[PS]Surface Geochemical Exploration After 100 Years: Lessons Learned and What More Must Be Done*

Dietmar (Deet) Schumacher[1]

Search and Discovery Article #42072 (2017)**
Posted May 15, 2017

*Adapted from poster presentation given at AAPG 2017 Annual Convention and Exhibition, Houston, Texas, United States, April 2-5, 2017

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Abstract

The science of surface geochemical exploration for oil and gas has made much progress since observations in early 1900's of geochemical and mineralogic changes associated with soils and sediments above oil and gas fields in the Middle East and the US Gulf Coast. This was followed by development of many geochemical and non-seismic methods for detection of hydrocarbons in soils, sediments, waters, and atmosphere. There is today a wider acceptance of hydrocarbon microseepage and hydrocarbon detection surveys due to improved analytical techniques, a better understanding of the migration mechanism and its varied near-surface effects, improved survey design and sampling strategies, and improved interpretation skills. Well-documented case histories of microseepage surveys appear regularly in peer-reviewed journals and books, and these illustrate the wide applications of this technology in all stages of exploration -- from frontier basin reconnaissance, to high-grading exploration leads and prospects based on their likely hydrocarbon charge, to identifying bypassed pay in mature fields, to monitoring production-related hydrocarbon drainage over time.

Nevertheless, many explorationists remain skeptical about the benefits of this technology. What more must be done to increase the acceptance of this reliable but under-utilized technology by the exploration community? We need a unified hydrocarbon microseepage model that links the many seemingly unrelated hydrocarbon-induced changes to surface and near-surface sediments. This model should predict the observed geochemical, mineralogical, and geophysical changes in different geologic settings. Also helpful would be better and more consistent integration of surface and subsurface data. Inferring the depth of origin for hydrocarbons that have migrated to the surface remains impossible with rare exceptions, however, detailed chemical and isotopic characterization of the hydrocarbons in seepage anomalies shows promise for enabling us to more reliably infer a depth of origin in the future, as does integration of geochemical data with passive electromagnetic data and gas chimney data. Lastly, we should strive for real-time hydrocarbon data acquisition where possible. If we can accomplish most if not all of these tasks in the next 5-10 years, we may find that our exploration colleagues are not only more willing to add this technology to their exploration tool box, but may actually base exploration decisions on hydrocarbon microseepage data.

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Surface Geochemical Exploration After 100 Years: Lessons Learned and What More Must Be Done

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OUTLINE

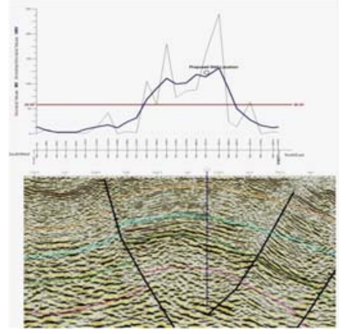
- Early History and Observations
- Characteristics of Microseepage
- Hydrocarbon Detection Methods
- Survey Objectives, Survey Design
- Measuring Success
- What We Know
- What More is Needed

Geochemical and Non-Seismic Detection of Hydrocarbons

Geochemical and non-seismic detection of hydrocarbons is the search for chemically (and non-seismic geo physically) 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.

Conventional vs Geochemical Exploration Methods

Finding Traps vs Finding Hydrocarbons



Why is Concept of Microseepage Controversial?

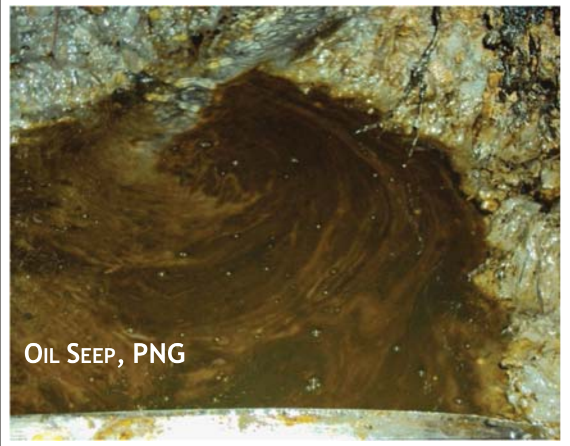
- Since microseepage not normally a visible process, direct observation has been difficult for geoscientists who rely heavily on direct observation.
- Also, if a hydrocarbon reservoir has held oil/gas for millions of years, by definition it must not be leaking even at low rates. Seals are seals.
- Making repeated and reliable measurements of the microseepage process is technically challenging. Gases are by their mobile nature, difficult to sample from soils and sediments in a reliable and repeatable manner.
- Due to the heterogeneity of soils and near-surface sediments and the small sample volume collected in most surveys, there is normally considerable variability in composition and concentration. Consequently, not all samples from an area of microseepage are anomalous, and not all samples from area of background have a background-like composition.

