail using seismic and borehole data.*

- *Deep-seated basement warp structures (BWS) that manifest similar surface expressions as the first group, but require tentative interpretation of gravity, magnetics and specially enhanced seismic data for subsurface detection.*

Analysis of deep seated basement structures require the use of various paleotectonic reconstruction techniques of erosional surfaces and analysis of drainage systems.

These two groups also vary significantly in their influence on hydrocarbon plays, with the shallow well defined structures form hydrocarbon structural traps, whereas the deep seated one influences, in most cases, reservoir distributions and related stratigraphic traps.

Most of the techniques for such detection of obscured and buried structures were developed in the early days of onshore exploration using conventional aerial photography. Later, these ideas were successfully adapted for use with various satellite images.

The mechanisms that cause surface expressions of the buried structures must be identified. One must learn to recognize, on images diagnostic features that indicate the presence of subtle obscured and buried structures. Finally, these should be combined to provide one with the ability to predict the shape of obscured or buried structures through the application of geomorphic models which describe their various topographic expressions.

Mechanisms of Surface Expression

Because obscured structures are partially exposed at the surface, it is easy to understand how they might influence surface conditions such as topography, drainage etc.

Buried structures, that are completely buried under soft or consolidated sediments, must influence surface conditions in a more indirect manner. The exact mechanisms by which this occurs are not fully understood, it is possible to postulate that the following are important ***Differential Loading, Differential Compaction, structural reactivation****,* ***disruption of near surface and groundwater flows, underground water flows and related erosional features****.*

All of these lead to the development of surface structures that. although more subtle, mimic the configuration of the underlying features.

Differential Loading : *Differences in the type and thickness of sediment in the vicinity of the buried structure can result in differential vertical stresses. These stresses may cause partial reactivation of structures and lead to local increases in topographic relief or increased fracture density at the surface.*

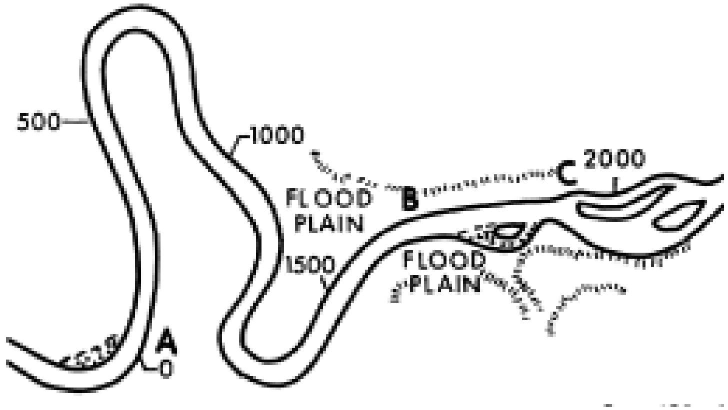
Differential Loading *: Differential Compaction. Lateral variations in the sedimentary column covering buried structures may result in differential compaction and subsidence and lead to local changes in topographic relief or surface fracturing.*

Analysis Criteria

Structurally Controlled Streams

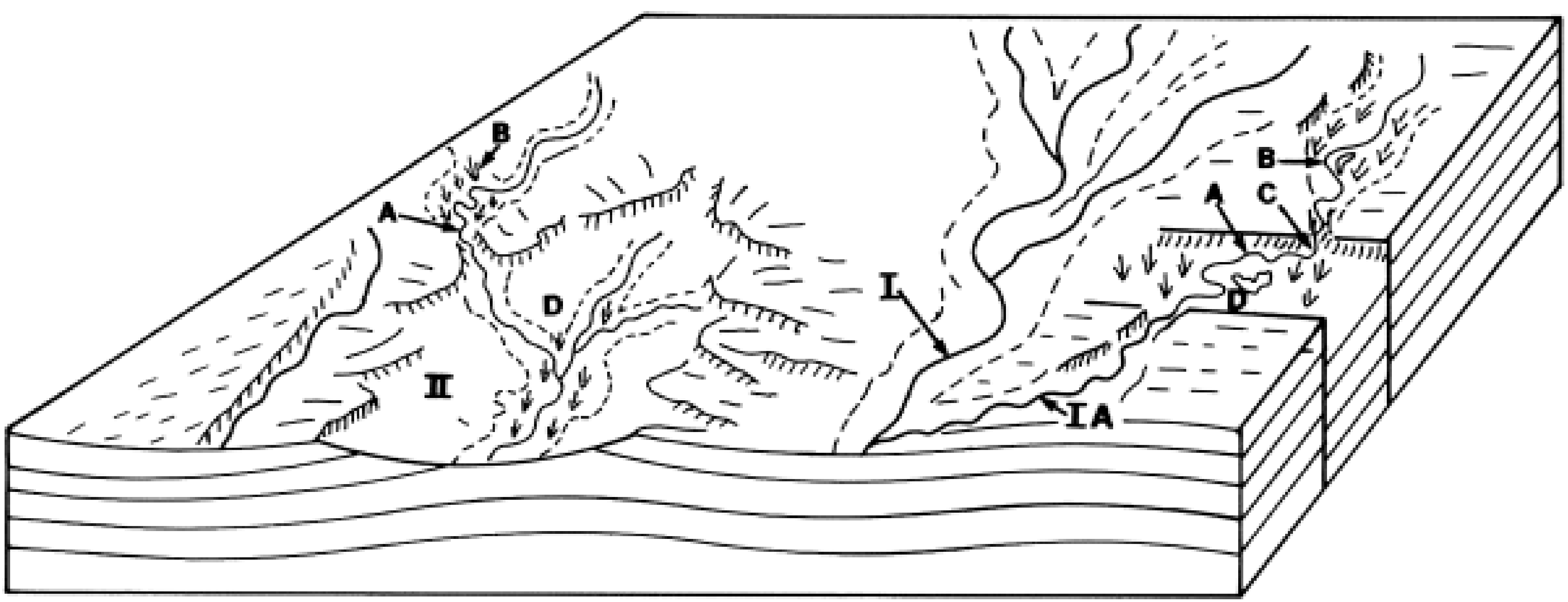
Streams in low relief terrains usually have gentle gradients and tend to flow down the regional slope in wide, shallow valleys. If no obstacles exist, they follow the most direct route from major drainage divides towards the confluence.

