PSNon-Seismic Detection of Hydrocarbons: An Overview*

Dietmar (Deet) Schumacher[1]

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[1] E&P Field Services, USA, France, and Malaysia, (deet@enp-services.com)

Abstract

Surface manifestations of hydrocarbon seepage and microseepage can take many forms, including (1) anomalous hydrocarbon concentrations in sediments; (2) microbiological anomalies; (3) mineralogic changes such as the formation of calcite, pyrite, uranium, elemental sulfur, and certain magnetic iron oxides and sulfides; (4) bleaching of red beds; (5) clay mineral changes; (6) acoustic anomalies; (7) electrochemical changes; (8) radiation anomalies; and (9) biogeochemical and geobotanical anomalies. These varied expressions of hydrocarbon seepage have led to the development and marketing of an equally diverse number of hydrocarbon detection methods. These include direct and indirect surface chemical methods, magnetic and electrical methods, radioactivity-based methods, and satellite remote sensing methods. Each has its proponents; each claims success; and all compete for the explorationists' attention and dollars. Is it any wonder many explorationists are confused, or at least skeptical?

What are the benefits of using geochemical and non-seismic geophysical hydrocarbon detection methods in conjunction with conventional exploration methods? A review of more than 2700 US and international wildcat wells – all drilled after completion of geochemical or non-seismic geophysical hydrocarbon detection surveys – showed that >80% of wells drilled on prospects associated with positive hydrocarbon microseepage anomalies resulted in commercial discoveries. In contrast, only 11% of wells drilled on prospects without such anomalies resulted in oil or gas discoveries.

Clearly, the benefits of such hydrocarbon detection surveys are significant. Although these geochemical and non-seismic methods cannot replace conventional exploration methods, they can be a powerful complement to them because they provide evidence of hydrocarbons in the prospect or area of interest. The need for such an integrated exploration strategy cannot be overemphasized. This presentation will be illustrated with examples from satellite remote sensing data, surface geochemical surveys, aeromagnetics/micromagnetic surveys, and passive and active electromagnetic.

NON-SEISMIC DETECTION OF HYDROCARBONS: AN OVERVIEW

Dietmar “Deet” Schumacher, E & P Field Services, USA - France - Malaysia

FIGURE 1: Photo of airplane used for collection of aeromagnetic data

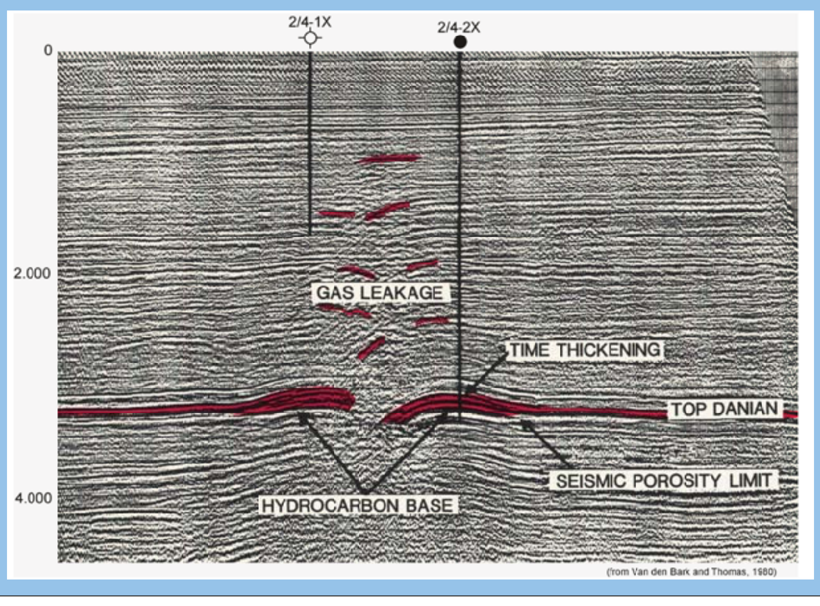
ABSTRACT

The surface expression of hydrocarbon seepage and hydrocarbon-induced alteration of soils and sediments can take many forms including (1) anomalous hydrocarbon concentrations in soils, sediments, and waters; (2) microbiological anomalies and the formation of “paraffin dirt”; (3) mineralogic changes such as formation of calcite, pyrite, uranium, elemental sulfur, and certain magnetic iron oxides and sulfides; (4) bleaching of redbeds; (5) clay mineral alteration; (6) electrochemical changes; (7) electromagnetic and telluric changes; (8) radiation anomalies; and (9) biogeochemical and geobotanical anomalies. These different surface and near-surface effects and their varied surface expressions have led to the development of an equally varied number of geochemical and non-seismic geophysical exploration techniques. These include direct and indirect geochemical methods, magnetic and electrical methods, radioactivity-based methods, and remote sensing methods.

What are the benefits of using geochemical and non-seismic geophysical hydrocarbon detection methods in conjunction with conventional exploration methods? In a review of more than 2600 US and International wildcat wells - all drilled after completion of geochemical or non-seismic hydrocarbon detection surveys - more than 80% of wells drilled on prospects associated with positive hydrocarbon anomalies resulted in commercial discoveries; in contrast, only 11% of wells drilled on prospects not associated with such anomalies resulted in discoveries. Clearly, the benefits of such hydrocarbon detection surveys are significant. Although these methods cannot replace conventional exploration methods, they can be a powerful complement to them. The need for such an integrated exploration strategy cannot be overemphasized. This presentation will be illustrated with examples from geochemical surveys, aeromagnetic-micromagnetic surveys, passive and active electromagnetic surveys, and remote sensing data.

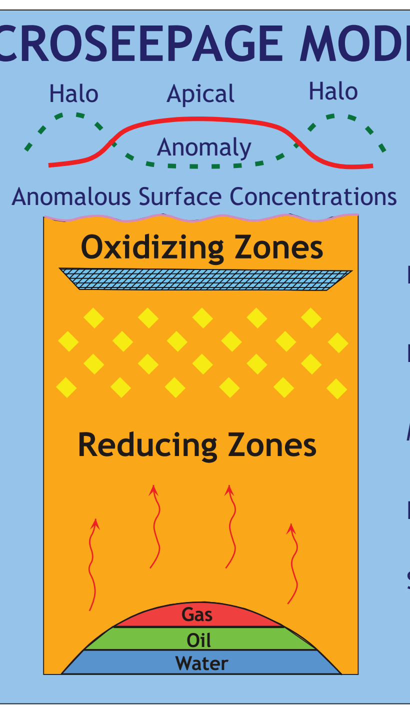
EKOFISK, NORTH SEA

East to west seismic cross section showing low seismic velocity zone due to gas migration



(from Van den Bark and Thomas, 1980)

MICROSEEPAGE MODEL



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

GEOPHYSICAL

High Resistivity Anomaly

High Polarization Anomaly

Magnetic Anomaly

Low Resistivity Anomaly

Seismic Velocity Anomaly

BASIS FOR GEOCHEMICAL AND NON-SEISMIC HYDROCARBON DETECTION

Geochemical and non-seismic hydrocarbon detection methods are based on the search for chemically or geophysically identifiable surface or near-surface occurrences of hydrocarbons and their alteration products, which can serve as clues to the location of undiscovered oil and gas accumulations.

BENEFITS OF GEOCHEMICAL AND NON-SEISMIC HYDROCARBON DETECTION

- Document an active petroleum system in the area of exploration interest.
- Direct detection of hydrocarbons and/or hydrocarbon-induced changes.
- High-grade basins, palys, or prospects prior to acquiring leases, and/or before conducting detailed seismic surveys.
- High-grade exploration leads and prospects after seismic evaluation.
- Generate unique geochemical or non-seismic leads for further geologic and seismic evaluation.
- These methods are non-invasive and have minimal environmental impact.
- Prospects associated with hydrocarbon seepage anomalies are 4 to 6 times more likely to result in a commercial discovery than prospects without such anomalies.

