Chapter 18

Surface Geochemical Exploration for Petroleum

by

Dietmar Schumacher

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Deet has a longstanding interest in the exploration and development applications of petroleum geochemistry, particularly surface exploration methods. He is editor, with Mike Abrams, of the recently published AAPG Memoir 66, *Hydrocarbon Migration and Its Near-Surface Expression.* He and Len LeSchack are now working on a follow-up volume for AAPG, *Surface Exploration Case Histories.* Deet is a Certified Petroleum Geologist (CPG-4301), a member of AAPG and GSA, and a past president of the Houston Geological Society.

Overview

Introduction

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 and nonseismic geophysical surface exploration methods have been developed. The application of these geochemical prospecting methods to oil and gas exploration has resulted in varied success and occasional controversy. Few question the fact that hydrocarbons migrate to the surface in detectable amounts, but many remain uncertain of how such information can best be integrated into conventional exploration and development programs. This chapter examines surface geochemical prospecting technology and discusses its application.

In this chapter

This chapter contains the following sections.

Section A
Principles of Surface Geochemical Exploration

Introduction

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. All surface geochemical methods assume that hydrocarbons generated and trapped at depth leak in varying but detectable quantities to the surface.

Geochemical exploration techniques can be direct or indirect. Direct techniques analyze small quantities of hydrocarbons that occur in the pore space of soil, that are adsorbed on the fine-grained portion of soil, or that are incorporated in soil cements. Indirect geochemical methods detect seepage-induced changes to soil, sediment, or vegetation.

Geological exploration data have found their greatest utility when integrated with geological and geophysical data. Poorly applied, the combination of surface and subsurface exploration methods leads to better prospect evaluation and risk assessment.

In this section

This section contains the following topics.

Basics

Definition

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.

Surface geochemical principles

The past decade has seen a renewed interest in surface geochemical exploration. Coupled with developments in analytical and interpretive methods, this interest has produced a new body of data and insights, many of which are summarized in AAPG Memoir 66 (Schumacher and Abrams, 1996). 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 (macroseepage) or only detectable analytically (microseepage).
- Hydrocarbons move vertically through thousands of meters of strata without observable faults or fractures in a relatively short time (weeks to years).
- Migration is mainly vertical but can also occur over great distances laterally.
- Relationships between surface anomalies and subsurface accumulations range from simple to very complex.

Significance of anomalies

Surface indications of oil and gas seepage have been noted for thousands of years; such seeps have led to the discovery of many important petroleum producing areas. Although the discovery of a surface geochemical anomaly does not guarantee the discovery of commercially significant petroleum, it does establish the presence of hydrocarbons in the area of interest. Hydrocarbon seeps at the surface represent the end of the migration pathway. Traps and structures along such pathways should be considered significantly more prospective than those not associated with such anomalies.

Benefits

The potential benefits of a successful geochemical exploration program are many and include the following:

- Directly detect hydrocarbons and/or hydrocarbon-induced changes in soils, near-surface sediments, and/or on the sea floor.
- Document the presence of a working petroleum system in the area of interest.
- Permit high-grading of basins, plays, or prospects prior to acquiring leases or before conducting detailed seismic surveys.
- Permit postseismic high-grading of leads and prospects; generate geochemical leads for further geological or geophysical evaluation.
- Use geochemical data to infill between seismic lines and constrain mapping of AVO/amplitude anomalies between lines.
- Evaluate areas where seismic surveys are impractical or are ineffective due to geological or environmental factors.
- Provide methods applicable to both stratigraphic traps and structural traps, with the ability to locate traps invisible or poorly imaged with seismic data.
- Have little or no negative environmental impact (most surface geochemical methods).

Assumptions

Traps leak

The underlying assumption of all near-surface geochemical exploration techniques is that hydrocarbons are generated and/or trapped at depth and leak in varying but detectable quantities to the surface. This has long been established as fact, and the close association of surface geochemical anomalies with faults and fractures is well known (Horvitz, 1939, 1985; Jones and Drozd, 1983; Price, 1986). The surface expression of hydrocarbon seeps is best developed in areas with numerous well-developed migration pathways and an active petroleum system.

Anomalies relate to traps

A further assumption is that the anomaly at the surface can be related reliably to a petroleum accumulation at depth. The success with which this can be done is greatest in areas of relatively simple geology and becomes increasingly difficult as the geology becomes more complex. The geochemical or microbial anomaly at the surface represents the end of a petroleum migration pathway, a pathway that can range from short-distance vertical migration at one end of the spectrum to long-distance lateral migration at the other extreme (Thrasher et al., 1996b). Relationships between surface geochemical anomalies and subsurface accumulations can be complex; proper interpretation requires integrating seepage data with geological, geophysical, and hydrologic data. Understanding geology—and, hence, petroleum dynamics—is the key to using seepage data in exploration.

Seepage styles

The figure below shows examples of contrasting seepage styles and migration pathways from the Gulf of Mexico and the North Sea.