* * * *

EARLY HISTORY AND OBSERVATIONS

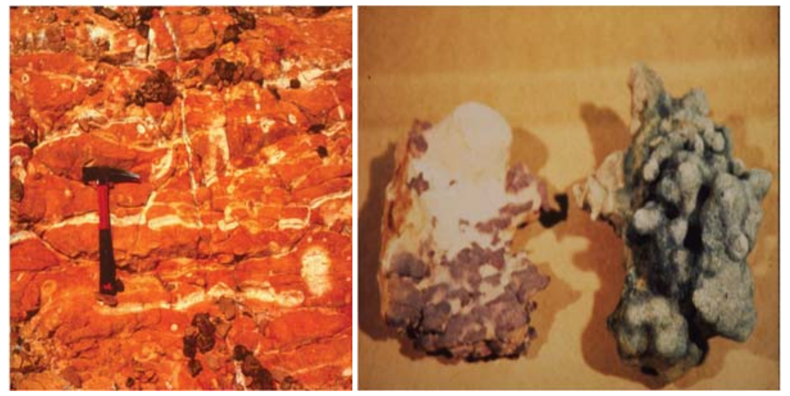
Before 1900, and going back almost 5000 years, people living in the vicinity of oil and gas seeps have exploited them. And, has has long been pointed out by petroleum industry historians, the presence of these seeps has led to the majority of early oil and gas discoveries and the recognition of future productive trends. As interesting as this very early history is, the history of scientific surface geochemical exploration trends begins at the beginning of the 20th Century.

1900-1935: The association of mineralogic changes and hydrocarbon seepage has been recognized since the earliest days of petroleum exploration. Many early explorationists noted the correlation of productive areas not only with seeps but also with paraffin dirt, saline or sulfurous waters, surface mineralization, and topographic highs. **Sawtelle** (1936) reported that such features were instrumental in the discovery of 70% of American Gulf Coast fields. **Harris** (1908) was among the first to report the presence of pyrite and other sulfides in strata overlying oil fields associated with some Louisiana salt domes. **Reeves** (1922) observed the discoloration of surface redbeds in the Cement Field area in Oklahoma, and noted the intense carbonate cementation over the crest of the Cement structure. **Thompson** (1933) observed that sulfur and pyrite are commonly associated with Persian oil fields.

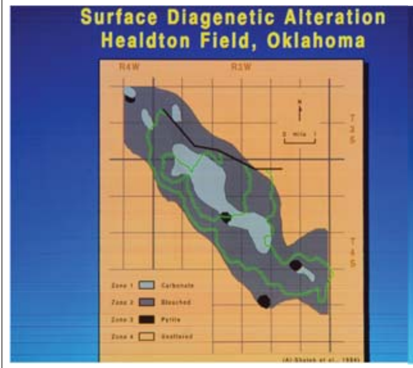


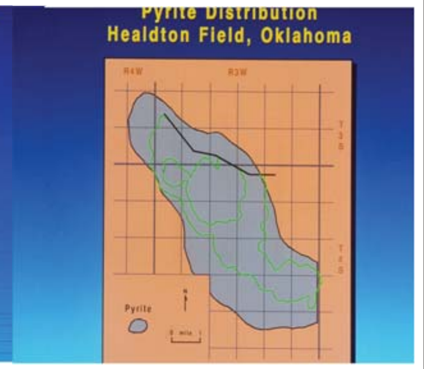
Hydrocarbon-Induced Alteration of Sedimentary Rocks