NON-SEISMIC METHODS FOR THE DETECTION OF HYDROCARBONS

Surface Geochemical Surveys

Direct detection of hydrocarbons by analyzing soil gas, adsorbed soil gas, aromatics and other higher hydrocarbons in onshore and offshore sediments.

Indirect detection of hydrocarbons and hydrocarbon-induced changes using microbiologic methods, trace elements, biogeochemistry, helium, etc.

Remote Sensing, Satellite Imagery

Detection of hydrocarbon-induced changes to soils and sediments; detection of oil slicks in oceans and in large lakes.

Magnetics, Micromagnetics

Detects hydrocarbon-induced mineralization at shallow depths in sediments above oil and gas accumulations; applicable onshore and offshore.

Radar, Laser

Detection of hydrocarbon gases, principally ethane or propane, in atmosphere.

Radiometrics

Gamma radiation surveys to detect the generally low radiation values at the surface above hydrocarbon accumulations.

Electrical, Electromagnetic

Several different methods to detect hydrocarbon-induced changes in sediments above hydrocarbon accumulations, or to directly detect resistive-hydrocarbon bearing formations.

These methods include (1) Induced Potential, IP, (2) Controlled source audio magnetotellurics, CSAMT, (3) Marine Controlled source electromagnetics, CSEM, (4) Multi-transient electromagnetics, MTEM, and (5) passive electromagnetics and passive tellurics.

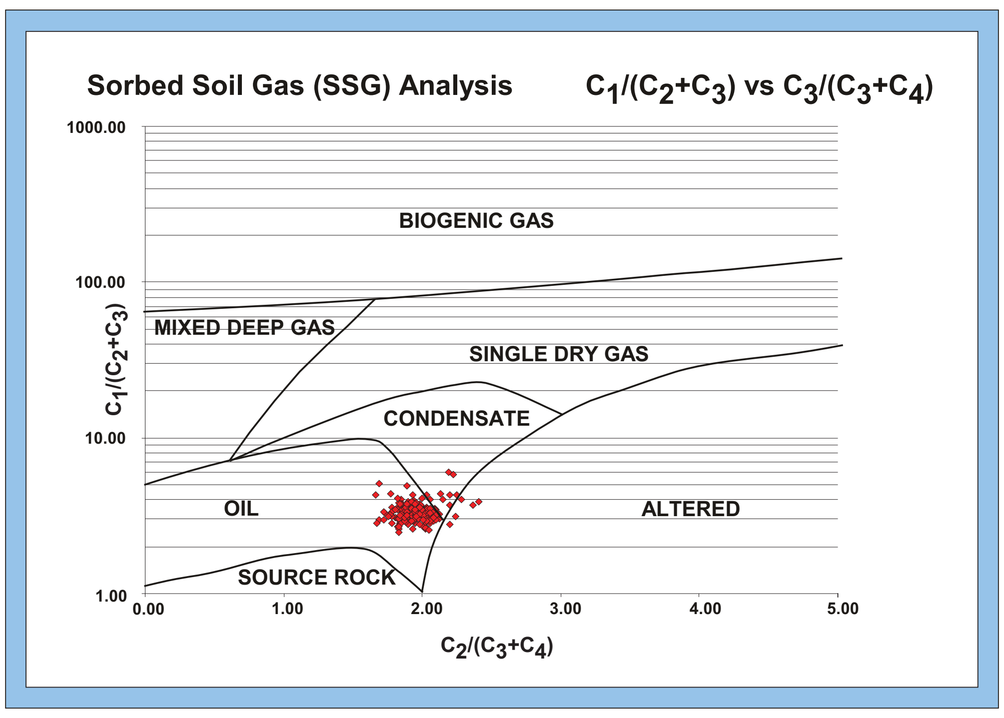
NON-SEISMIC DETECTION OF HYDROCARBONS: AN OVERVIEW

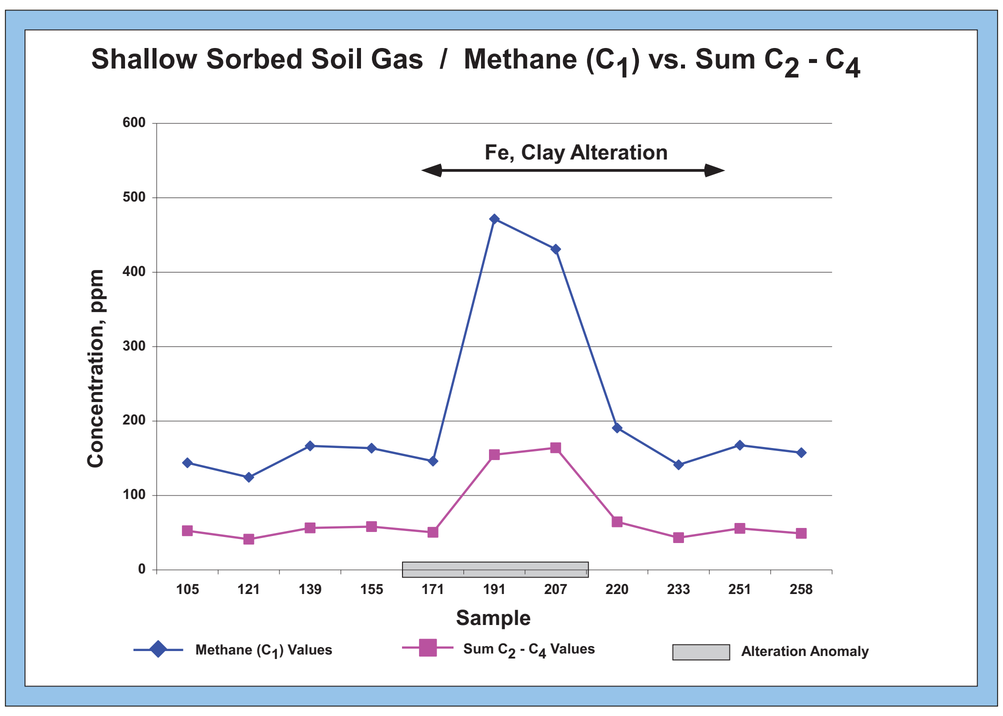
SATELLITE DETECTION OF SEEPAGE AND MICROSEEPAGE

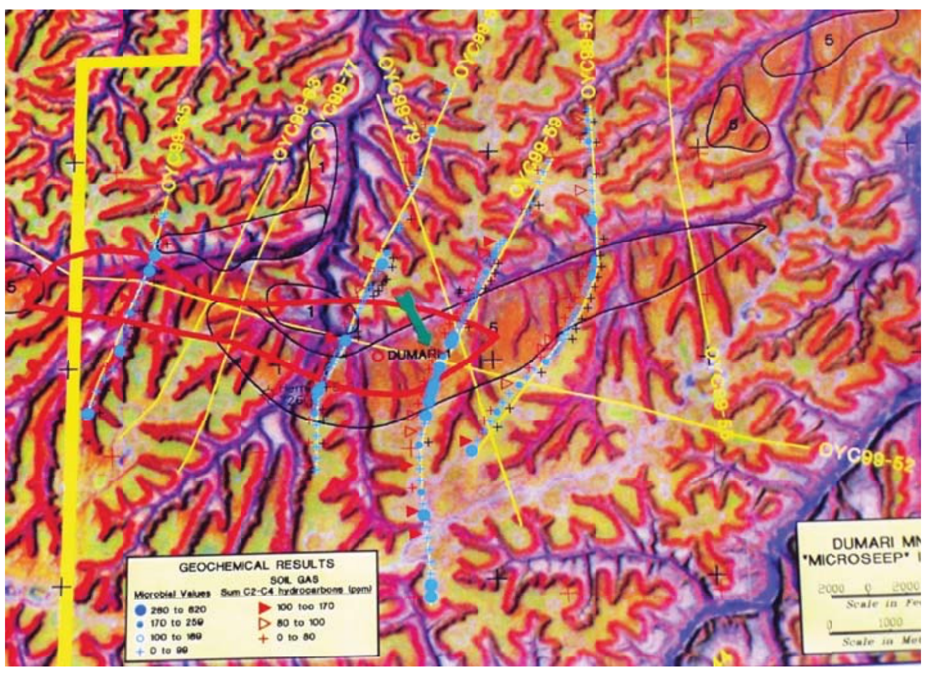
Satellite-based remote sensing of hydrocarbon-induced alteration of soils and sediments holds great promise as a rapid and cost-effective means of detecting areas of elevated hydrocarbon seepage and microseepage. The leakage of hydrocarbon gases creates an oxidation-reduction cell which leads to numerous geochemical and mineraloic changes in soils and near-surface sediments. Among the changes that occur in chemically reducing environments associated with hydrocarbon seepage are (1) reduction of iron from a ferrous state to a ferric state, (2) conversion of feldspars and micas to clay minerals, and (3) the replacement of mixed-layer clays by kaolinite. These and other changes can be detected by analysis of satellite imagery, as well as by hyperspectral analysis of soils, sediments, and vegetation.