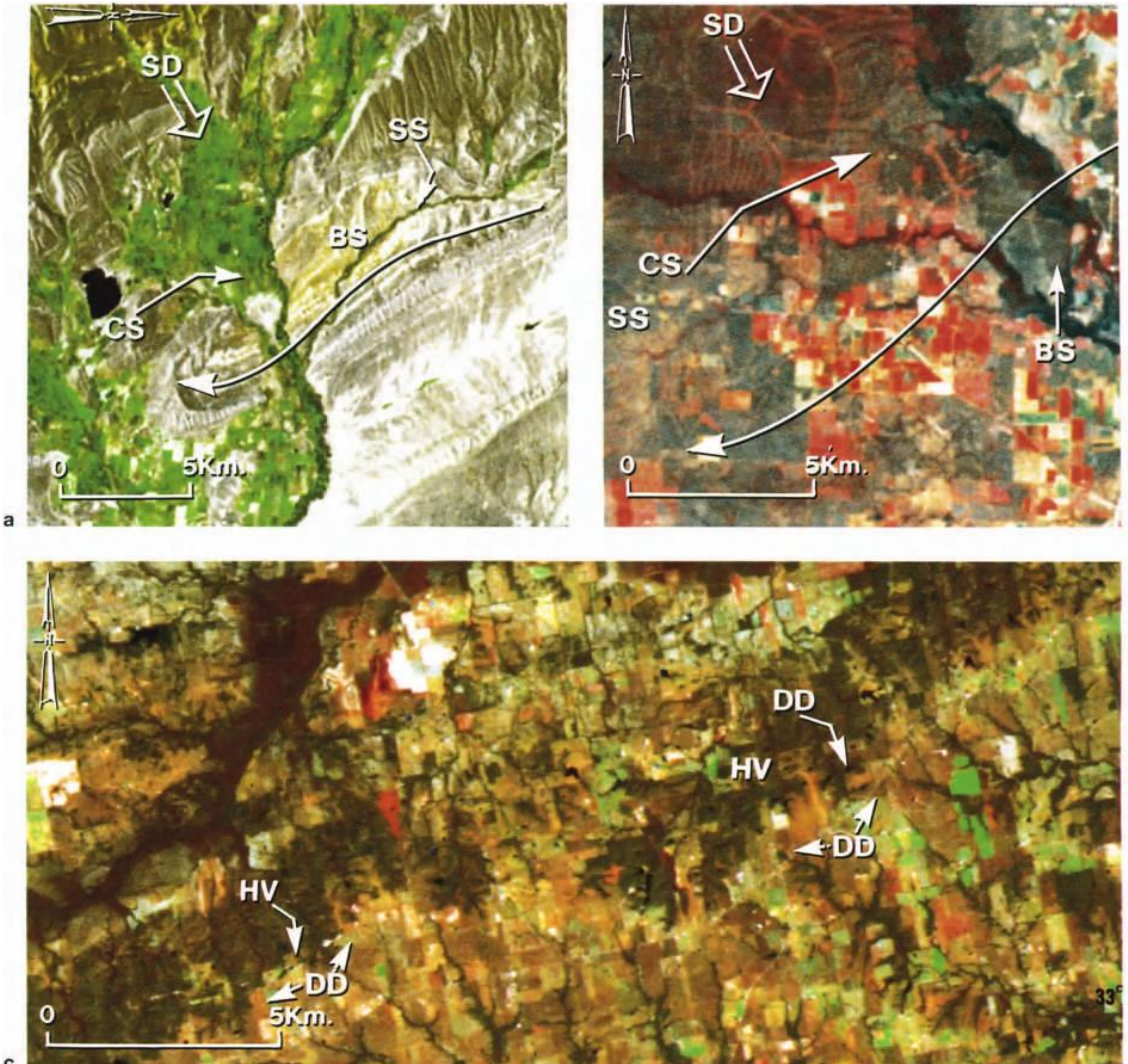
Because of the low gradient, such streams are sensitive to changes in terrain conditions that often occur over and in the vicinity of obscured and buried structures and in adjusting to such changes, these streams develop unique drainage patterns that are anomalous with respect to the regional drainage systems. These local drainage phenomena are often called "drainage anomalies" or "structurally controlled streams"



Channel I represents a channel that developed without the influence of structural features.

Channel IA was disrupted by the presence of an obscured graben feature and channel II is cutting through a breached fold. A Locally pertubed drainage patterns; B abrupt change in channel and valley width; C local deflection of a stream; D local areas of anomalous drainage densities and topographic dissection





Structurally controlled drainages

A - An exposed breached fold

B - A buried fold

C - Obscured normal faults

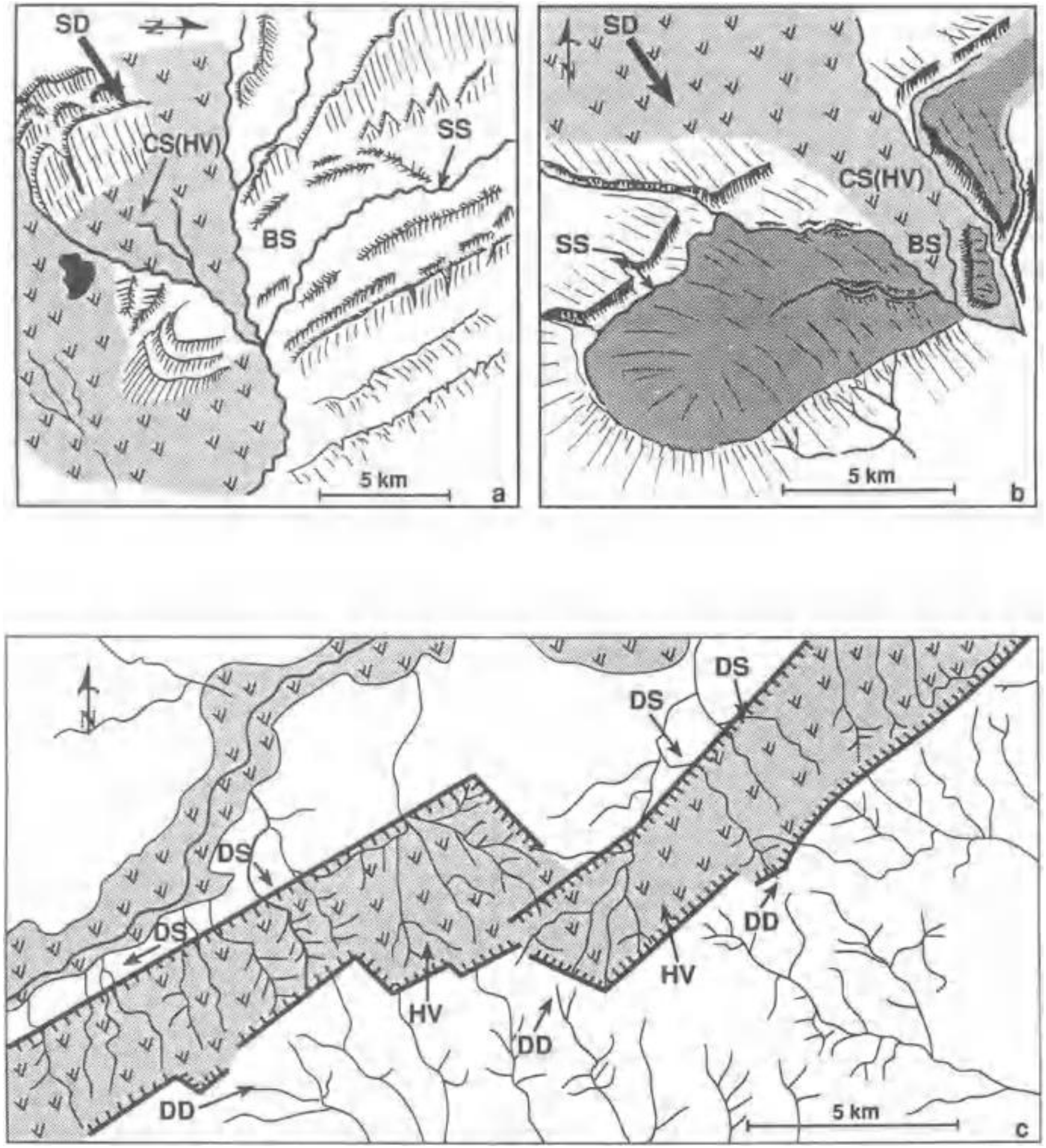
CS - Cone-shaped valley representing abrupt change in width;

SS - Subsequent stream following the strike of the eroded limbs of the anticlines;

DD - structurally controlled drainage divides;

HV – heavy vegetative cover related to increase in moisture conditions;

SD - slope direction



Local deflection of a stream's orientation may occur in preexisting streams upon crossing or circumnavigation of obscured and buried structures (C).

Local areas of anomalous drainage density or topographic dissection may be caused by an increase in relief and surface fracturing. These areas produce textural patterns that are visible on Landsat imagery (D).