Bleached Redbeds along Fractures | Iron Removal | Calcite Cementation



Hydrocarbon-Induced Alteration Above Oil and Gas Fields





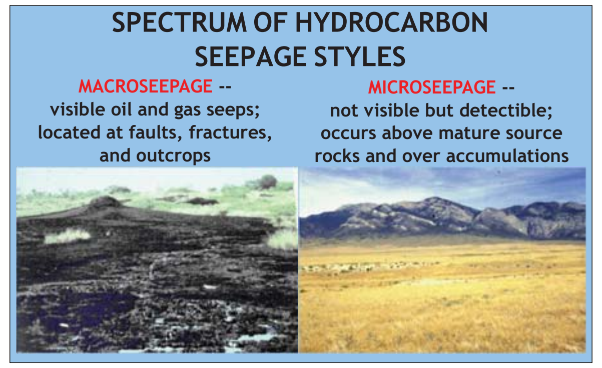
1925-1935: The first attempt to relate near-surface hydrocarbons to subsurface oil or gas accumulations was made in Germany in 1929 and reported by **Laubmeyer** in 1929. He drilled holes to depths of 1-2m, sealed them, and after 24-48 hours removed a sample of the enclosed air for analysis. Results showed that soil air from holes above a gas accumulation contained higher concentration of methane than air removed from holes from non-productive areas. In 1932, Russian investigators began similar studies. **Sokolov** (1935) improved on Laubmeyer's technique by deepening the holes to 2-3m and removing most of the air initially present before collecting air for analysis. In addition to methane, Sokolov and colleagues found that their samples also contained a "heavy" fraction, presumably ethane and higher light hydrocarbons.

1935-1950: Research in the USA began in 1936, but from the very beginning the soil itself was investigated as the sampling medium rather than the soil air. These early investigators (**Rosaire**, 1938; **Horvitz**, 1939) reasoned that analysis of the adsorbed hydrocarbons in soil would yield higher hydrocarbon concentrations than would soil air. Other advantages were that samples could be collected and shipped and stored more easily, and sampling could be done in all areas including offshore. Other early American proponents of surface geochemistry were **Ludwig Blau** (Humble Oil), **Eugene McDermott** (founder of GSI, later to become Texas Instruments), **Everett DeGolyer** and **William Duchcsherer**. Rosaire was founder of Subterrex and hired Horvitz to work for him. Horvitz later founded Horvitz Research Laboratories and provided industry with soil hydrocarbon data until the mid-1980s.

During the last 40 years, the results of continuing academic and industry research, as well as many hundreds of individual hydrocarbon detection surveys have further expanded the array of geochemical and non-seismic hydrocarbon detection methods available to us, as well as greatly improved our understanding of hydrocarbon migration and its varied near-surface expressions.

CHARACTERISTICS OF HYDROCARBON MICROSEEPAGE

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 structures, structural and stratigraphic traps, and outcropping carrier beds. A further assumption is that the geochemical 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 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. Relationships between surface anomalies and subsurface accumulations can be complex. Proper interpretation requires integrating seepage data with geological, geophysical, and hydrologic data.



Evidence for Hydrocarbon Microseepage

Increase in non-methane hydrocarbons as reservoir is approached during drilling and mud-logging

Increase in soil gas concentrations and soil gas ratios (C2/C1, C3/C1, and C4/C1) over hydrocarbon reservoirs

Sharp lateral changes in soil gas concentrations and soil gas ratios at edge of surface projection of the reservoir

Stable carbon isotopic ratios for methane in soil gases which are similar to those found in hydrocarbon reservoirs

Rapid decline of surface anomaly with production

Re-appearance of anomaly in response to increased reservoir pressure due to waterflooding or gas injection

Characteristics of Hydrocarbon Microseepage

Detailed geochemical surveys and research document that hydrocarbon microseepage from oil and gas accumulations is