ONSHORE APPLICATION

The first example is from the Masilah basin, onshore Yemen, and illustrates a seep-induced remote sensing anomaly and the results of a ground-truth surface geochemical survey across that anomaly. Of 22 remote sensing anomalies evaluated independently by surface geochemistry, 18 were associated with strong hydrocarbon seepage - as seen in the example below.

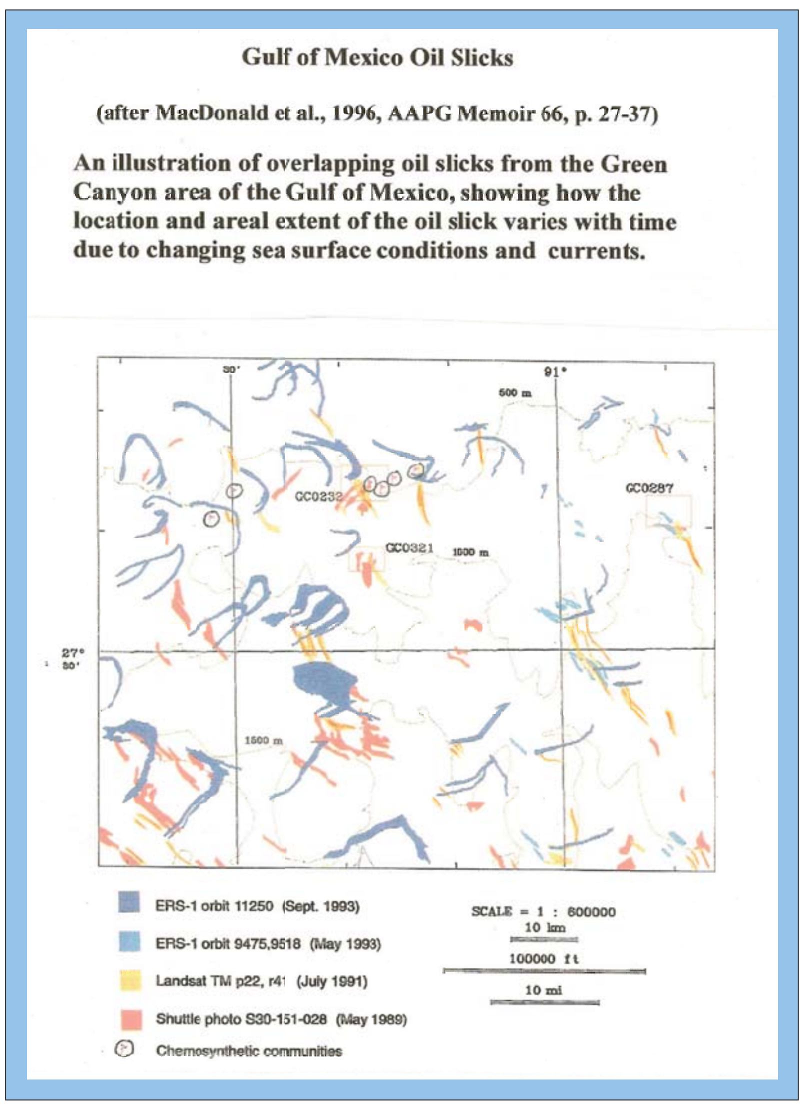






OFFSHORE APPLICATION

In offshore areas, satellite detection of oil slicks represents a highly effective and low-cost technique for reducing the risk of hydrocarbon source and hydrocarbon charge in high-cost exploration environments, such as the deep and ultra-deep waters off Africa, North America, and elsewhere. Satellite seep data enables pre-lease high-grading of basins and plays, and identifies locations for follow-up surface sampling to characterize geochemically the composition and origin of the seeping hydrocarbons. The examples that follow illustrate the nature of oil slicks in the Gulf of Mexico, the South Caspian Sea, and in the Lower Congo basin.



Gulf of Mexico Oil Slicks

(after MacDonald et al., 1996, AAPG Memoir 66, p. 27-37)

An illustration of overlapping oil slicks from the Green Canyon area of the Gulf of Mexico, showing how the location and areal extent of the oil slick varies with time due to changing sea surface conditions and currents.

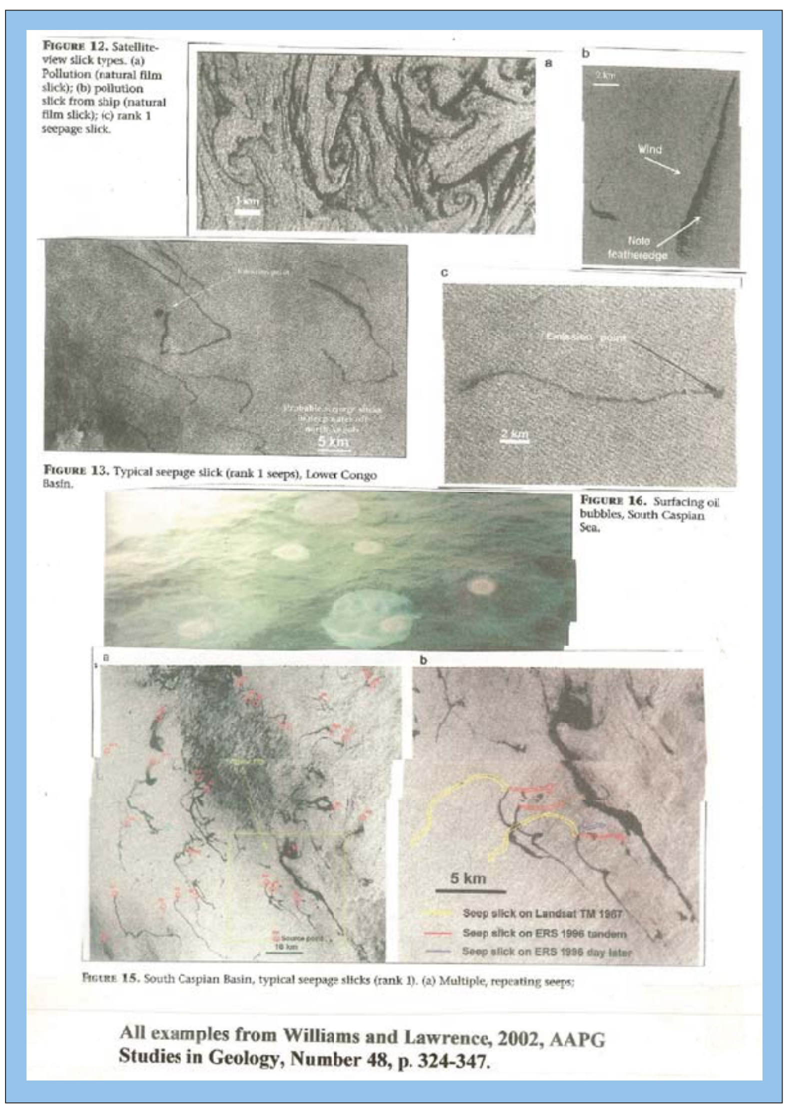


FIGURE 12. Satellite-view slick types. (a) Pollution (natural film slick); (b) pollution slick from ship (natural film slick); (c) rank 1 seepage slick.