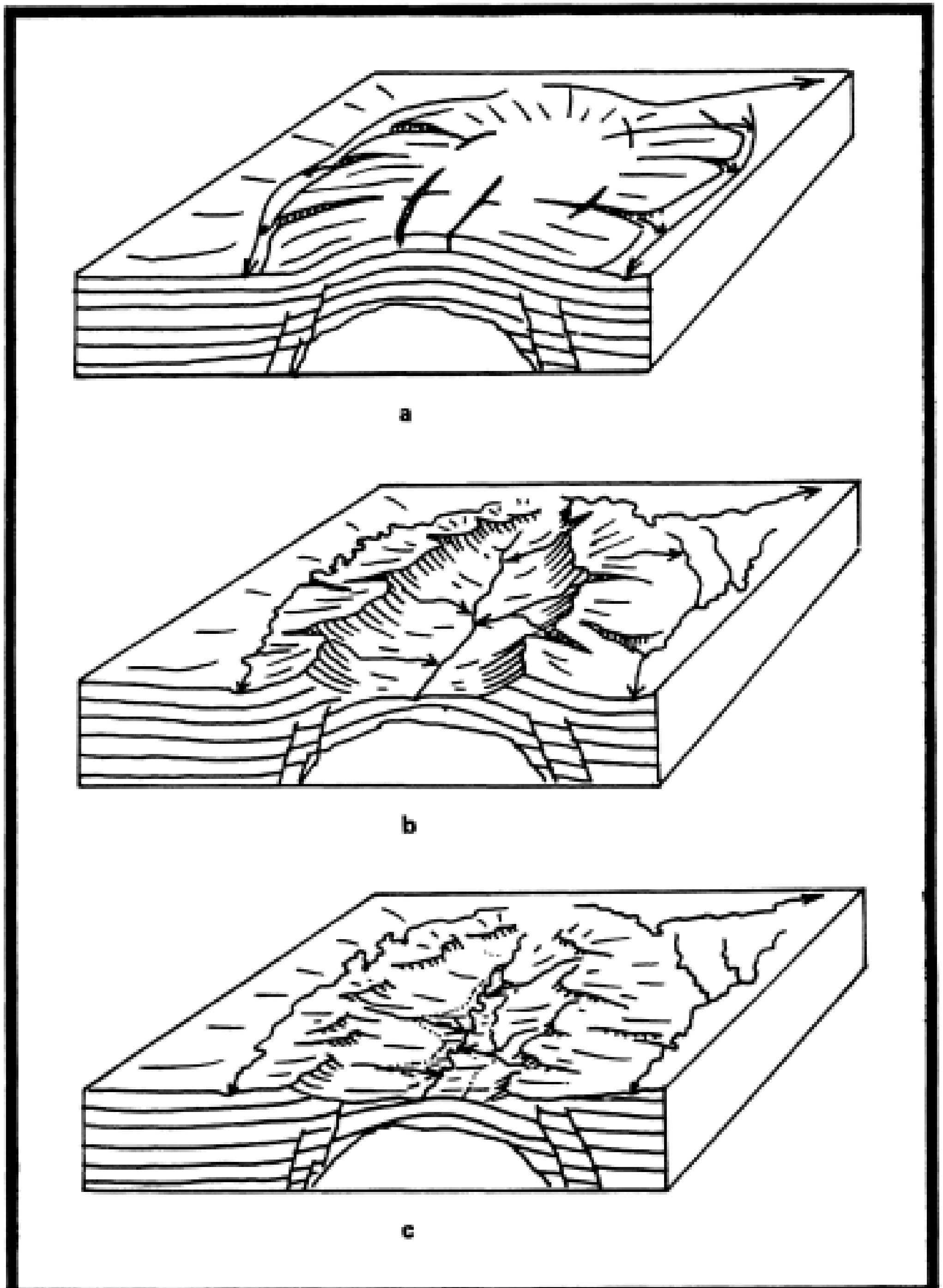
The upper left image (a) shows an example of a partially exposed Anticline. The most important drainage feature to note here is the abrupt change in the channel and valley width that occurs in the valley that crosses and breaches the structure. This surface element is depicted on the image as a profound "cone-shaped“ stream valley.

Also, a tributary on the right half of the image joins the main stream valley at a relatively obtuse angle, following the general strike direction of the anticline rather than the general slope of the basin. This segment of the stream should be regarded as structurally controlled, exhibiting anomalous drainage orientation for this area.

Lineaments and linear features are surface indicators of faults and fractures. The term lineaments refers to regional scale faults and zones of weaknesses in the basement whereas Linear features are individual faults and fractures of diverse origins.

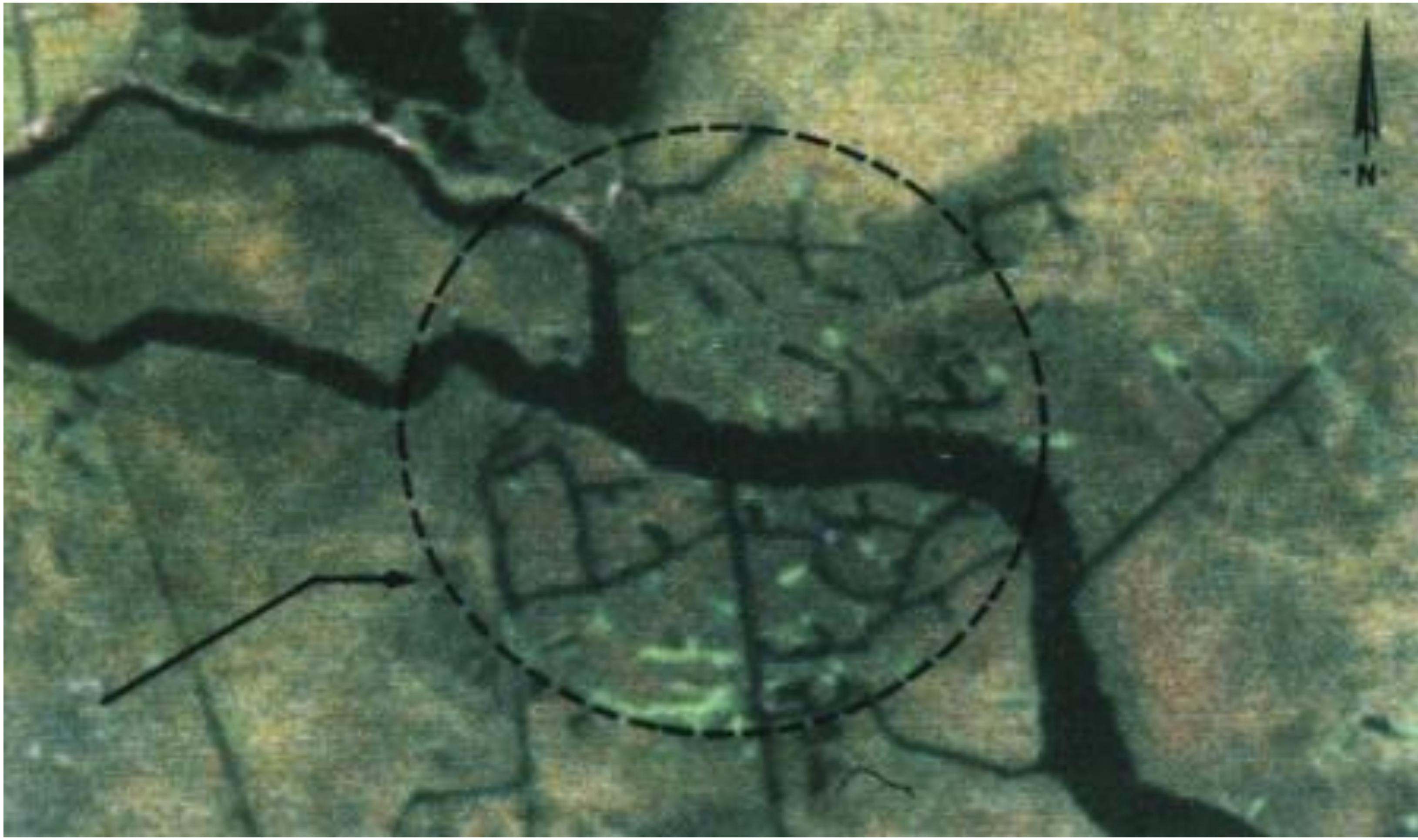
Various types of techniques can be used to reconstruct the topography of buried and obscured structures and their possible geometries in the subsurface.