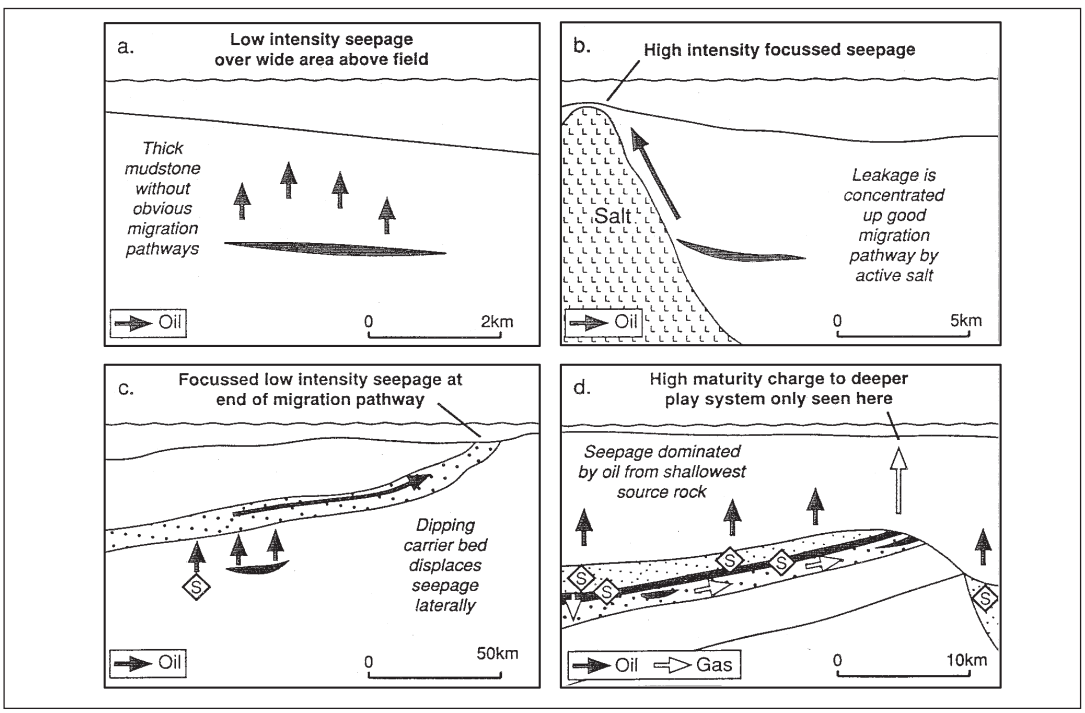

Figure 18–1. Modified from Thrasher et al., 1996b; courtesy AAPG.

Limitations and Uncertainties

Introduction

While the potential benefits of a successful surface geochemical exploration program are very real and can significantly affect the economics of an exploration or development program, the user must be aware of limitations associated with geochemical exploration methods. Some limitations of surface geochemical exploration are related to geology; others are related to the method itself.

Limitations related to geology

The following are limitations of surface geochemical prospecting related to geology:

- The geochemical expression of seepage is complex and varied.
- There is generally no simple one-to-one correlation between a surface anomaly and a subsurface accumulation. Some anomalies approximate the productive limits of an accumulation, but many do not.
- Successful integration of surface geochemical data with subsurface geology becomes increasingly difficult as the geology becomes more complex.
- False seep anomalies can be caused by reworked hydrocarbons and/or reworked source rocks.
- Reservoirs that are significantly underpressured or contain heavy oil may not be detected by some surface geochemical methods.

Limitations related to the method

The following are limitations of surface geochemical prospecting related to the method:

- No single method works everywhere; there are many methods to choose from.
- A surface anomaly generally cannot be related to a specific source reservoir or depth; however, compositional fingerprinting techniques can sometimes discriminate seepage from different reservoir zones.
- Undersampling and/or use of improper sampling techniques causes ambiguity that leads to interpretation failures.
- Discovery of a surface geochemical anomaly does not guarantee discovery of commercially significant volumes of hydrocarbon.
- Geochemical exploration methods cannot replace existing exploration technology; however, they can add value to existing geological and geophysical exploration data.

Seepage Activity

Types of seepage activity

Seepage activity refers to the relative rate of hydrocarbon seepage. Abrams (1992, 1996a) defines two distinct end members of seepage activity: active and passive.

Active seepage

The term **active seepage** refers to areas where subsurface hydrocarbons seep in large concentrations into shallow sediments and soils and into the overlying water column. Active seeps often display acoustic anomalies on conventional or high-resolution seismic profiles. Active seepage occurs in basins now actively generating hydrocarbons or that contain excellent migration pathways. These seeps are easily detected by most sampling techniques.

Passive seepage

Areas where subsurface hydrocarbons are not actively seeping are referred to as characterized by **passive seepage.** Such seeps usually contain low-molecular-weight hydrocarbons and volatile high-molecular-weight hydrocarbons above background levels. Acoustic anomalies may be present, but water column anomalies are rare. Anomalous levels of hydrocarbon seepage may only be detectable near major leak points or below the zone of maximum disturbance.

Zone of maximum disturbance

The **zone of maximum disturbance,** defined by Abrams (1992, 1996a), is a near-surface zone of variable depth and thickness in which sedimentary and biological processes alter or destroy volatile hydrocarbons. Anomalous concentrations of hydrocarbons may not be detectable if samples are not obtained from below the zone of maximum disturbance. The figure below illustrates the zone of maximum disturbance in shallow marine sediments. Deeper sampling may be required in areas of passive seepage.