FIGURE 13. Typical seepage slick (rank 1 seeps), Lower Congo Basin.

FIGURE 16. Surfacing oil bubbles, South Caspian Sea.

FIGURE 15. South Caspian Basin, typical seepage slicks (rank 1). (a) Multiple, repeating seeps;

All examples from Williams and Lawrence, 2002, AAPG Studies in Geology, Number 48, p. 324-347.

NON-SEISMIC DETECTION OF HYDROCARBONS: AN OVERVIEW

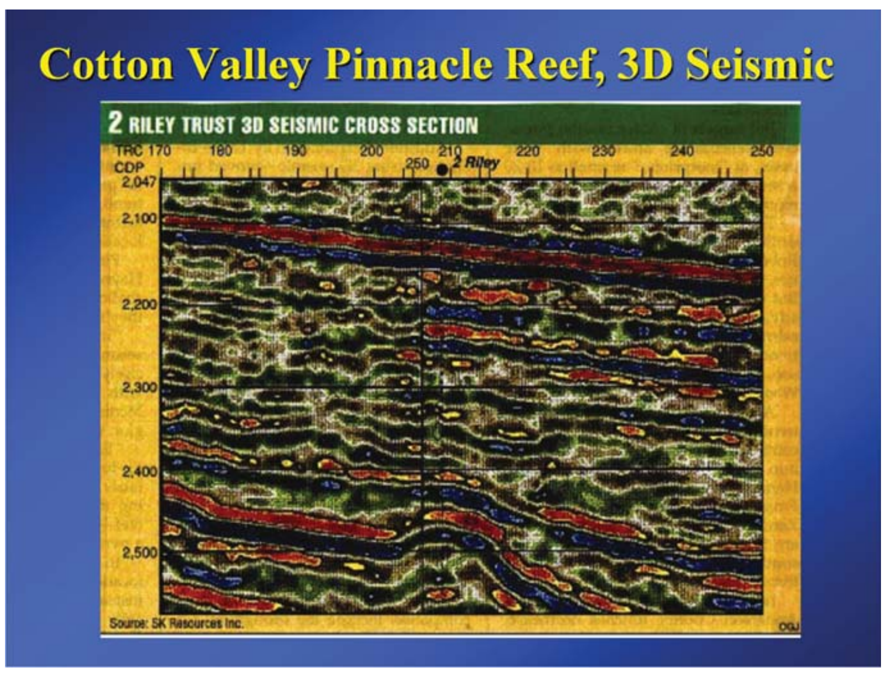
SURFACE GEOCHEMICAL EXPLORATION OF OIL AND GAS

Surface indications of oil and gas seepage have been noted for thousands of years, and such visible seeps have led to the discovery of many important oil producing areas. The underlying assumption of all near-surface geochemical exploration methods is that hydrocarbons are generated and/or trapped at depth and leak in varying but detectible quantities to the surface. Detailed geochemical surveys and research studies document that hydrocarbon microseepage from oil and gas accumulations is common and widespread, is predominantly vertical (with obvious exceptions in some geologic settings), and is dynamic (responds quickly to changes in reservoir conditions). The mechanisms for hydrocarbon migration and microseepage are still not well understood, but present evidence suggests that the likely mechanism for microseepage is buoyancy of gas microbubbles.

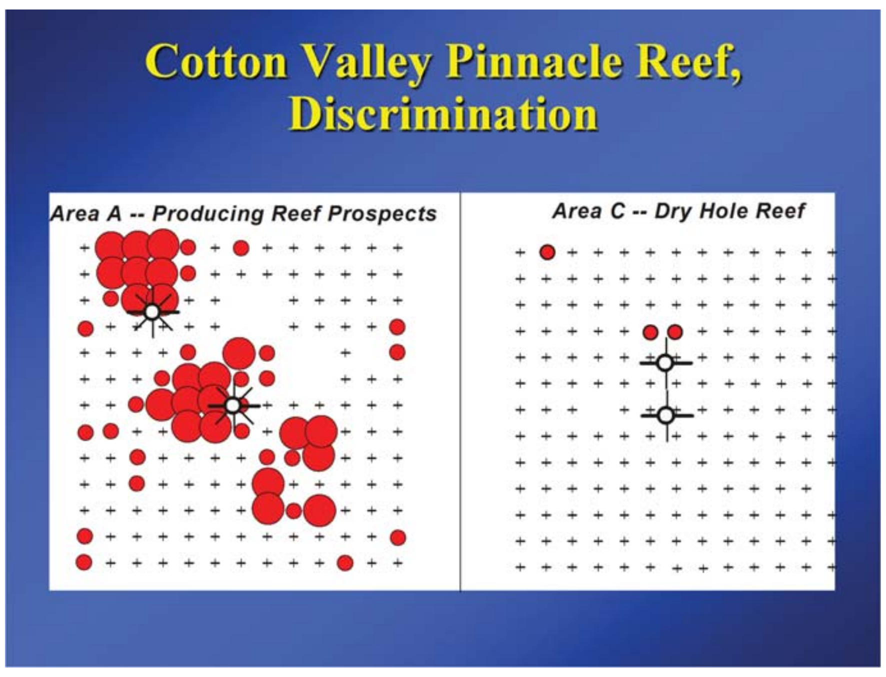
Although several dozen different surface geochemical methods have been developed over the years, two methods in most common usage involve the analysis of soil gas hydrocarbons and the analysis of hydrocarbon-oxidizing microbes in soils. The following examples illustrate the results of surface geochemical surveys from a variety of geologic and environmental settings.

Survey Design Considerations

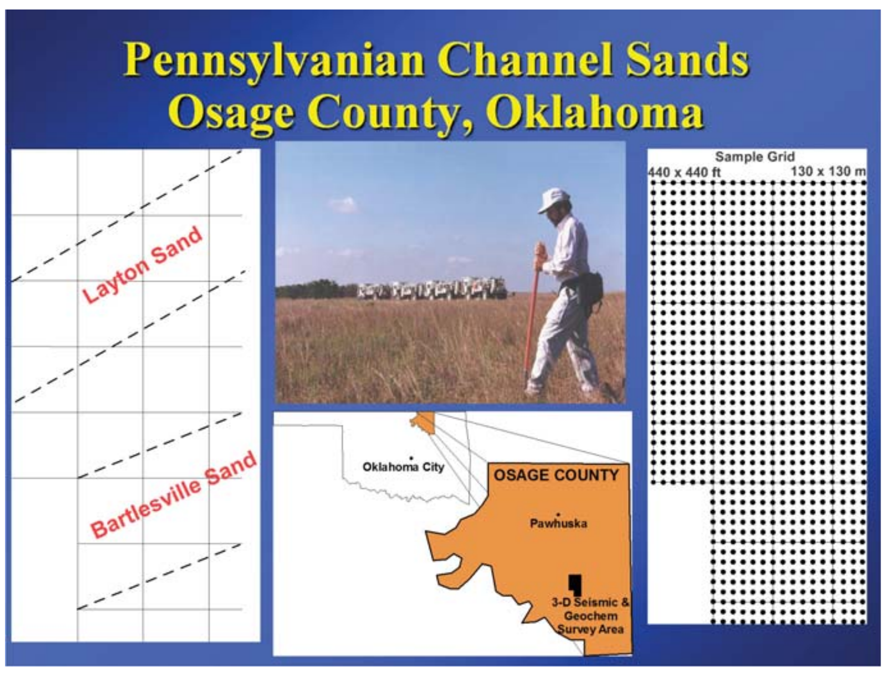
- Survey Objectives
- Target Size, Shape
- Geologic Setting
- Topography, Vegetation
- Logistical Considerations
- Ability to Sample Along, Between Seismic Lines
- Geologic Analogs for Calibration
- Permitting; Environmental Issues
- Prior Experience