One method is to use a model of a typical domal feature describing its basic slope and drainage component. dome undergoes the erosional processes which modified its original topographic expressions. Three basic erosional stages are recognized and include the positive relief stage. breached stage and obliterative stage. The recognition of the erosional stages of structures can be used to make predictions about their subsurface conditions as well as to guide the interpretations of their subsurface geometries.



Typical surface expression of obscured and buried structures as defined by slope and drainage components.

a Positive relief stage;
b breached stage;
c obliterative stage.



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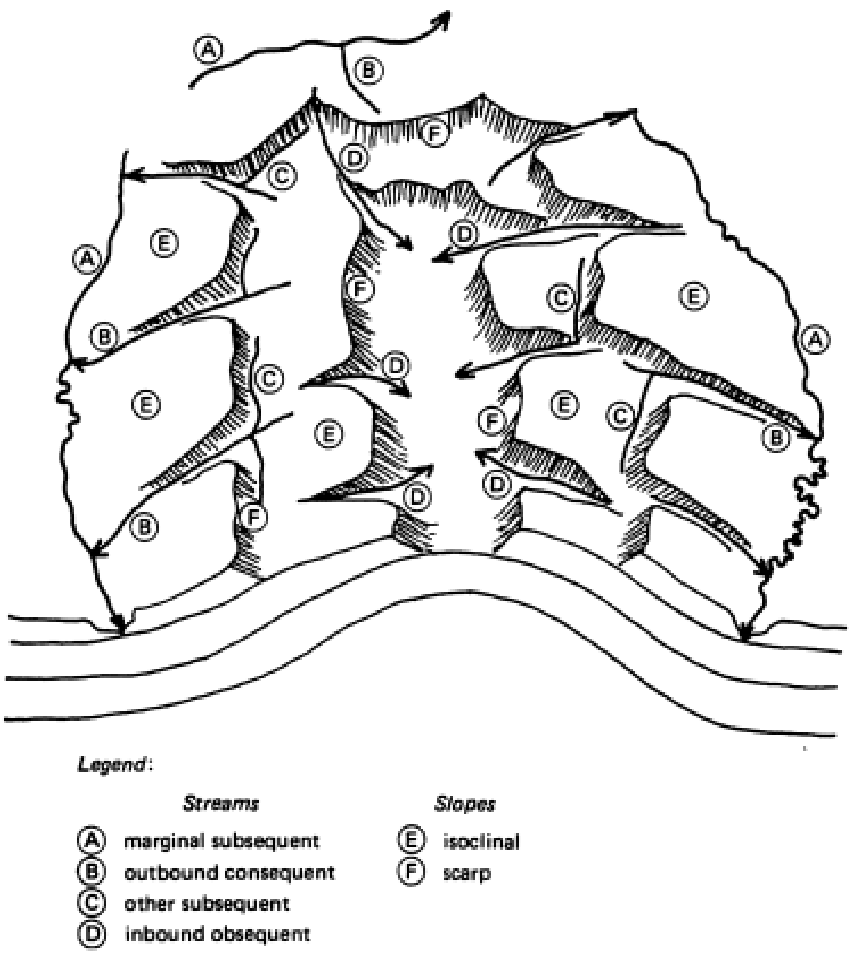
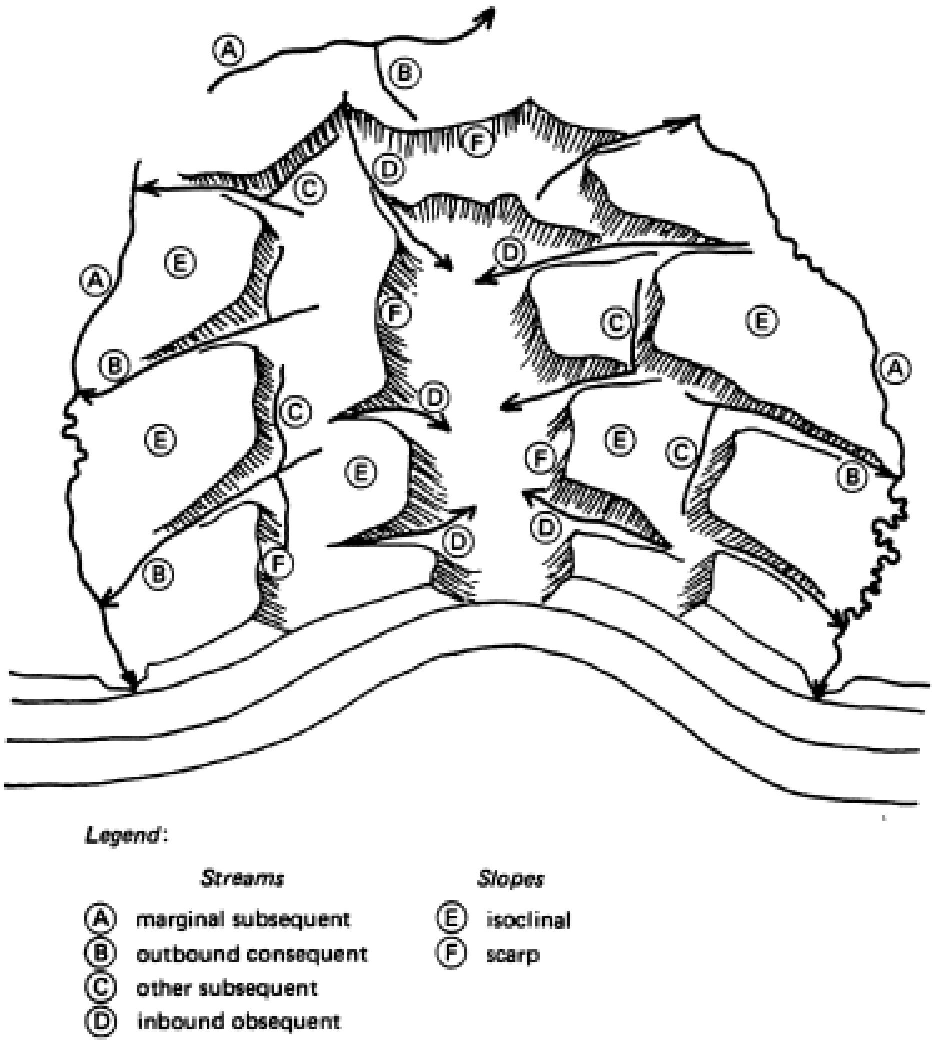
Topographic Models of Obscured and Buried Folded Strata

Obscured and buried domes or other folded structures exhibit similar relationships between topography and structures as their exposed counterparts, except that their topographic expressions are more subtle and require a careful analysis of topographic slopes and drainage elements.