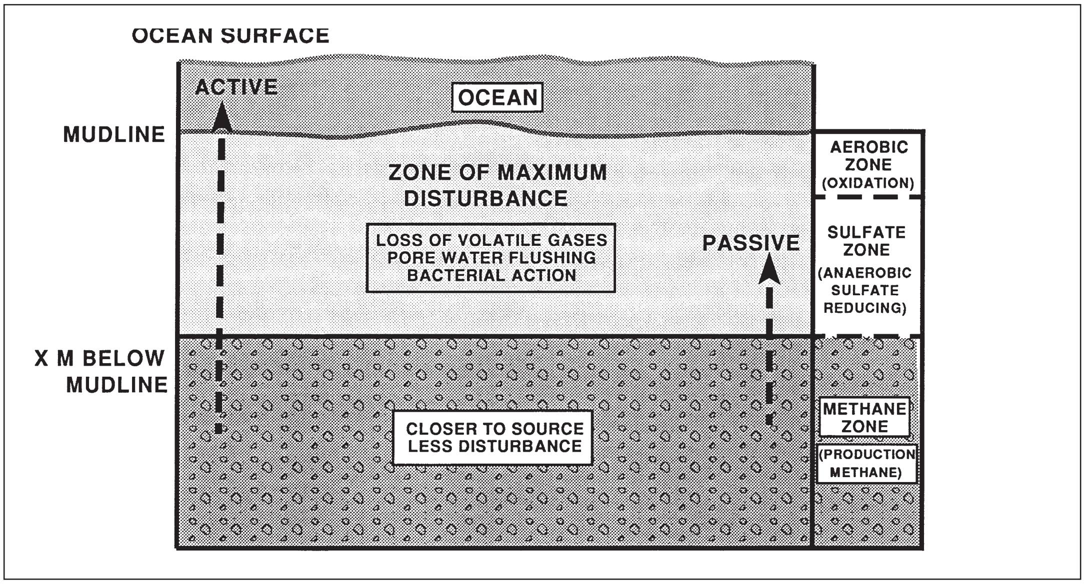

Figure 18–2. From Abrams, 1996a; courtesy AAPG.

Macroseepage vs. Microseepage

Macroseeps

There is a seepage continuum from the smallest detectable levels to visible oil and gas seeps. The term **macroseepage** refers to visible oil and gas seeps. Macroseeps are very localized areas containing large concentrations of light hydrocarbons as well as, if available, high-molecular-weight hydrocarbons. They are localized at the termination of faults, fractures, and outcropping unconformities or carrier beds. These visible seeps have led to the discovery of many of the world's important oil and gas producing areas (Link, 1952; Macgregor, 1993).

Microseeps

Microseepage is defined as high concentrations of analytically detectable volatile or semivolatile hydrocarbons in soils, sediments, or waters. These invisible seeps are recognized only by the presence of anomalous concentrations of the following:

- Light hydrocarbons (principally C_1–C_5)
- Volatile or semivolatile high-molecular-weight hydrocarbons (such as 2–4 ring aromatics)
- Hydrocarbon-oxidizing microbes
- Hydrocarbon-induced alteration products

High-molecular-weight hydrocarbons may be present in ever-wet or intermittently wet environments; however, only volatile or semivolatile hydrocarbons are expected above the water table. Most surface geochemical methods, including both direct and indirect methods, were developed to detect microseepage.

Microseepage evidence

The existence of microseepage is supported by a large body of empirical evidence (Price, 1986; Klusman, 1993; Klusman and Saeed, 1996; Matthews, 1996a). This includes the following:

- Increased concentration of light hydrocarbons and hydrocarbon-oxidizing microbes in soils and sediments above hydrocarbon reservoirs.
- Increased key light hydrocarbon ratios in soil gas over oil and gas reservoirs.
- Sharp lateral changes in these concentrations and ratios at the edges of the surface projections of these reservoirs.
- Similarity of stable carbon isotopic ratios for methane and other light hydrocarbons in soil gases to those found in underlying reservoirs.
- The disappearance and reappearance of soil gas and microbial anomalies in response to reservoir depletion and repressuring.

Microseep migration

Research and field studies suggest that the dominant migration medium is as a continuous-phase, buoyancy-driven gas flow within carrier and reservoir rocks and capillary imbibition in the transition from sources and seals into carrier rocks. Hydrocarbon microseepage is predominantly vertical and is dynamic; migration rates range from less than 1 meter per day to tens of meters per day (Arp, 1992; Klusman and Saeed, 1996; Matthews, 1996a).

Surface Expression

Geochemical evidence of seepage

The surface geochemical expression of petroleum seepage can take many forms:

- Anomalous hydrocarbon concentrations in sediment, soil, water, and even the atmosphere
- Microbiological anomalies and the formation of paraffin dirt
- Anomalous nonhydrocarbon gases such as helium and radon
- Mineralogical changes such as the formation of calcite, pyrite, uranium, elemental sulfur, and certain magnetic iron oxides and sulfides
- Clay mineral alterations
- Radiation anomalies
- Geothermal and hydrologic anomalies
- Bleaching of red beds
- Geobotanical anomalies
- Altered acoustical, electrical, and magnetic properties of soils and sediments

Oxidation reduction zones

Bacteria and other microbes play a profound role in the oxidation of migrating hydrocarbons. Their activities are directly or indirectly responsible for many of the diverse surface manifestations of petroleum seepage. These activities, coupled with long-term migration of hydrocarbons, lead to the development of near-surface oxidation-reduction zones that favor the formation of this variety of hydrocarbon-induced chemical and mineralogical changes. This seep-induced alteration is highly complex, and its varied surface expressions have led to the development of an equally varied number of geochemical exploration techniques. Some detect hydrocarbons directly in surface and seafloor samples, others detect seep-related microbial activity, and still others measure the secondary effects of hydrocarbon-induced alteration (Schumacher, 1996; Saunders et al., 1999). The figure below shows a generalized model of hydrocarbon microseepage and hydrocarbon-induced effects on soils and sediments.