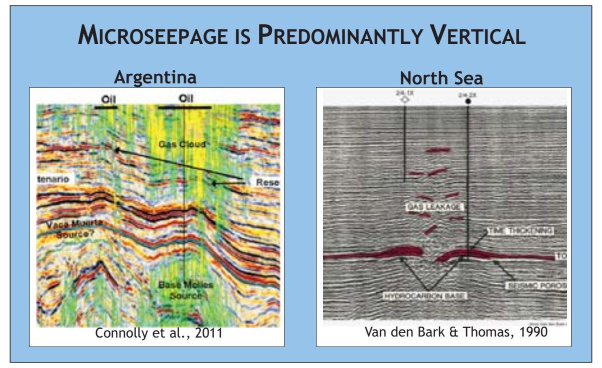
Common and Widespread

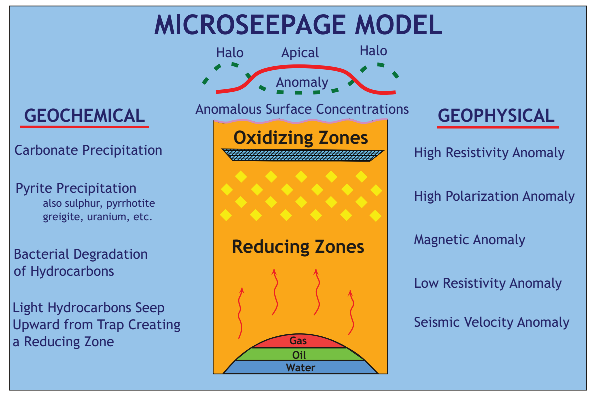
and

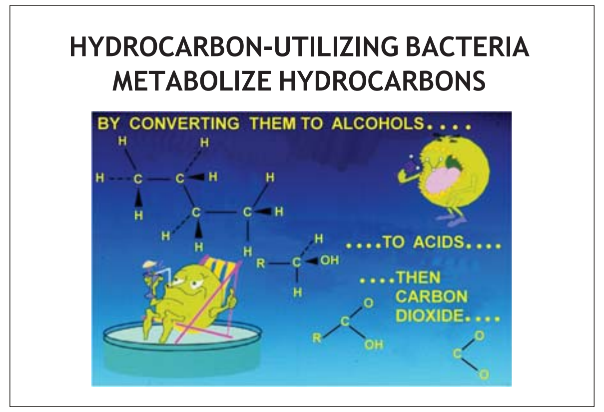
Predominantly Vertical

and

Dynamic







HYDROCARBON DETECTION METHODS

Geochemical exploration techniques can be direct or indirect, and measurements can be instantaneous or integrative. Direct techniques analyze small quantities of hydrocarbons that occur in the pore space of soil, are adsorbed onto clay minerals, or are incorporated in soil cements. Indirect methods detect seepage-induced changes to soil, sediment, or vegetation. Non-seismic geophysical methods for detection of hydrocarbons or their alteration products include satellite image analysis for seep-induced alteration such as unique spectral signatures, high-resolution aeromagnetic data to identify sedimentary magnetic anomalies that form in the seepage environment, radiometric surveys, radar and laser detection of hydrocarbon gases in atmosphere, and passive electromagnetic and telluric measurements. A detailed discussion of these methods is beyond the scope of presentation, but a list of the more commonly used hydrocarbon detection methods appears below.

Hydrocarbon Detection Methods

REMOTE SENSING, SATELLITE IMAGERY
- detects hydrocarbon-induced alteration, oil slicks

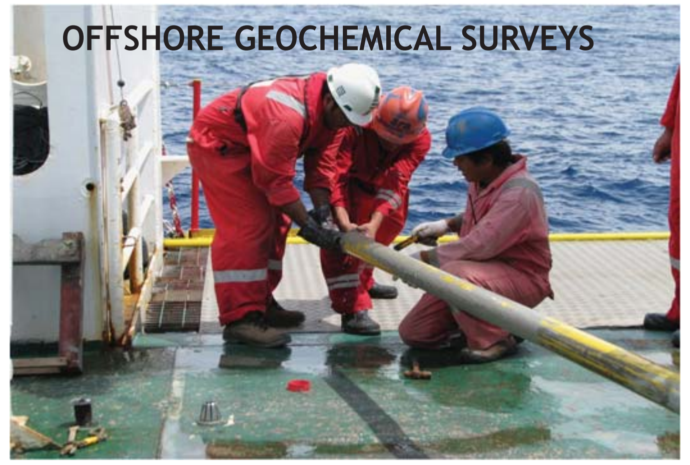
AEROMAGNETICS, MICROMAGNETICS
- detects hydrocarbon-induced alteration