1. Marginal subsequent (strike) streams. These form as preexisting major streams and stream segments and tend to adjust their flow around the newly formed round obstacle. They form a general circular pattern which outlines the outer perimeter of the dome.
2. Outbound consequent (dip) streams. These form in a radiating pattern from the dome center. They may be either collected by the marginal subsequent components or flow directly outward.
3. Other (strike) consequent streams. These streams develop along the eroded consequent cuestas of the inner portion of the dome to follow a concentric drainage pattern.



4. Inbound obsequent (anti-dip) streams. These streams flow toward the dome center. They are usually collected by the central breaching stream following inversion of topography.

5. Isoclinal slopes. These are the long and gentle slopes or slope segments conforming with the arched sediments. These slopes may parallel the gently dipping bedding planes. However, they may also evolve into other inclined erosional surfaces.

6. Scarp slopes. These are short and steep slopes marking the lithological contact between different eroded layers. They always dip towards the breached crest of the dome.

Detection and Analysis of Basement Warp Structures

These structures are more subtle and originate in the deep basement, they differ from the obscured and buried structures in two significant aspects.

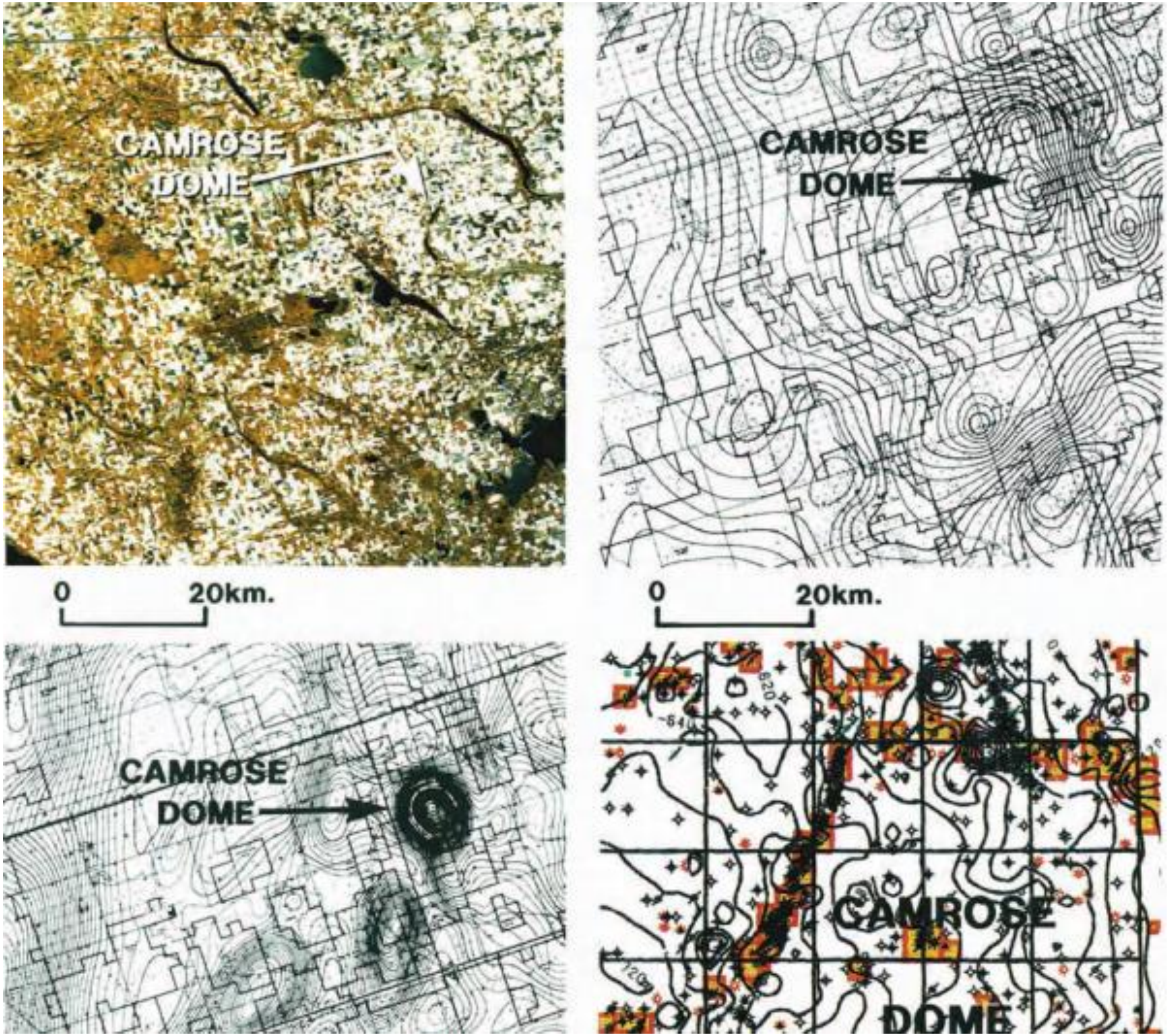
First, their subsurface constraints are often difficult to define with conventional interpretation techniques.

Second, they usually do not form pure structural traps, but rather exert significant control on the development of reservoir rocks in their vicinities.

Detection and evaluation of BWSs require the use of several analytical techniques.

First, the recognition of these structures on imagery must be accompanied by the identification of corresponding basement signatures on gravity and magnetic data. (Satellite images along with gravity and magnetic data are often referred to collectively as reconnaissance tools.)

Second, the expressions of these features in the sedimentary cover must be ascertained through the subsurface mapping techniques that are specially designed to capture such subtle subsurface structures. For example, enhanced seismic lines are often used in these circumstances.


CAMROSE
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A well-known phenomenon associated with hydrocarbon reservoirs is the leakage of hydrocarbons from the deep reservoir rocks to the surface, known as seepage.

Hydrocarbon seepage is generally categorized in two different phenomena: ***macro seepage*** *and* ***micro seepage****.*

The first being fluxes of oil seeps reaching the surface and accumulating in visible quantities, while the second type consists of feeble volatile hydrocarbon migrations.

Long-term upward leakage of hydrocarbon can induce local alterations of the surface due to geochemical and biochemical processes induced by microbial activity. So far, remote sensing has been successfully used for both macro seepage direct detection and micro seepage indirect detection.

Apart from these Remote sensing from satellites or aircraft enables to find one or more indicator of surface anomalies. this is the so-called micro seepage model, which leads to specific geochemical anomalies.

Microseeps are invisible traces of light hydrocarbons (primarily C_1 – C_5 substances) that seep to the surface from an oil or gas reservoir. When hydrocarbons migrate upward and reach exposed air at the surface, several manifestations occur at or near the surface that we can monitor with remote sensing.

While remote sensing cannot directly detect micro seeps, it can reveal alteration patterns at a large scale that provide a starting point for further exploration.

Also, drainage patterns at broader scales may reflect control by underlying rocks involved in suitable traps. And even vegetation distribution may disclose signs of structure. These and other indicators identifiable in space images appealed to exploration geologists as another means to survey large sedimentary basins.

*The two most useful indicators identifiable in aerial photos or space borne images are **fracture systems** (mainly faults/lineaments) which can control or affect the migration of gas and oil to the surface and **geochemical alterations** of surficial rocks by hydrocarbons which lead to compositional and color changes.*

Micro seepages are the result of vertical movement of light hydrocarbons from the reservoir to the surface through the network of fractures, faults etc. that provide permeable routes within the overlying rock. Micro seepages express themselves at the surface in an array of alterations and anomalies, such as chemical or mineralogical changes in overlying soils and sediments.

Macro seeps are typically regarded as direct clues for the existence of mature source rock whereas micro seeps, which occur in a near vertical fashion over an accumulation, are employed as a targeting tool for petroleum exploration.