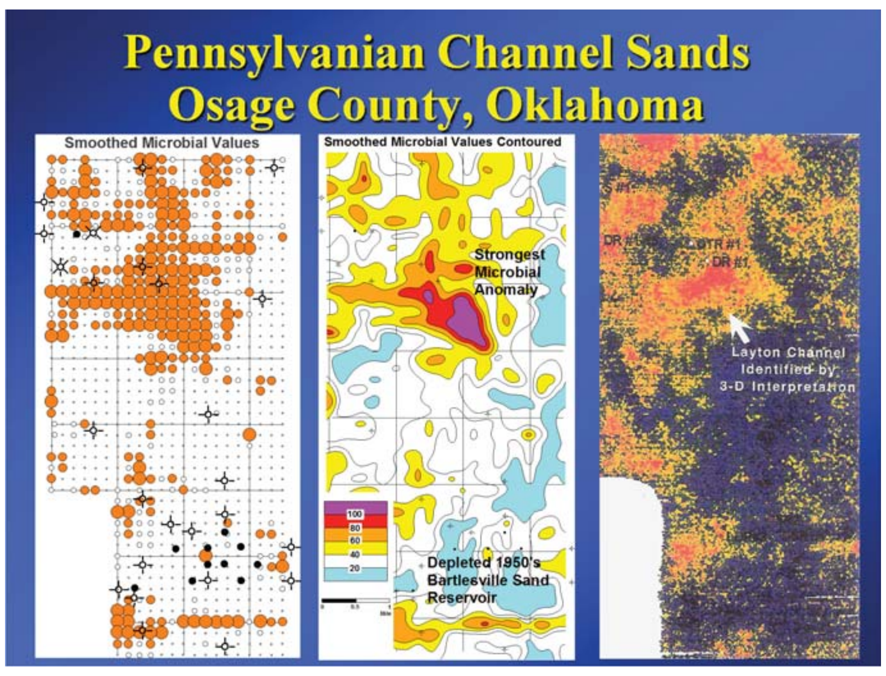
Cotton Valley Pinnacle Reef, 3D Seismic



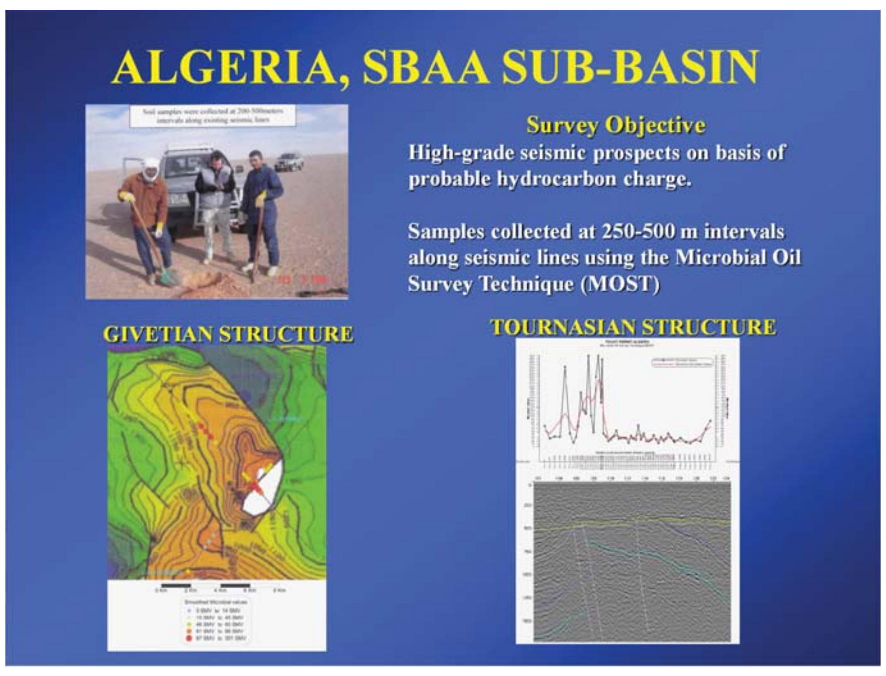
Cotton Valley Pinnacle Reef, Discrimination



Pennsylvanian Channel Sands
Osage County, Oklahoma



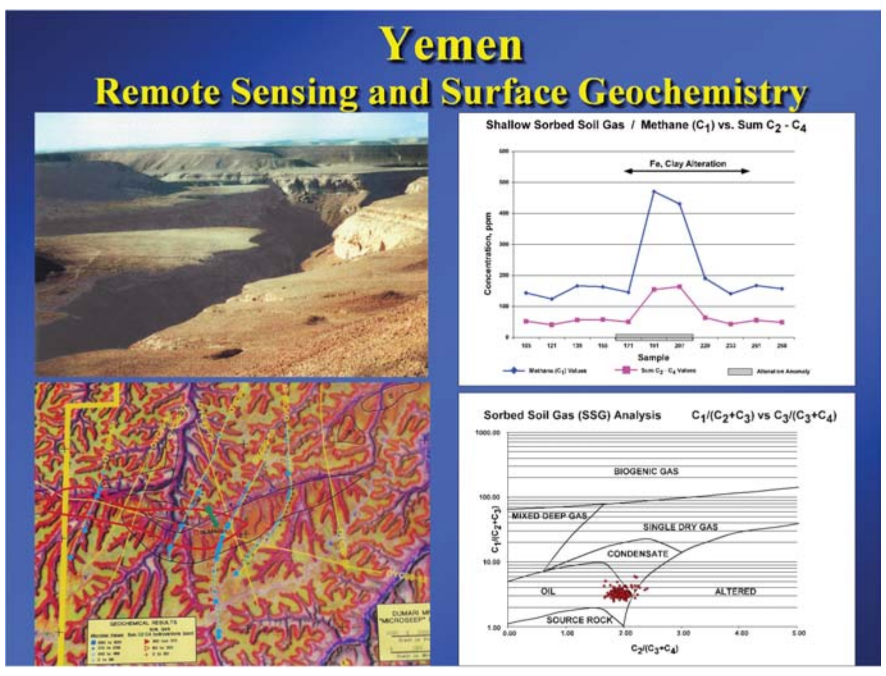
Pennsylvanian Channel Sands
Osage County, Oklahoma



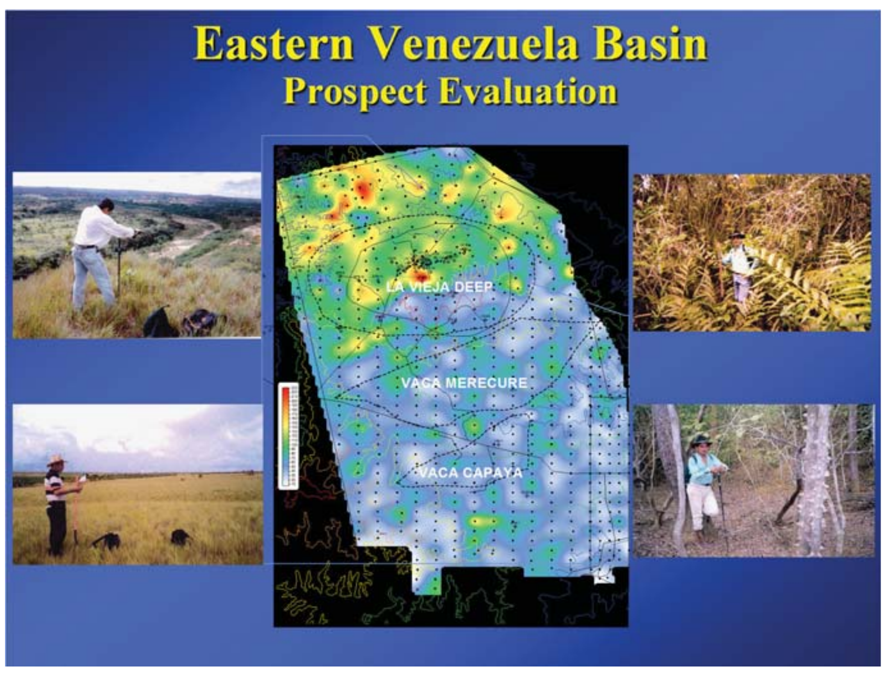
ALGERIA, SBAA SUB-BASIN

Survey Objective
High-grade seismic prospects on basis of probable hydrocarbon charge.