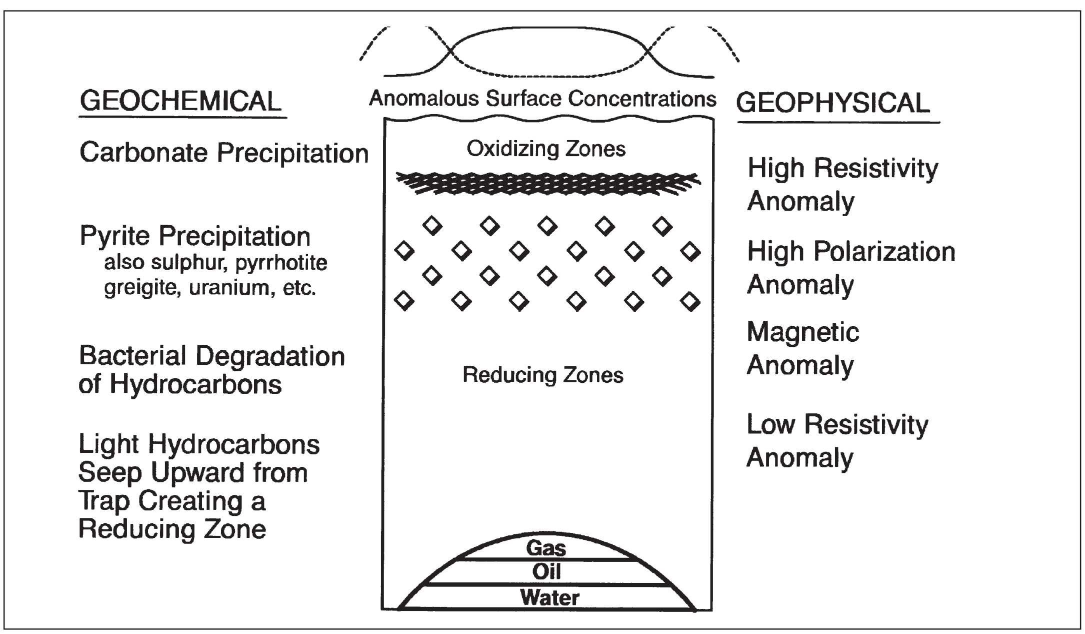

Figure 18–3. From Schumacher, 1996; courtesy AAPG.

Section B

Designing Surface Geochemical Surveys

Introduction

Survey design and sampling strategy for geochemical surveys must be dictated by the exploration objectives, expected target size, and logistical consideration. Best results are realized when surface geochemical survey design is integrated with all available geological and geophysical data. This section reviews methods available for surface geochemical surveys and discusses how to design a survey for maximum effectiveness.

In this section

This section contains the following topics.

Hydrocarbon Detection Methods

Direct methods

Direct detection methods are geochemical exploration methods designed to detect the presence of hydrocarbons in soils, near-surface sediments, seafloor sediments, and waters.

Detection of light hydrocarbons

The analysis of light hydrocarbons (chiefly methane through pentane) in soils and soil gases represents one of the earliest surface geochemical methods used and is one of the most researched and tested geochemical survey approaches. Light hydrocarbons can reside in soils and shallow sediments in a number of ways:

- Free gas in the effective porosity
- Interstitial gas occluded in pore spaces between grains
- Gas adsorbed onto sedimentary particles or trapped within carbonate cements
- Gas dissolved in water or present in the atmosphere

Detection of heavier hydrocarbons

Volatile and semivolatile heavier hydrocarbons such as aromatic compounds, gasoline-range hydrocarbons, and even normal or biodegraded oils can also be found, particularly where migration occurs along fault and fracture pathways. These different manifestations have led to the development of different techniques for sampling and analyzing hydrocarbons. It is beyond the scope of this chapter to discuss the advantages and limitations of specific methods or sampling procedures; however, such information is available in publications by Abrams (1996a), Barwise and Hay (1996), Brooks et al. (1986), Horvitz (1985), Jones and Drozd (1983), Klusman (1993), Price (1986), Richers and Maxwell (1991), Schiemer et al. (1985), and Schumacher and Abrams (1996).

Indirect methods

Indirect methods for detecting hydrocarbon seepage and microseepage are based on what are assumed to be seepage-induced soil and sediment alteration. Indirect detection methods include the following:

- Microbial
- Helium
- Radiometrics
- Iodine
- Soil alteration
- Trace elements
- Electrical
- Magnetics
- Biogeochemical
- Geobotanical

Indirect detection of hydrocarbons

Some indirect detection methods are better understood and more consistently reliable than others. Microbial methods, for example, detect the presence of hydrocarbon-oxidizing microbes in soils and sediments. These microbes would not be expected to be present in significant concentrations if there were no hydrocarbon source present, such as from a hydrocarbon seep or microseep. Helium, by contrast, is not uniquely associated with petroleum. However, it is a common constituent of petroleum accumulations and due to its mobility, chemical inertness, and abiogenic nature forms a very good indirect geochemical marker.

Indirect detection of hydrocarbons (continued)

The formation of radiation anomalies and other secondary alteration anomalies (soil carbonate, iodine, trace metal, Eh, pH, electrical, magnetic, geobotanical, etc.) is less well understood. The cause of these altered soils and sediments may well be seepage related, but migrating hydrocarbons are an indirect cause at best and not always the most probable cause. Even if due to hydrocarbons, the cause could be shallow biogenic gas and thus unrelated to leakage from deeper oil and gas accumulations.

Additional information about these various indirect geochemical methods can be found in Al Shaieb et al. (1994; general), Beghtel et al. (1987; microbial), Cunningham et al. (1987; helium), Curry (1984; radiometrics), Duchscherer (1984; soil carbonate), Foote (1996; magnetics), Klusman (1993; general), Machel (1996; magnetics), Price (1993; microbial), Rock (1984; geobotany), Saunders et al. (1999; general); Schumacher (1996; general), Schumacher and Abrams (1996; general), Sternberg (1991; electrical), Tedesco (1995; iodine), and Weart and Heimberg (1981; radiometrics).