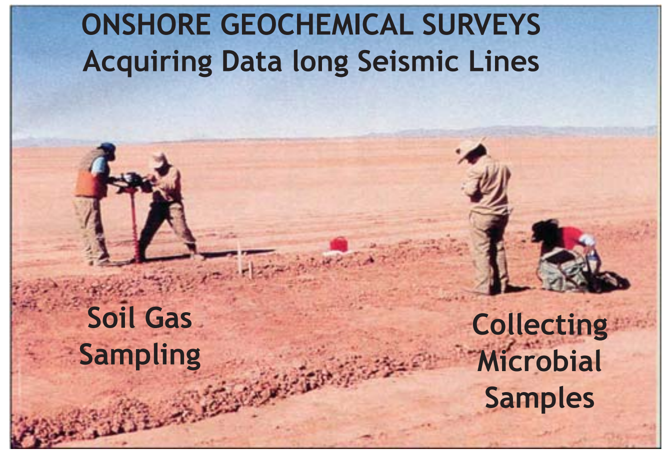
SOIL GAS, FLUORESCENCE, HEAVY HCS
- measures hydrocarbon concentration

MICROBIOLOGICAL
- measures HC-oxidizing bacteria

BIOGEOCHEMICAL, GEOBOTANICAL
- trace elements, vegetation stress

ELECTROMAGNETIC, TELLURIC
- oil/gas presence, approx. depth and thickness

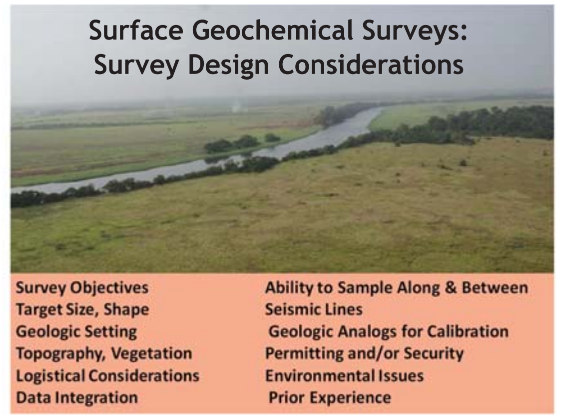


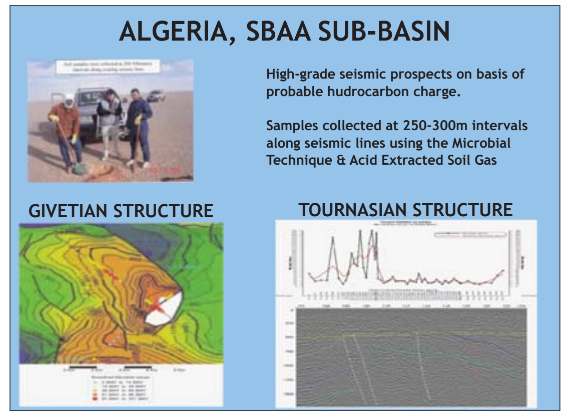


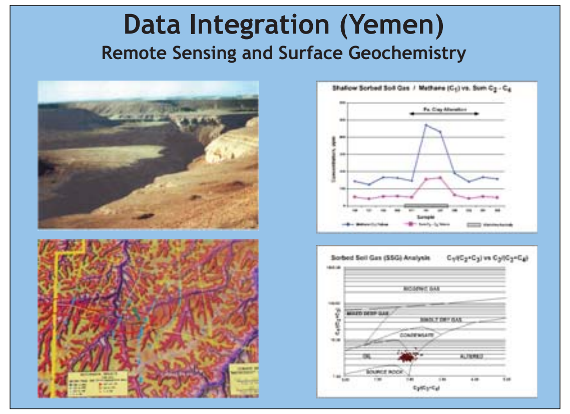
SURVEY OBJECTIVES AND SURVEY DESIGN

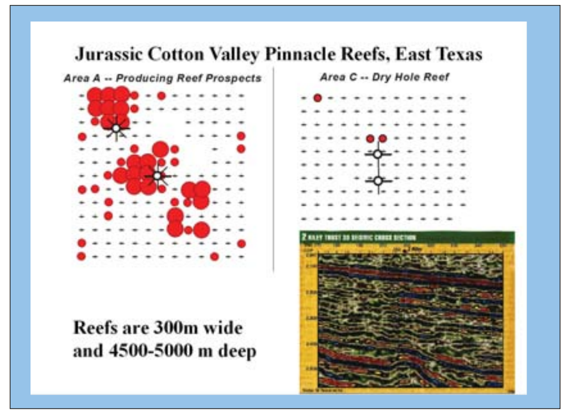
The design and sampling strategy for geochemical surveys must be dictated by the exploration objectives, expected target size, and logistical considerations. Best results are realized when the survey design is integrated with all available geological and geophysical data. What are the objectives of the survey? Is it to document the presence and characteristics of an active petroleum system in a frontier area, or to high-grade previously defined exploration leads and prospects based on their likelihood of hydrocarbon charge or hydrocarbon composition, or to look for bypassed oil in a mature area?