Over the years, a range of techniques, including remote sensing, has been employed for seepage detection. The remote sensing approach holds a great promise because it is a fast and cost-effective tool applicable to for both direct and indirect seepage mapping.

Initially, multispectral images were processed by simple techniques, like band arithmetic, to discriminate broad alteration patterns. Recently, hyperspectral sensors have started to be used for oil seep identification. While conventional multispectral sensors record the reflectance / emittance only at a handful of wavelengths, hyperspectral sensors measure the reflectance at hundreds contiguous and narrow wavelength bands (bandwidth between 5 and 10 nm), spanning from the visible to the infrared.

Hyperspectral images provide greater spectral information to identify and distinguish between spectrally similar (but unique) materials, providing the ability to make proper identification among materials with only subtle signature differences. Hence, have potentiality for micro seep detection.

Every material on earth has unique reflectance and absorption features (a spectral signature) that can be used for its remote identification. The dominant minerals and chemical composition in a rock can be detected using this methodology.

Satellite (e.g., Hyperion) and airborne (e.g., HyMap and AVIRIS) hyperspectral remote sensing systems have practically continuous spectral coverage across the wavelength interval of 0.45-2.5 μm, and they are successfully used to map a variety of surface materials, mineral deposits, rock alterations, etc., with a spatial resolution ranging from 3 to 30 m.

Spectroscopy is the measurement of light as a function of wavelength reflected or emitted from a material. The resultant spectrum conveys information about the material, whether rock, water body etc.

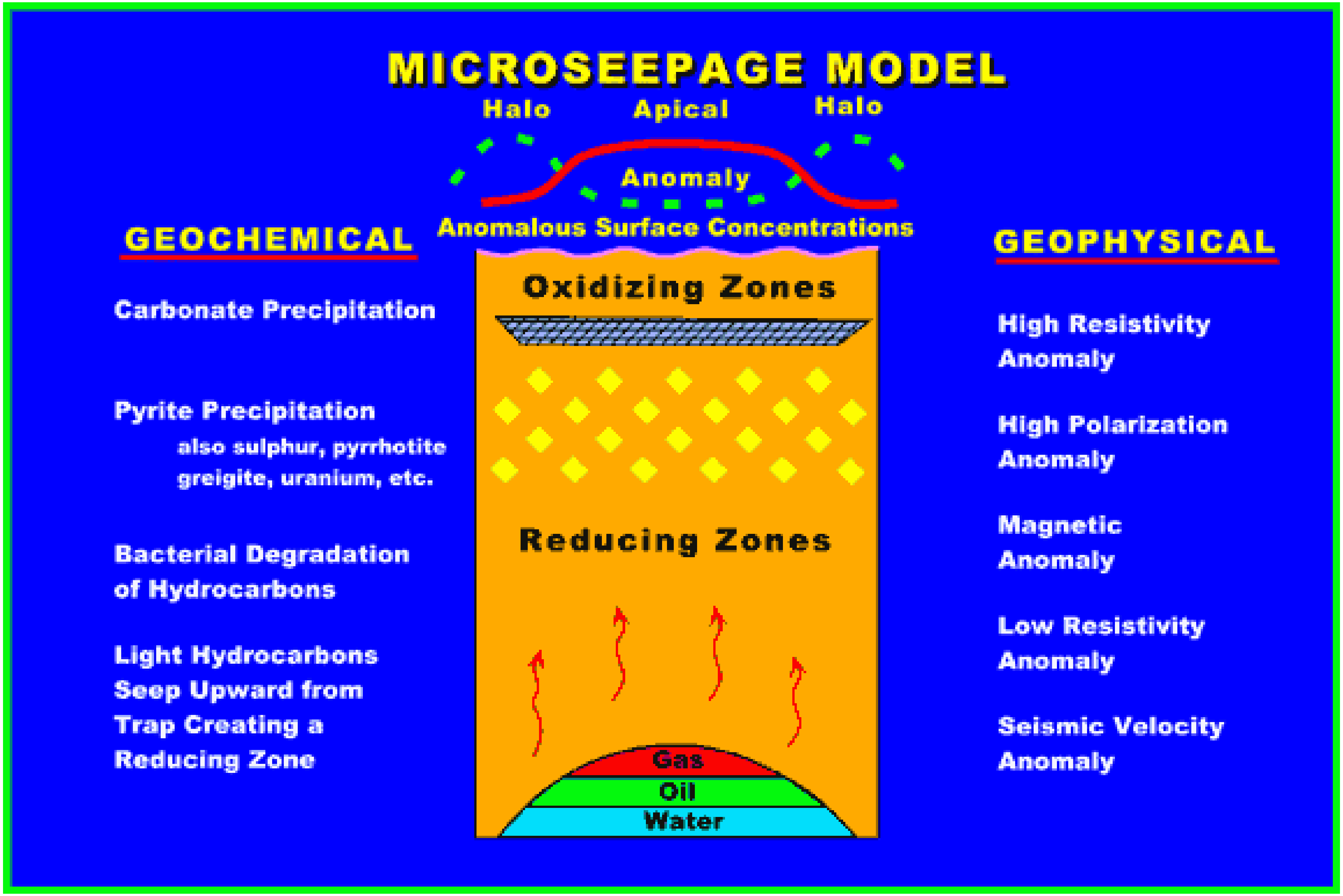
In the early 70s researchers established a link between observed variation in reflectance / emittance spectra with chemical and physical properties of minerals and demonstrated their potential use in remote sensing.

Minerals, rocks, and other terrestrial compounds like hydrocarbons exhibit diagnostic absorption features in either the visible-near infrared (VNIR - 0.4-1.0 μm), shortwave infrared (SWIR - 1.0-2.5 μm), mid infrared (MIR - 3-5 μm), and/or far infrared (FIR - 8-14 μm) wavelength ranges.

Hyperspectral remote sensing, also known as imaging spectroscopy, is a relatively new technology that is currently being investigated by researchers and scientists with regard to the detection and identification of minerals, terrestrial vegetation etc.

Imaging spectroscopy has been used in the laboratory by physicists and chemists for over 100 years for identification of materials and their composition. Spectroscopy can be used to detect individual absorption features due to specific chemical bonds in a solid, liquid, or gas.

Recently, with advancing technology, imaging spectroscopy has begun to focus on the Earth. The concept of hyperspectral remote sensing began in the mid-80's and to this point has been used most widely by geologists for identifying rocks / minerals.


MICROSEEPAGE MODEL
Halo
Apical
Halo
Anomaly
Anomalous Surface Concentrations
GEOCHEMICAL
Carbonate Precipitation
Pyrite Precipitation
also sulphur, pyrrhotite
greigite, uranium, etc.
Bacterial Degradation
of Hydrocarbons
Light Hydrocarbons
Seep Upward from
Trap Creating a
Reducing Zone
Oxidizing Zones
Reducing Zones
Gas
Oil
Water
GEOPHYSICAL
High Resistivity
Anomaly
High Polarization
Anomaly
Magnetic
Anomaly
Low Resistivity
Anomaly
Seismic Velocity
Anomaly

The long-term leakage of hydrocarbons in a micro seepage system normally induces a set of diagenetic, physio-chemical and mineralogical transformations in the area directly above (Chimney column) hydrocarbon accumulations.