Geochemical Survey Objectives

Principal objectives

The principal objectives of a geochemical exploration survey are to

(1) establish the presence, distribution, and composition of hydrocarbons in the area of exploration or development interest and
(2) determine the probable hydrocarbon charge to specific exploration leads and prospects.

Reconnaissance objectives

The objective of a reconnaissance survey is to find seeps and microseeps that provide direct evidence that thermogenic hydrocarbons have been generated, i.e., they document the presence of a working petroleum system. Additionally, the composition of these seeps can indicate whether a basin or play is oil prone or gas prone (Jones and Drozd, 1983). Hydrocarbons from surface and seafloor seeps can be correlated with known oils and gases to identify the specific petroleum system(s) present. Seepage data allow the explorationist to screen large areas quickly and economically, determining where additional and more costly exploration is warranted. For example, results of preseismic geochemical surveys can guide the location and extent of subsequent seismic acquisition by ensuring that areas with significant hydrocarbon anomalies are covered by seismic data.

Published examples of reconnaissance surface geochemical surveys include Abrams (1992), Piggot and Abrams (1996), Schiemer et al. (1995), Thrasher et al. (1996a), and Williams et al. (1995).

Evaluating leads and prospects

If the objective is to evaluate individual exploration leads and prospects, the results of geochemical surveys can identify those leads associated with strong hydrocarbon anomalies and thereby enable high-grading prospects on the basis of their association with hydrocarbon indicators. Regional geochemical surveys can help determine which leases should be renewed and which ones do not warrant additional expense. Detailed seepage surveys can also generate geochemical leads for evaluation with geologic and seismic data—leads that might otherwise go unnoticed. Published examples of these kinds of applications include Foote (1996), Lopez et al. (1994), Potter et al. (1996), Rice (1989), and Saunders et al. (1993).

Evaluating development projects

For development projects, detailed microseepage surveys can help evaluate infill or step-out drilling locations, delineate productive limits of undeveloped fields, and identify bypassed pay or undrained reservoir compartments. Hydrocarbon microseepage surveys have the potential to add value to 2-D and 3-D seismic data by identifying those features or reservoir compartments that are hydrocarbon charged. Published studies of development applications are few but include Belt and Rice (1996), Rice (1986), Schumacher et al. (1997), and Tucker and Hitzman (1994).

Selecting a Survey Method

Introduction

How does one select a method(s) for a surface geochemical exploration program? The choice of method(s) depends on the kinds of questions you hope the survey results will answer.

- What are the objectives of the survey—to demonstrate the presence of an active petroleum system in a frontier area, to high-grade previously defined exploration leads and prospects, or to determine the type of petroleum (i.e., oil vs. gas) likely to be encountered?
- What other data are presently available for the area of interest (satellite imagery, aeromagnetics, gravity, seismic, etc.)?
- What geochemical methods have previously been used successfully in the area of interest or in a geologic analog area?
- What limitations are imposed by the survey area (onshore or offshore, deep water or shallow, jungle or desert, mature basin or remote area, budget and personnel constraints)?

Direct vs. indirect methods

As a generalization, direct hydrocarbon methods are preferred over indirect methods because they can provide evidence of the very hydrocarbons we hope to find in our traps and reservoirs. Additionally, chemical and isotopic analysis of these hydrocarbons, especially the high-molecular-weight hydrocarbons, can provide insight into the nature and maturity of the source rock that generated these hydrocarbons.

Offshore methods

The table below lists the principal geochemical methods used for offshore exploration.

Medium to be Sampled	Target to be Analyzed	Methods
Atmosphere	Hydrocarbons	Radar or laser
Water surface	Oil slicks or sheens	Satellite, airborne sensors (radar, multispectral, hyperspectral, laser, fluorescence), or direct sampling
Water	Dissolved hydrocarbons (LMW, HMW, or aromatics)	Marine sniffer, water analysis
Sea bottom	Hydrocarbon macro- or microseepage	High-resolution seismic, side-scan sonar, direct sampling (gravity core, vibro-core, piston core, jet core, etc.)
	Hydrocarbon-induced alteration	Topographic, acoustic, and temperature contrasts; sediment sampling for microbial or geochemical indicators

Onshore methods

The table below lists the principal geochemical methods used for onshore exploration.

Medium to be Sampled	Target to be Analyzed	Methods
Land surface	Oil and gas macroseeps,stains, impregnations	Geologic mapping; historical records; satellite and airborne sensors (multispectral, hyperspectral); direct sampling of seeps, stains
	Hydrocarbon microseeps	Soil/sediment sampling for hydrocarbon analysis
	Hydrocarbon-induced alteration	Soil/sediment sampling for indirect microbial or geochemical indicators, aeromagnetic, electrical, or radiometric
Soil air	Light hydrocarbons	Probe or adsorptive collectors
	Nonhydrocarbons	Probe or adsorptive collectors
Soil/sediment	Light hydrocarbons, aromatics	Sample disaggregation and/or acid extraction for chromatography, UV-fluorescence
	Nonhydrocarbons or diagenetic anomalies	Hydrocarbon-oxidizing microbes, soil salts (i.e., carbonates, chloride, iodine, sulfate, etc.); clay minerals; trace metals; magnetic susceptibility, aeromagnetics, ground magnetics; electrical (IP, CSAMT, resistivity, MT); radiometrics

Recommendations

Whenever possible, use more than one geochemical survey method, for example, combine a direct method with an indirect method. The use of multiple methods can reduce interpretation uncertainty because seepage-related anomalies tend to be reinforced while random highs and lows tend to cancel each other. If surface conditions or budgetary constraints preclude the use of direct hydrocarbon detection methods, the next best choice is the indirect method most closely linked to hydrocarbons and hydrocarbon accumulations (microbial, helium, and perhaps certain magnetic and radiometric methods).