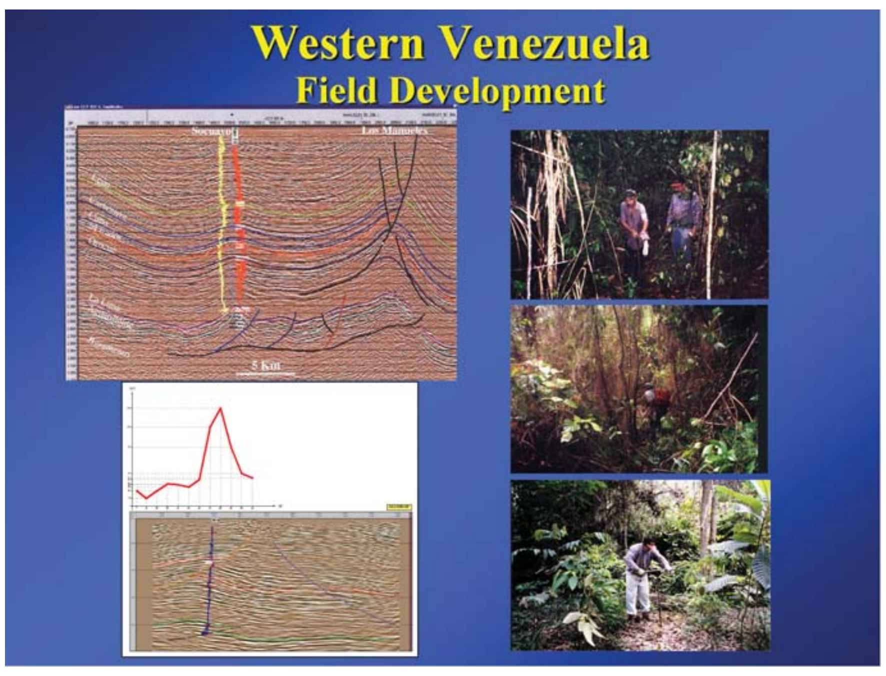
Samples collected at 250-500 m intervals along seismic lines using the Microbial Oil Survey Technique (MOST)



Yemen
Remote Sensing and Surface Geochemistry



Eastern Venezuela Basin
Prospect Evaluation



Western Venezuela
Field Development

NON-SEISMIC DETECTION OF HYDROCARBONS: AN OVERVIEW

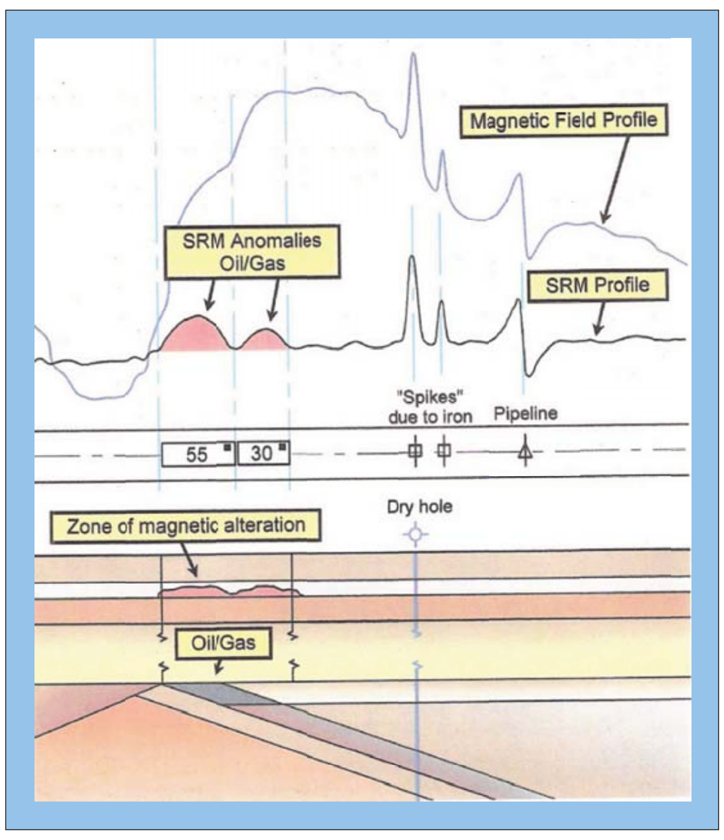
AEROMAGNETICS -- MICROMAGNETICS: SEEPAGE-INDUCED MAGNETIC ANOMALIES

The presence of magnetic anomalies over oil and gas fields has been noted for several decades, but it is only in recent years that the phenomenon has been critically examined. Studies of geologically and geographically diverse regions document that (1) authigenic magnetic minerals occur in near-surface sediments over many petroleum accumulations, (2) this hydrocarbon-induced mineralization is detectable in high resolution, broad bandwidth magnetic data acquired at low altitude and with closely-spaced flight lines, and in ground magnetic surveys, (3) the magnetic susceptibility analysis of drill cuttings and near-surface sediments confirms the existence of the aeromagnetic anomalies, (4) sediments with anomalous magnetic susceptibility frequently contain ferromagnetic minerals such as greigite, maghemite, magnetite, and pyrrhotite, and (5) more than 80% of oil and gas discoveries are associated with hydrocarbon-induced magnetic anomalies.

The association between hydrocarbon seepage and the formation of authigenic magnetic minerals in the near-surface has important applications in hydrocarbon exploration. Application of this methodology can quickly identify the areas or prospects with the greatest petroleum potential. Although the discovery of shallow sedimentary magnetic anomalies does not guarantee the discovery of hydrocarbon accumulations, it does identify areas requiring more detailed evaluation, thereby focusing attention and resources on a relatively small number of high potential sites.