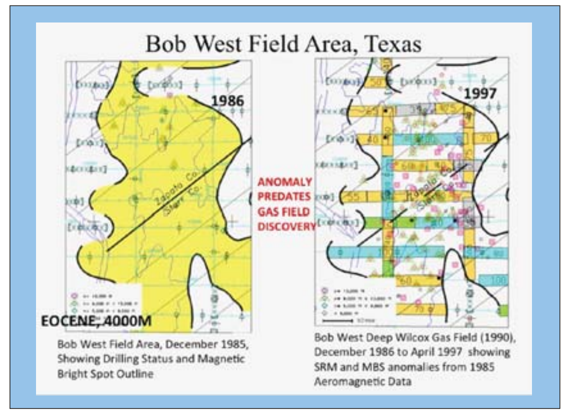
Hydrocarbon microseepage data are inherently noisy and require adequate sample density to distinguish between anomalous and background areas. Undersampling is probably the major cause of ambiguity and interpretation failures involving surface geochemical investigations. Whenever possible, use more than one hydrocarbon detection 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 out.











Successful Surface Geochemical Surveys
Seven Pitfalls to Avoid

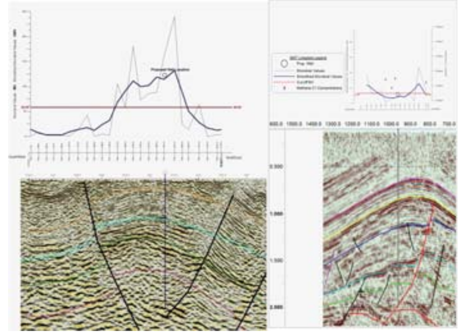
1. Survey Objectives Poorly Defined
2. Improper Survey Design
3. Too Few Samples
4. Poor Data Quality
5. Interpretation Errors
6. Absence of Good Analogs
7. Data Integration Poor or Incomplete

Undersampling is probably the single most common source of ambiguity and interpretation failures in surface geochemical surveys.