Designing a Geochemical Survey

Design considerations

Survey design and sampling strategy for geochemical surveys should be flexible and must be dictated by the following:

- Exploration objectives
- Geologic setting
- Basin hydrodynamics
- Anticipated target size and shape of the anomaly (or geologic target)
- Ability to sample along (and/or between) key seismic lines
- Logistical considerations
- Expected natural variation in surface measurements
- Probable signal-to-noise ratio (Matthews, 1996b)

Procedure

Use the table below as a guide for designing a surface geochemical survey.

Step	Action
1	Research the method(s); investigate contractor, past clients.
2	Use more than one geochemical survey method when possible.
3	Be guided by past experience in the basin or exploration trend.
4	Base the geochemical sample program on the target's size, geology.
5	Conduct a calibration survey(s) over an analog field or recent discovery.
6	Integrate available geological and geophysical data to achieve the most meaningful results.

Sample locations

In frontier areas, geochemical exploration often begins with a search for, and analysis of, visible oil and gas seeps. Additional geochemical data may then be acquired along the trace of existing seismic lines or along regional geochemical traverses located to cross features of geologic and structural significance. Depending on survey objectives, sample spacing for geochemical surveys may vary from 500–1,000 m at one extreme to 50–100 m at the other. Sampling along geochemical grids is recommended for small exploration targets and/or 3-D seismic programs; however, grids are not cost effective for large reconnaissance surveys.

Analogs

Whenever possible, it is advisable to acquire surface geochemical data over a nearby geologic analog or recent discovery. A dry hole can be as valuable an analog as a recent discovery if the well penetrated the target horizon and found it water wet (or lacking the reservoir facies).

Designing a Geochemical Survey, continued

Seeps

Oil and gas seeps, if present, are also valuable analogs because they permit direct correlation of seeping hydrocarbons with soil gas and fluorescence data as well as other microbial or geochemical data. Old producing fields may not provide good analogs since production and pressure decline may have reduced or even eliminated their surface geochemical expression (Horvitz, 1969).

Sample density

Hydrocarbon microseepage data, whether soil gas or microbial or other geochemical measurements, are inherently noisy and require adequate sample density to distinguish between anomalous and background areas. Matthews (1996b) reviews the importance of sampling design and sampling density in target recognition. He states that undersampling is probably the major cause of ambiguity and interpretation failures involving surface geochemical studies.

Recognizing anomalies

Defining background values adequately is an essential part of anomaly recognition and delineation; Matthews (1996b) suggests that as many as 80% of the samples collected be obtained outside the area of interest. This is a good recommendation for reconnaissance and prospect evaluation surveys. However, for very small targets such as pinnacle reefs or channel sandstones, optimum results are obtained when numerous samples are collected in a closely spaced grid pattern, (100–160-m sample interval or less) over the feature of interest (Schumacher et al., 1997).

Example

The recognition of surface geochemical anomalies improves by increasing sample number and reducing sample spacing. The example below from Oklahoma illustrates the value of geochemical grids over geochemical traverses for anomaly recognition.

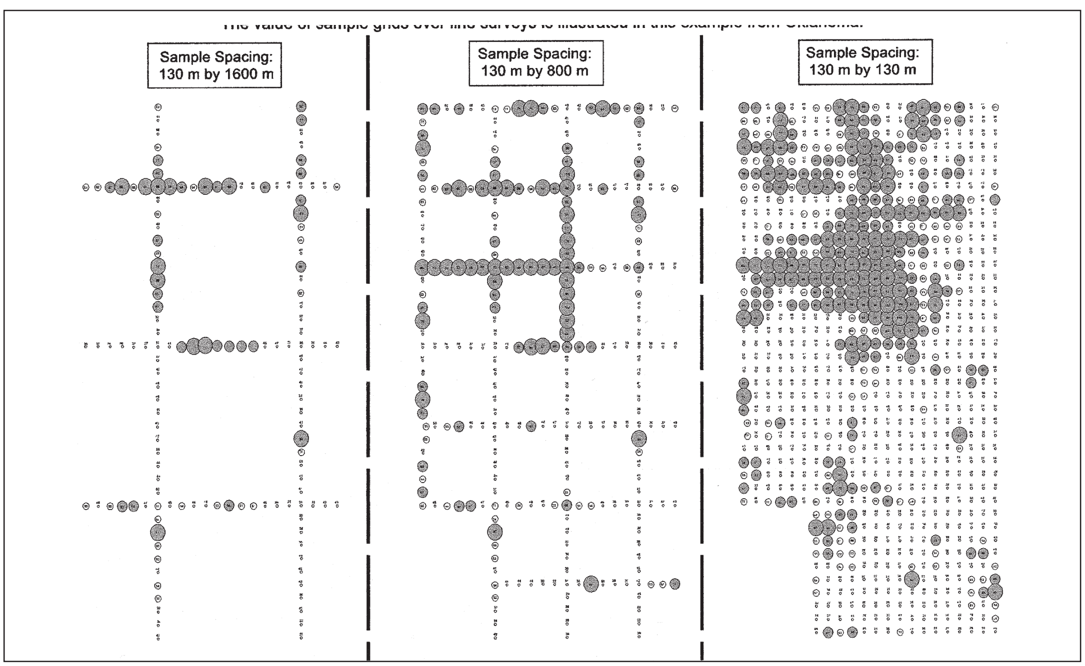

Figure 18–4. Courtesy Geo-Microbial Technologies, Inc.