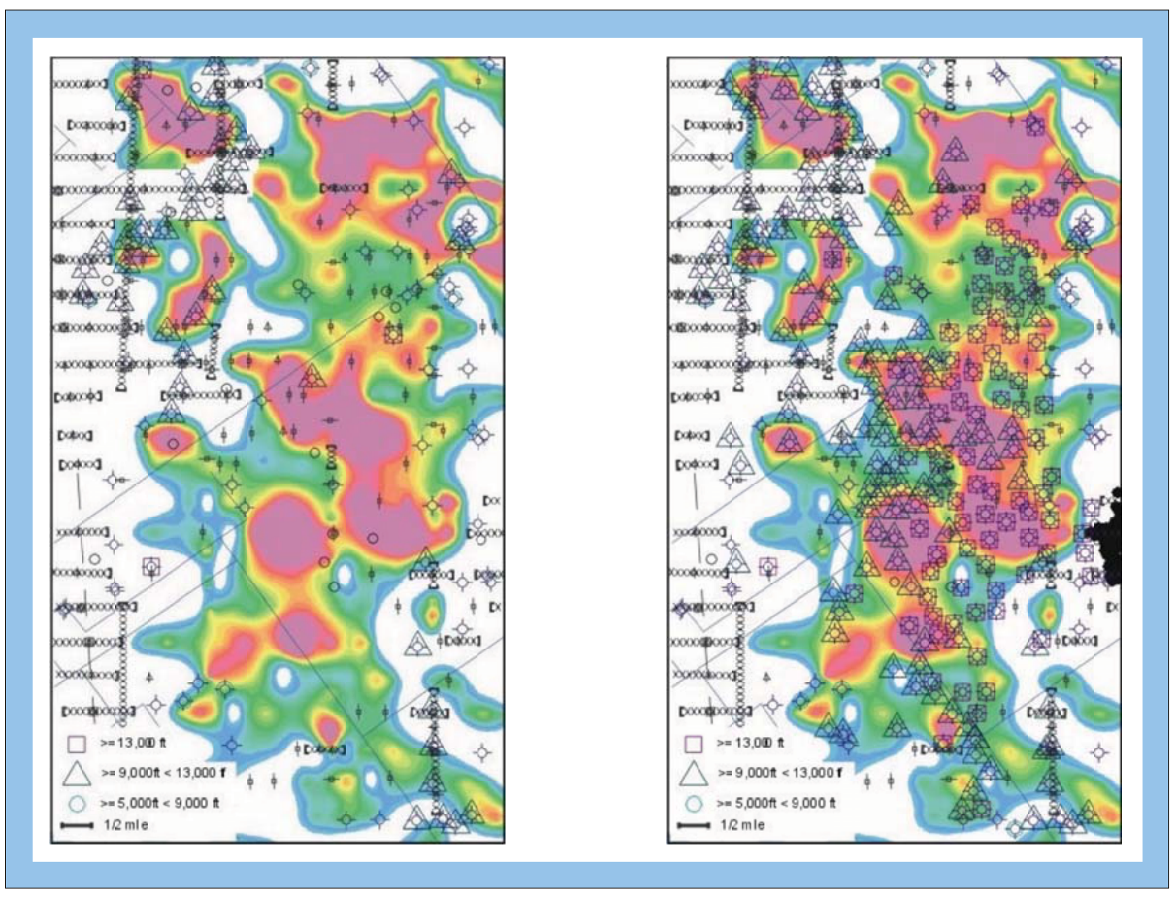
Authigenic magnetic mineralization in shallow sediments above hydrocarbon deposits create subtle but recognizable change in the magnetic field profile. Removal of the magnetic effect of deeper basement rocks produces the Sedimentary Residual Magnetic (SRM) profile. Only then can the low-level magnetic effects created by hydrocarbon microseepage be identified as SRM anomalies.

The Magnetic Bright Spot (MBS) represents an interval of magnetically-enriched sediment or sedimentary rock which overlies an oil or gas accumulation. The areal extent of the MBS approximates the productive limits of the oil or gas accumulation.



Onshore Example: El Huerfano Field, Texas

The El Huerfano fas field is located in Zapata County, south Texas, and produces from the Cretaceous Edwards Formation. The field was discovered in 1977, however, the main phase of field development occurred between 1985 and 1997. The adjacent figure (left) shows the drilling status as of 1985 and the location of a large, well defined MBS anomaly based on 1985 aeromagnetic data. The second Figure (right) shows the striking correlation between the 1985 outline of the MBS anomaly and the 1997 gas field boundary.



Offshore Example: Thunder Horse Field, Gulf of Mexico

This is an example of anomaly resolution in deep water; water depths are 1675-1980m (5500-6500 ft). The large MBS anomaly in Mississippi Canyon blocks 732, 776, 777, 778, and 882 includes the BP/Exxon Mobil discoveries of Thunder Horse and Thunder Horse North fields. Seven wells are shown; well status is for August 2003. Estimated reserves are up to 3 billion barels, making these fields the largest in North America south of Prudhoe Bay.

The color contour map illustrates the distribution of the MBS anomalies and compares drilling status of July 1990 with August 2003.

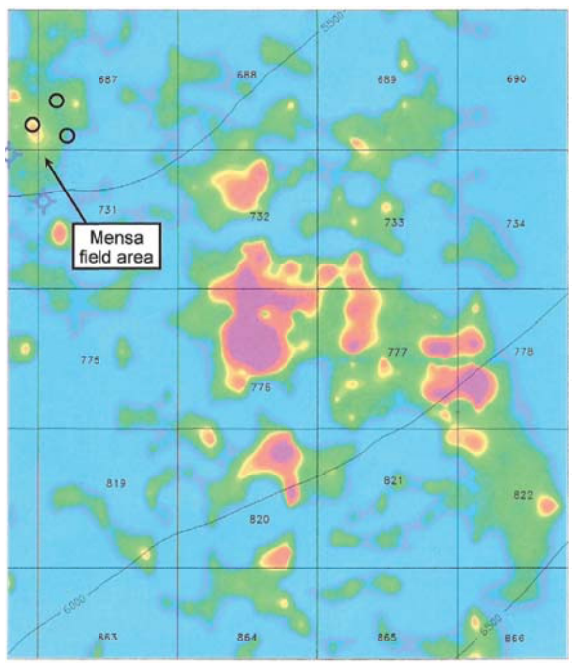


Figure 9A, MBS anomalies in Mississippi Canyon showing Mensa and Thunder Horse field area drill status as of July 1990.

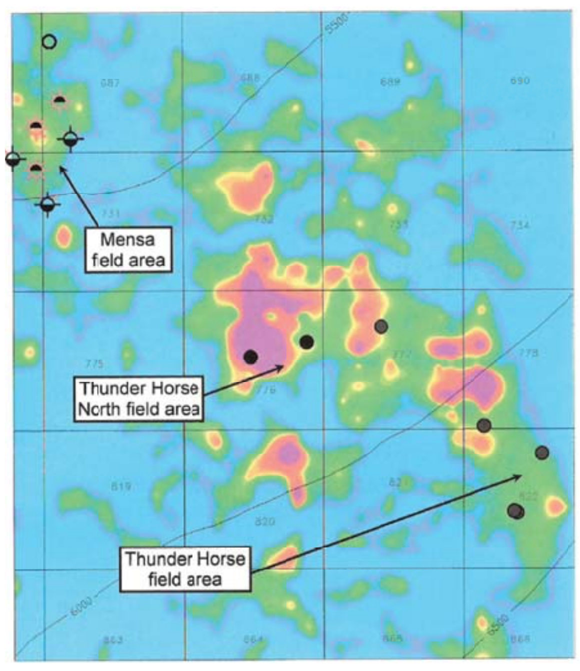


Figure 9B, MBS anomalies in Mississippi Canyon showing Mensa and Thunder Horse field area drill status as of August 2003.

NON-SEISMIC DETECTION OF HYDROCARBONS: AN OVERVIEW

ELECTRICAL AND ELECTROMAGNETIC DETECTION OF HYDROCARBONS

The main electrical and electromagnetic methods available for the detection of hydrocarbons are:

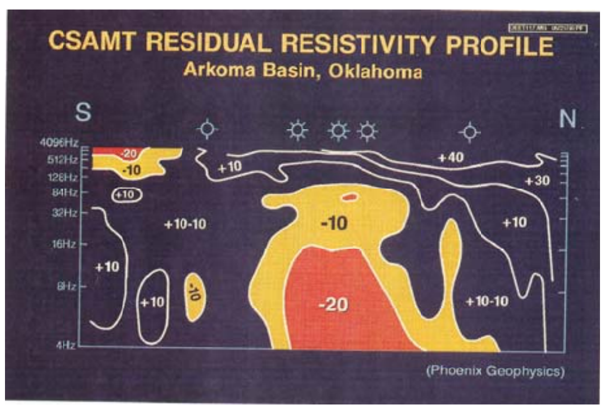
IP, Induced Potential

The IP method attempts to detect the alteration zone or "pyrite chimney" caused by microseepage from hydrocarbon reservoirs into iron-rich sediments near the surface.