The activity and by-products of bacteria and other microbes are believed to change the pH, Eh of the overlying stratigraphic column and initiate a series of diagenetic changes like

(1) anomalous hydrocarbon concentrations in sediments, soil, water, and even atmosphere

(2) microbiological anomalies and the formation of "paraffin dirt"

(3) anomalous non-hydrocarbon gases such as helium and radon

(4) mineralogical changes such as the formation of calcite, pyrite, uranium, elemental sulphur, and certain magnetic iron oxides and sulphides

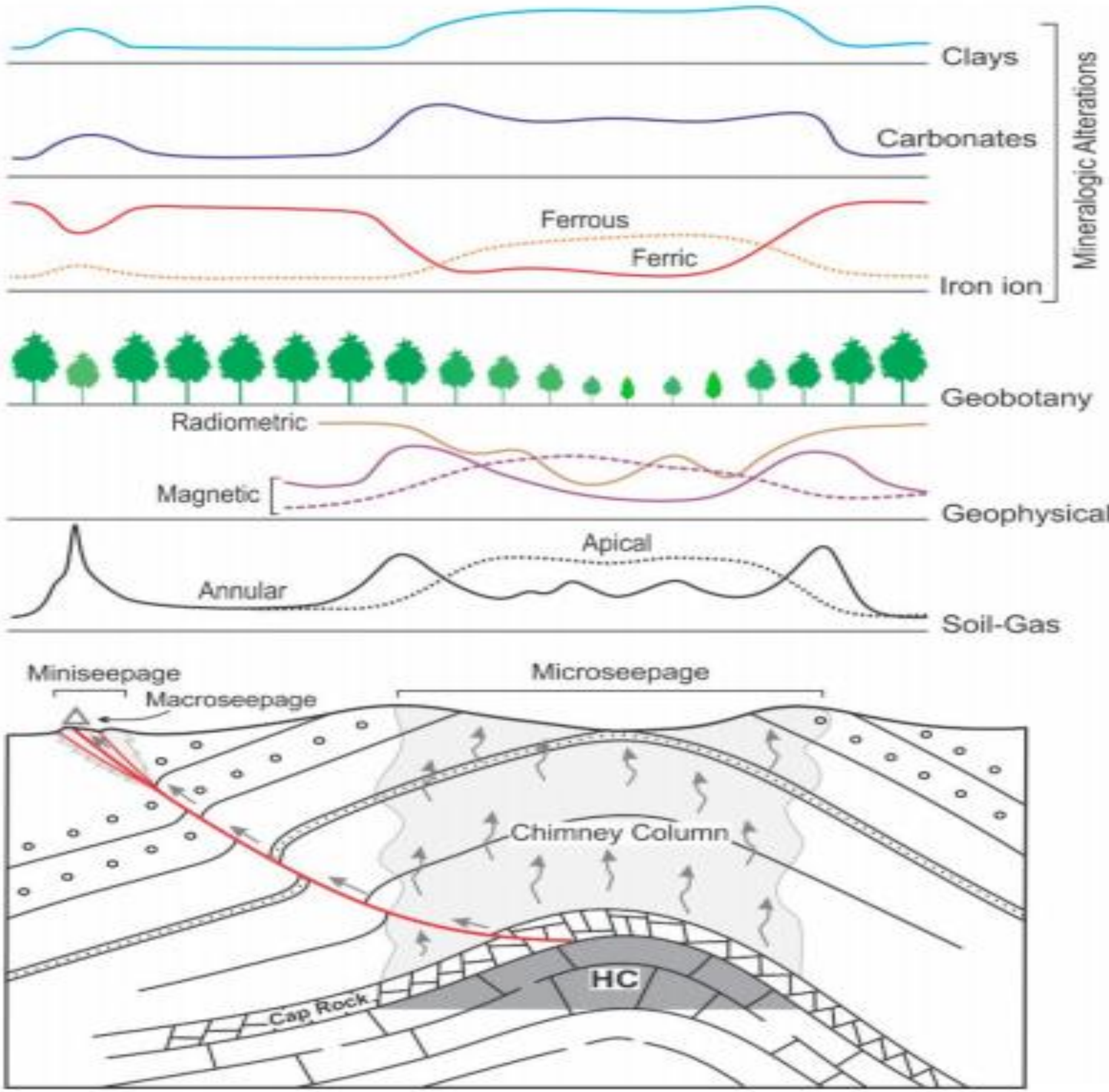
(5) clay mineral alterations

(6) radiation anomalies

(7) geothermal and hydrologic anomalies

(8) geobotanical anomalies

(9) altered acoustical, electrical, and magnetic properties of soils and sediments.



Clays
Carbonates
Ferrous
Ferric
Iron ion
Mineralogic Alterations
Geobotany
Radiometric
Magnetic
Geophysical
Apical
Annular
Soil-Gas
Miniseepage
Microseepage
Macroseepage
Chimney Column
HC
Cap Rock

Carbonate precipitation*: carbonate rocks are quite common in areas of micro seepages. The diagenetic carbonate species detected so far is very diverse and ranges from calcite to dolomite, ankerite, siderite, rhodochrosite, and aragonite; though calcite by far is the dominant.*

These near-surface diagenetic carbonates are formed principally as a byproduct of petroleum oxidation, particularly of methane, as shown below:

1. Aerobic: $CH_4 + 2O_2 + Ca^{2+} = CaCO_3 + H_2O + 2H^+$
2. Anaerobic: $CH_4 + SO4^{2-} + Ca^{2+} = CaCO_3 + H_2S + H_2O$

Bleached red-beds*: The presence of bleached and discolored red sandstones at the surface above petroleum accumulations has been widely noted. Sandstone formations normally have a reddish color if they contain iron oxide (hematite). When hydrocarbons migrate upward, they dissolve the iron oxide and bleach the sandstone. These areas will show reduced amounts of ferric iron with an increase in elements like pyrite and siderite. The possible reducing agents responsible for bleaching red beds above petroleum accumulations include hydrocarbons, H_2S, and CO_2.*

Clay formation: *clay formation is mostly related to slightly acidic conditions in the chimney column. Kaolinite, which by far is the prevalent clay in micro seepage-induced alterations, is believed to form after the alteration of feldspars or the conversion of then unstable illitic / smectitic clays. This process can liberate potassium (K) from clays, and thus lead to low gamma ray radiations above HC deposits.*

Sulfides

The formation of secondary Pyrite and other sulfides has been documented for many petroleum fields. Pyrite is the dominant sulfide mineral in these hydrocarbon induced alteration zones but pyrrhotite, marcasite, galena, sphalerite and native sulfur are also found.

Pyrite can be precipitated in a reducing environment, given a source of sulfur and iron. The major source of sulfur in a petroleum province is hydrogen sulfide gas from the petroleum itself, from anaerobic bacterial activity, or from the oxidation of petroleum in the near-surface.

Sources of iron include iron oxide grain coatings in sandstone, pore-filling clays such as chlorite, rock fragment inclusions, and deeper meteoric waters.

The reaction of hydrogen sulfide and iron (from hematite) to precipitate pyrite or marcasite can be summarized as

$$Fe_2O_3 + 4\ H_2S = 2\ FeS_2 + 3\ H_2O + 2\ H^+ + 2e^-$$

The development of a pyrite alteration zone depends on the sulfur content of the oils, the geology and groundwater geochemistry of the sedimentary sequence, and the nature of the bacterial degradation.

Uranium

The occurrence of uranium has been linked to HC deposits. The association between petroleum and heavy metals such as uranium (as well as lead, zinc, and even gold) is due to the reducing environment created by migrating hydrocarbons and associated fluids favors the precipitation of uranium and other heavy metals.

Oxidized uranium (UO_2^{2+}) is soluble in groundwater, although when reduced, it precipitates from solution as Uraninite (UO_2), which is relatively insoluble.

In order to correctly interpret the hyperspectral data, the retrieved spectral signatures must be correlated to specific materials. Therefore specific spectral libraries, containing the spectral signature of the materials to be detected, must be built up.

This requires that highly accurate measurements of samples of the investigated material must be performed in the lab or in the field.