Interpretation Guidelines

Introduction

The presence of hydrocarbon macroseeps or microseeps in the area of a geochemical survey is direct evidence that petroleum has been generated. Hydrocarbon seepage at the surface represents the end of a petroleum migration pathway. These hydrocarbons may represent hydrocarbon leakage from an accumulation or leakage along a carrier bed or other migration pathway. Anomalies defined by multiple samples from one or more survey lines may indicate the location of discrete structural or stratigraphic targets within the survey area.

Anomalies and vertical migration

If the basin or play is characterized by predominantly vertical migration, then the correlation of a strong geochemical anomaly at the surface with a possible trap at depth suggests that the trap is charged with hydrocarbons. Conversely, if the trap is not associated with a positive geochemical anomaly, we assume the trap is not charged with hydrocarbons.

Anomalies and lateral migration

If the structural or geologic setting of the area suggests that microseepage may be predominantly lateral or pathway selective, such as along dipping stratigraphic surfaces and unconformities, the interpretation will be more difficult since geochemical anomalies may then not be located vertically above a trap. Which of these migration scenarios is more likely in your area of investigation? What is the relationship of the anomalies to outcrop geology, mapped structural closures, stratigraphic pinch-outs, faults, or basement highs? Because relationships between surface geochemical anomalies and subsurface accumulations can be complex, proper interpretation requires integration of surface geochemical data with geologic, geophysical, and hydrologic data. The importance of such integration cannot be overstated (Thrasher et al., 1996b).

Hydrocarbon composition from macroseeps

Hydrocarbon seep composition can play an important role in evaluating the exploration potential of a basin, play, or prospect. Petroleum in most visible oil and gas seeps (i.e., macroseeps) generally has been altered by processes such as biodegradation, water washing, and evaporative loss of volatile components. Despite these changes, chemical and isotopic analysis of such seeps can enable inferences about the nature of the source rock facies and maturity as well as permit correlation with known source rocks and reservoired petroleum.

Hydrocarbon composition from microseeps

Obtaining compositional information from the analysis of hydrocarbon microseeps is more difficult because microseeps generally consist of only light hydrocarbons (methane through pentane). Sometimes, however, the heavier gasoline-range and aromatic hydrocarbons are also present. One can infer the composition of the migrating petroleum from these light hydrocarbons from soil gas/hydrocarbon ratios, carbon isotopic composition of soil gases, fluorescence characteristics of soil or sediment extracts, and chromatographic analysis of such extracts. A detailed discussion of these methodologies is beyond the scope of this article, but published examples of such analyses and their interpretations include Abrams (1996b), Barwise and Hay (1996), Belt and Rice (1996), Brooks et al. (1986), Horvitz (1985), Jones and Drozd (1983), Kornacki (1996), Piggot and Abrams (1996), Schiemer et al. (1985), Stahl et al. (1981), and Thrasher et al. (1996a).

Section C
Case Histories

Introduction

The case histories presented in this section document the effectiveness of geochemical surveys.

In this section

This section contains the following topics.

Case History 1: Structural Traps

Introduction

Meyer et al. (1983) published an excellent but little-known case history documenting vertical migration and microseepage from undisturbed structural traps. In the early 1980s, a series of microseepage surveys were conducted over 49 proposed well locations in Kansas and Colorado.

Sampling

Soil samples were collected at one-tenth-mile intervals within one-half mile of each proposed drilling site and analyzed for the presence of hydrocarbon-oxidizing microbes. All samples were collected and analyzed prior to drilling, and the results were placed in escrow until after the wells were drilled.

Survey vs. drilling results

When compared with the subsequent drilling results, the soils overlying productive reservoirs contained microbial populations that were readily distinguishable from those of samples that were collected from nonproductive sites. The 39 wells subsequently drilled yielded three producers, three wells with uncommercial shows, and 33 dry holes. The microbial survey correctly predicted all 33 dry holes and identified the three producing wells and two of the three wells with uncommercial shows. The one show well that was not recognized tested 9 BO/D with a very low GOR.

The figure below illustrates ten representative seismic prospects surveyed and later drilled. Each prospect displays good four-way dip closure on a Cretaceous horizon, and each is located in a productive basin. Only one was associated with a surface geochemical anomaly; it was the only one of the ten shown that resulted in a commercial discovery.

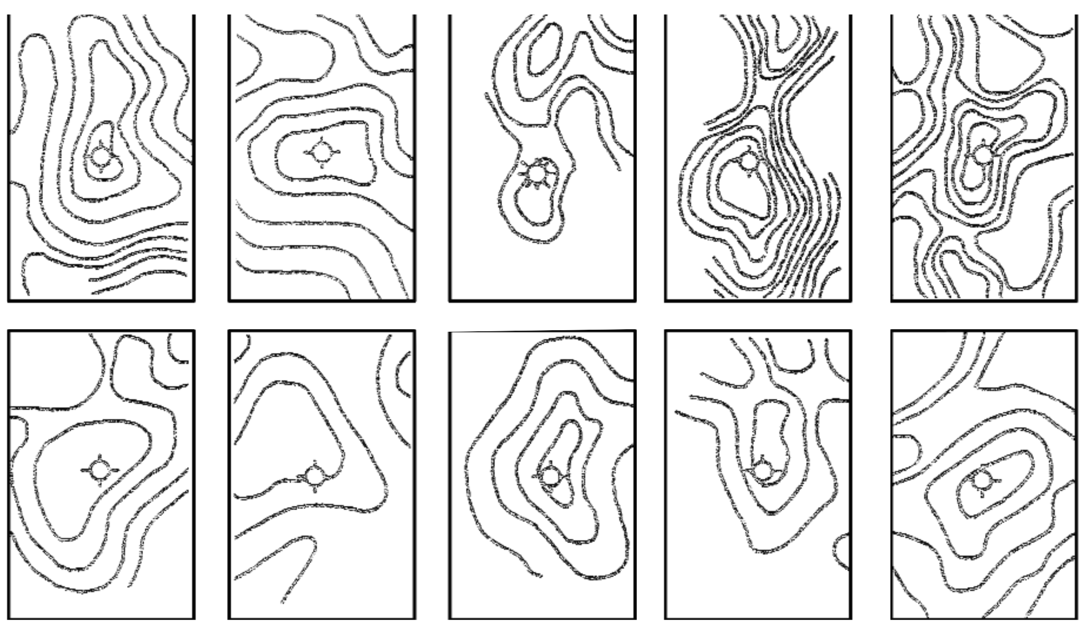

Figure 18–5. Based on Meyer et al., 1983; courtesy Barringer Technologies Inc.