CSAMT, Controlled Source Audiomagnetotellurics

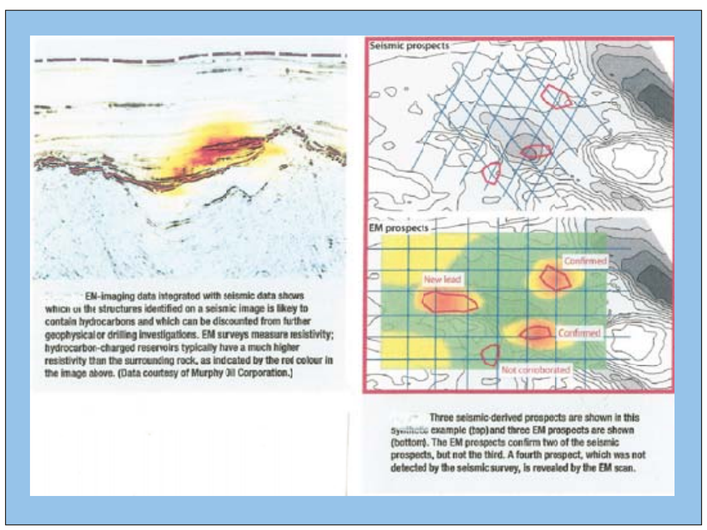
The CSAMT method measures electrical field and magnetic field, and detects the electrical low resistivity zone associated with the hydrocarbon leakage "chimney" present over many oil and gas fields.

The example below illustrates a well-developed electrical resistivity anomaly over the Ashland gas field in the Arkoma basin, Oklahoma. The anomaly consists of a shallow high-resistivity zone (calcite-cemented sands) above a very prominent low resistivity zone, or conductive chimney.



CSEM, Marine Controlled Source Electromagnetics

CSEM imaging is a relatively recent development that uses electromagnetic energy to detect electrically resistive, including hydrocarbon reservoirs, beneath the seafloor. A powerful EM source towed close to the seafloor emits low frequency energy into the subsurface. Lines or grids of receivers detect EM energy that is propagated through the sea and the subsurface. Processing and modeling, including inversion and depth migration of EM data, results in maps and cross-sections that show the location and depth of resistive bodies.



EM-imaging data integrated with seismic data shows which of the structures identified on a seismic image is likely to contain hydrocarbons and which can be discounted from further geophysical or drilling investigations. EM surveys measure resistivity; hydrocarbon-charged reservoirs typically have a much higher resistivity than the surrounding rock, as indicated by the red colour in the image above. (Data courtesy of Murphy Oil Corporation.)

Three seismic-derived prospects are shown in this synthetic example (top) and three EM prospects are shown (bottom). The EM prospects confirm two of the seismic prospects, but not the third. A fourth prospect, which was not detected by the seismic survey, is revealed by the EM scan.

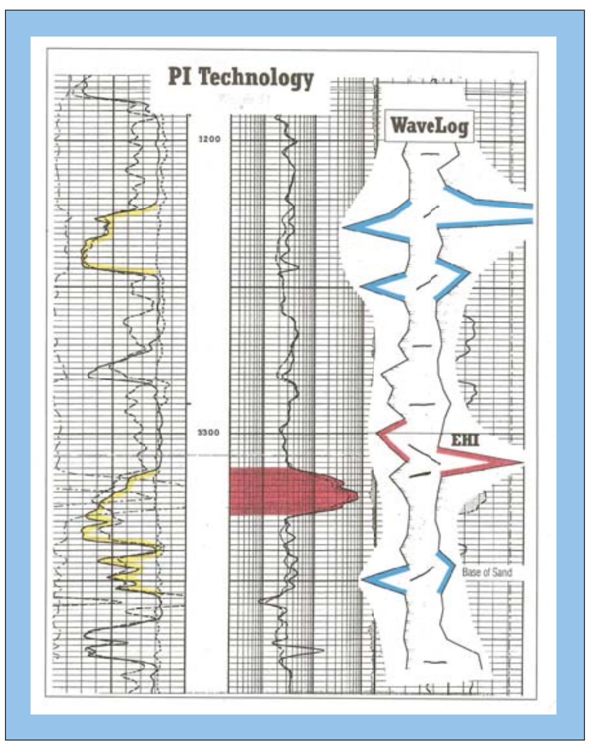
MTEM, Multi-transient Electomagnetics

The MTEM technique produces resistivity profiles over prospective reservoirs to determine whether or not hydrocarbons are likely to be present. Application of MTEM entails injecting a series of pulse-coded electrical transient signals into the subsurface and measuring the voltage response between pairs of receiver electrodes along the logging profile. The process is repeated multiple times to acquire a detailed vertical and lateral resistivity profile. Although the MTEM methodology can be used in the marine environments, most of its applications to date have been from onshore locations.

Passive Electromagnetic "Logging"

The Wave Technology Group (Houston TX) has developed a new and powerful technology for electromagnetic sounding (or logging) of the subsurface. This passive electromagnetic "logging" tool has been shown to reliably determine the depth and thickness of major stratigraphic units and, more importantly, the presence of and depth to hydrocarbon-bearing zones before drilling.

This technology, called Power Imaging --- PI, is an outgrowth of research conducted at Lawrence Livermore Labs in the 1970s (Lytle and Lager, 1976). The power grid induces electromagnetic waves in the earth; these waves are at specific frequencies which are harmonics and subharmonics of 60 or 50 cycles, depending on the local power grid. The waves propagate as plane waves and encounter the various geologic boundaries. Those boundaries having dielectric and/or conductivity contrast reflect a potion of the waves back to the earth's surface. In this manner, waves become organized such that there is a direct relationship between the many resonating frequencies and the depths to the various geologic boundaries.



Because of the electrical contrast between hydrocarbon-bearing rocks and their surrounding formations, an electromagnetic signature can be detected by measuring the resonant frequencies at the earth's surface. Interpretation of this signature yields an Electromagnetic Hydrocarbon Indicator -- EHI, thereby allowing for the direct detection of hydrocarbons, along withy the depth and approximate thickness of the hydrocarbon-bearing interval. To date, this technology has been successfully tested at depths ranging from 450-4875 m (1500-1600 ft).

Passive Tellurics

Passive telluric survey methods and instruments have been available since the 1980's and this telluric technology is available from a number of individuals and companies. Passive telluric measurements are made from the ground surface using hand-carried equipment. Supporters of the technology claim that telluric measurements can reliably determine depth to formation tops and the presence and depth of hydrocarbon-bearing zones.

Telluric currents are a spectrum of alternating currents (AC) whose frequencies are in the audio range (between 0-20000 hz). These currents can be detected by a very low frequency receiver connected to an integral antenna, both enclosed within a field-portable box. There does not yet appear to be a satisfactory scientific theory to explain the mechanics of passive telluric measurements. The generally accepted theory seems to be based on solar plasma energizing the ionosphere which in turn generates an electromagnetic field which bathes the earth. That field generates AC telluric currents in the earth whose frequencies are dependent on the depths from which they were regenerated. These currents are then modulated by electrical transients create by lightning strikes around the world.

Although some explorationists are highly enthusiastic about passive telluric methods, conventional geophysicists remain highly skeptical about the technology and its scientific basis.

Economic Benefit of Non-Seismic Hydrocarbon Detection Methods

What is the economic benefit of incorporating geochemical and non-seismic geophysical hydrocarbon detection methods in your exploration strategy? Can it be quantified? One way to do so is to compare survey results with the result of subsequent drilling and production. Numerous such case histories have been reported. In a review of more than 2600 U.S. and International wildcat wells -- all drilled after completion of either geochemical or non-seismic hydrocarbon detection surveys -- 81% of wells drilled on prospects associated with positive geochemical anomalies resulted in commercial oil or gas discoveries. In contrast, only 11% of wells drilled on prospects not associated with such hydrocarbon anomalies resulted in a commercial discovery.

Non-seismic hydrocarbon detection methods cannot replace conventional exploration methods, but they can be a powerful complement to them. Geochemical and other hydrocarbon detection methods have found their greatest utility when used in conjunction with available geological and geophysical information. The need for such an integrated approach cannot be overemphasized. Properly applied, the combination of surface and subsurface exploration methods has the potential to reduce exploration and development risks and costs by improving success rates and shortening development time.