The absorption characteristics related to HC micro seepage is mainly in the wavelength regions of **1720-1750 nm** (1.720-1.750 μm), **2310-2350 nm**. The absorption is stronger at 2310-2350 nm, but it gets overlapped with absorption features of other mineral (ex. calcite).

*Hence, careful processing and analysis as diagnostic spectral feature of oil and gas hydrocarbons extracted, at diagnostic absorption features is weaker at **1720-1750 nm**.*

In order to effectively detect, we need high performance hyperspectral remote sensing instruments. Combing with the hydrocarbon alteration minerals (e.g.: kaolinite, illite etc.) hyperspectral extraction models, we can also indirectly identify the target filled of land oil and gas reservoirs by using hyperspectral remote sensing technology.

Altered Minerals Mapping

Based on the hydrocarbon micro-seepage theory, the contents of Fe^{2+}, *carbonate, and clay minerals in the overlying soil, are important indicators for alterations. And they all present obviously the spectral absorption features at the visible to near-infrared wavelengths*.

To analyze hyperspectral image, pixel unmixing process is used. Pixel unmixing process involves identifying the pure pixels from the data cube. The pure pixels identified are known as end members.

End members are the macroscopic objects available in the scene. It can be either vegetation, water, mineral, soil etc. Hyperspectral analysis includes estimation of end members available in a hyperspectral image (HSI) and their abundance in each pixel of the scene.

Further, the end members which have been recognized can be used to plot in the spatial distribution, and interpreted by associating its signature and abundances

Remote sensing is offering a unique opportunity to detect the full range of onshore seepage indications; typically, the ***VNIR–SWIR*** *wavelengths have been used to map the alteration of micro seepage systems and the SWIR–LWIR wavelengths to detect the manifestation of oil and gas macro seeps.*

Spectral Angle Mapper (SAM) *and* ***Mixture Tuned Matched Filter (MTMF)*** *techniques were often utilized for micro seeps identification. SAM is a method for directly comparing image spectra to known spectral end members input by the user and/or defined from the image spectra itself.*

MTMF *method provides a means of detecting specific materials based on matches to user end member input or image-derived end member spectra. However, unlike SAM, which picks the best match to a given spectrum in the image, MTMF first maximizes the response of the known end members and suppresses the response of the unknown background signal in the image prior to matching.*

SAM analysis is more effective in the classification of anomalous areas, or areas that are distinct from their surroundings.

Gas-plume sensing

In the marine environment gas seeps are easily noticeable whereas on the land terrestrial seepage of gas often get unnoticed. Generally, where the emission of such gas seeps occur as concentrated point sources, the escaping methane can form discernible gas-plume in the atmosphere and thus constitute detectable target.

Current orbital gas remote sensing instruments like the Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY) and the Greenhouse Gas Observing Satellite (GOSAT) have the capability to measure methane and other trace gasses but only in continental scales.

The delineation of point source gas plumes at local-scale, thus studied with high spatial (GSD<20 m) and spectral resolution hyperspectral imaging instruments.

The detection and mapping of methane plumes relies on its diagnostic absorption features in the SWIR (~2.3 μm) and/or the LWIR (~7.6 μm) wavelengths.

In the SWIR, AVIRIS images were successful in detecting the concentrated sources of CH_4. In the case of terrestrial methane mapping where emissions occur over non-uniform and heterogeneous background, encouraging results were achieved by more advanced processing algorithms such as the Cluster-Tuned Matched Filter (CTMF) and the Iterative Maximum a Posteriori Differential Optical Absorption Spectroscopy (IMAP-DOAS).

In the LWIR wavelength has already given encouraging results for CH4 detection. The data from the airborne Hyperspectral Thermal Emission Spectrometer (HyTES) at ~ 2 m sp.resolution were successful to map several individual methane plumes over oil fields in the San Joaquin Valley, California

Gas-plume sensing capability depends heavily on the seepage intensity, wind speed, the specification of the sensor (i.e. the spectral resolution and signal-to-noise ratio), and background cover, with spectrally uniform images being more advantageous relative to spectrally and thermally heterogeneous scenes.

Unlike the SWIR range, which is dependent on surface albedo, sensors in the LWIR range on the thermal emission and thermal contrast between ground and target gas. Hence, gas sensing in the LWIR could be more effective over a wider variety of land covers. Simultaneous SWIR–LWIR data acquisition is required to investigate this notion

Gas-plume sensing studies have been confined to methane detection, ethane (C2+) constitutes a better exploration indicator because methane emissions from geologic sources can incorporate 2–6% ethane on average, the recorded signal over natural plumes can be the overlap of methane and ethane signatures. The possibility of tracing ethane across geologic plumes is being explored.

Subsurface hydrocarbon traps are not correctly sealed, and hydrocarbons move vertically from the reservoir as invisible traces in the form of micro seepages. Long term hydrocarbon micro seepages cause surface or near-surface alterations such as bleaching of red beds, enrichment of ferrous iron minerals and higher concentrations of clay and carbonate minerals in soils/rocks. Multi and hyperspectral remote sensing data have successfully been used to detect such alterations in many parts of the world.

Generally, Landsat 7 ETM+ images have been used to find out hydrocarbon micro seepage-bearing areas. Based on the spectral characteristics of the hydrocarbon microseepage induced altered minerals, two spectral enhancement techniques, viz. **principal component analysis (PCA)** and **band ratio analysis**, have been carried out on the Landsat 7 ETM+ images.

PCA reveals that three principal component images – 1457 PC3, 1345 PC2 and 3457 PC4 - show relatively better enhancement for the hydrocarbon-bearing alteration areas. Again, band ratio analysis of the images indicates that ratio images - 3/1, (2 + 5)/(3 + 4) and 7/5 - show excellent spectral enhancement for the hydrocarbon-induced mineral alterations.

The three PC images have been combined with the three band ratio images to find out probable hydrocarbon micro seepage areas. The remote sensing-derived prospect areas have been validated with surface geochemical, seismic/geologic and gravity data available in the area.

Soil tonal changes

Surface indications of oil and gas seepage have been noted for thousands of years, and such seeps have led to the discovery of many important petroleum producing areas. Over the past sixty years, numerous geochemical exploration methods have been developed.

Long-term leakage of hydrocarbons, either as macro or micro seepages, can induce near-surface oxidation-reduction zones that favor the development of several chemical and mineralogical changes.

The bacterial oxidation of light hydrocarbons can directly or indirectly bring about significant changes in the pH and Eh of the surrounding environment, thereby changing the stability fields of the different minerals present in that environment.

These changes result in the precipitation or solution and remobilization of various minerals and elements, such that the rock column above a leaking petroleum accumulation becomes significantly and measurably different from laterally equivalent rocks.

Geochemical exploration for petroleum is the search for chemically identifiable surface or near-surface occurrences of hydrocarbons and their alteration products, which serve as clues to the location of undiscovered oil and gas accumulations.

This alteration chimney or plume has been documented and its surface expression can range from subtle biogeochemical anomalies to the dramatic **hydrocarbon-induced diagenetic aureoles (HIDAs).** Because such changes are measurable and mappable, they have formed the basis for many different surface exploration methods over the years.

The past decade has seen a renewed interest in surface geochemical exploration. There is now consensus with the following points:

- All petroleum basins exhibit some type of near-surface hydrocarbon leakage.
- Petroleum accumulations are dynamic and their seals are imperfect.
- Hydrocarbon seepage can be active or passive and is visible (macro seepage) or only detectable analytically (micro seepage).
- Hydrocarbons move vertically through thousands of meters of strata without observable faults or fractures in a relatively short time (weeks to years).
- Relationships between surface anomalies and subsurface accumulations range from simple to very complex.