Case History 2: Stratigraphic Trap

Introduction

In this case history, the client conducted a soil gas hydrocarbon survey along the trace of the seismic line to look for evidence of hydrocarbon microseepage from a seismically defined trap at CDP 1070 (Figure 18–6, left). Propane soil gas anomalies were detected at CDP 1070 and 1096. The wildcat well drilled at CDP 1070 resulted in a new field discovery. The geochemical lead at CDP 1096 was reevaluated seismically. After additional processing, a revised interpretation (right) also predicted porosity development there and coincident with the surface geochemical anomaly. A second productive well was drilled at CDP 1096.

This is a good example, illustrating how we can use surface geochemical data to evaluate a geophysical lead and a geochemical lead.

Anomaly map

The figure below is a seismic section and soil gas profile of a stratigraphic trap located at approximately 5,600 ft (1.5 sec) in the Cretaceous Escondido Sandstone in La Salle County, Texas.

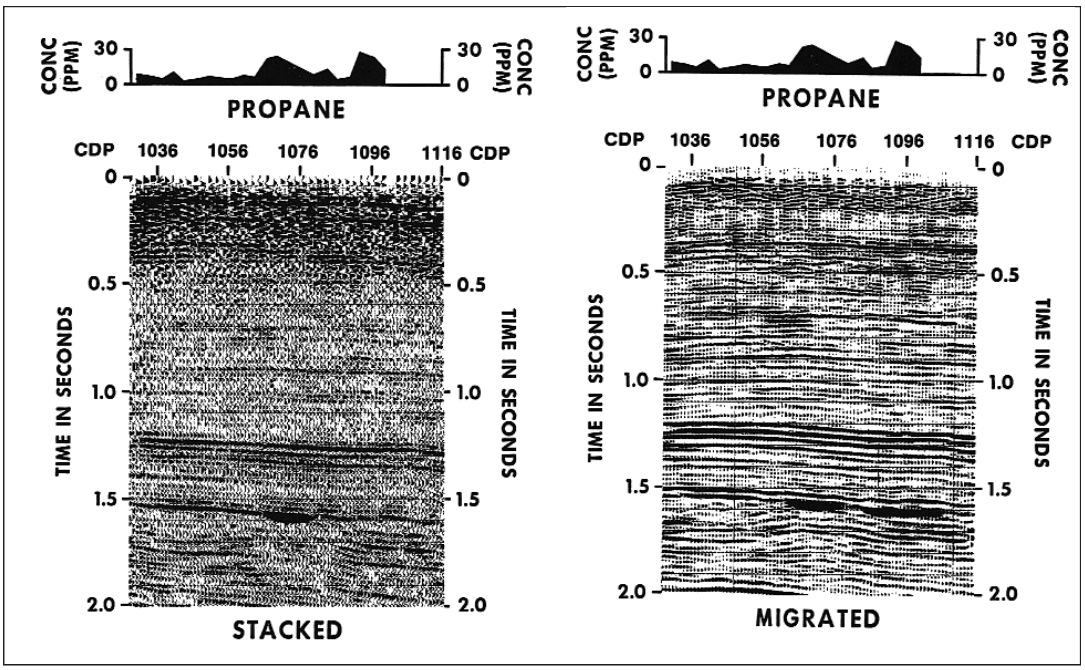

Figure 18–6. Modified from Rice, 1989; courtesy Oil & Gas Journal.

Case History 3: Predrilling/Postdrilling Comparison

Introduction

The significance of surface geochemical anomalies in hydrocarbon exploration are often difficult to quantify. Potter et al. (1996) summarize one company's experience with a soil gas geochemical method. Their exploration program involved geochemical surveys of 139 prospects located in both mature basins and frontier basins, onshore and offshore, in a wide variety of environments. Targets ranged in depth from 1,000–15,000 ft (305–4,572 m) and covered the full spectrum of trap styles; survey areas ranged from as small as a few hundred acres to regional programs covering 1,000 mi^2 (2,590 km^2).

Results

The 139 surveys led to the drilling of 141 wells in previously undrilled prospects. A total of 43 wells were drilled in negative geochemical anomalies, and 41 of these encountered no hydrocarbons. Of the 98 wells drilled in positive geochemical anomalies, 92% encountered reservoired hydrocarbons and 76% were completed as producers. This company's experience is fairly typical and documents that integration of seismic data and geochemical data yields greater definition of exploration targets than provided by either method separately.

Conclusion

Although the discovery of a surface geochemical anomaly does not guarantee the discovery of commercially significant hydrocarbons, it does establish the presence of hydrocarbons in the area of exploration interest. Seeps and microseeps at the surface represent the end of a petroleum migration pathway. Traps and structures along such migration pathways should be considered significantly more prospective than those not associated with hydrocarbon anomalies.

Surface geochemical exploration methods cannot replace conventional exploration methods, but they can be a powerful complement to them. Geochemical and other surface 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 methods will lead to better prospect evaluation and risk assessment.

Section D
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