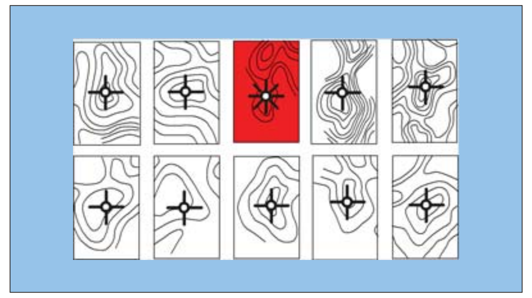
MEASURING SUCCESS

In order to quantify the benefit of integrating hydrocarbon microseepage data with conventional geological and geophysical exploration data, I have compiled published microseepage survey results for more than 3000 exploration wells with the results of subsequent drilling. These prospects are located in both frontier basins and mature basins, onshore and offshore, and occur in a wide variety of geologic settings. Target depths ranged from 300 meters to more than 4900 meters and covered the full spectrum of trap styles. Prospects were surveyed using a variety of hydrocarbon detection methods including interstitial soil gas, integrative and/or acid-extracted soil gas, microbial, iodine, radiometrics, and micromagnetics. The majority of wells were drilled on conventionally developed prospects after completion of the hydrocarbon detection surveys. Preliminary results were published in Schumacher (2010), and updated results are being presented elsewhere in this AAPG Conferene. Of the wells drilled on prospects associated with a positive hydrocarbon microseepage anomaly, 80% resulted in discoveries. In contrast, only 14% of wells drilled on prospects without a hydrocarbon anomaly yielded a discovery. Had drilling decisions included serious consideration of the hydrocarbon microseepage data, exploration success rates would have more than doubled for most prospects.

Hydrocarbon-Detection Surveys -
How do we Measure Success



Predicting Success . . .



Only One of These Ten Seismic Prospects Resulted in a Producer. It was the Only Prospect with a Surface Geochemical Anomaly

Reducing Exploration Risk
Post-Survey Drilling Results

SUMMARY

3308 Wells, Various Companies,
Various Methods, Various Basins

In Negative Anomalies

- 1590 Wells Drilled
- 1374 Wells Dry (86%)
- 216 Discoveries (14%)

In Positive Anomalies

- 1718 Wells Drilled
- 349 Wells Dry (20%)
- 1369 Discoveries (80%)

For all wells drilled, the success rate based only on geology and seismic was 48% (Schumacher, 2010, 2017)

Comparison of Exploration Success Rates

METHOD	GEOL/GEOPH ONLY	PROSPECTS W/ HC INDIC	PROSPECTS NO HC INDIC
SOIL GAS	49% *(227)*	76% *(122)*	18% *(105)*
MICROBIAL	44% *(531)*	79% *(271)*	8% *(260)*
RADIOMETRIC	57% *(284)*	79% *(99)*	28% *(185)*
MICROMAGN	39% *(1579)*	81% *(685)*	10% *(921)*
TOTALS	46% *(2321)*	80% *(1150)*	11% *(1371)*

WHAT WE KNOW AND WHAT MORE IS NEEDED

There is today a wider acceptance of hydrocarbon microseepage and hydrocarbon detection surveys due to improved analytical techniques, a better understanding of the migration mechanism and its varied near-surface effects, improved survey design and sampling strategies, and improved interpretation skills. Well documented case histories of microseepage surveys appear regularly in peer-reviewed journals and books, and these illustrate the wide applications of this technology in all stages of exploration - ranging from frontier basin reconnaissance, to high-grading exploration leads and prospects based on their likely hydrocarbon charge, to identifying bypassed pay in mature fields, and even for monitoring production-related hydrocarbon drainage over time.

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WHAT HAS IMPROVED IN RECENT YEARS

Wider acceptance of surface geochemical exploration
Improved analytical techniques
Better understanding of hydrocarbon migration and surface effects
Improved survey strategies, design
Improved interpretation skills
More applications to exploration, field development and production

WHAT MORE NEEDS TO BE DONE?

Need a unified predictive model for hydrocarbon microseepage and its varied surface and near-surface expressions

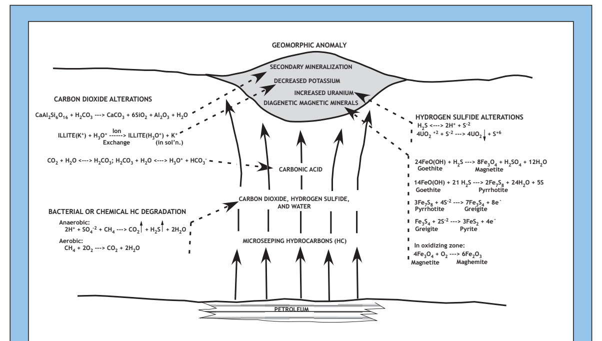
Better and more consistent integration of surface, subsurface, and spectral data with microseepage data

Improving depth of origin estimate for microseepage anomalies

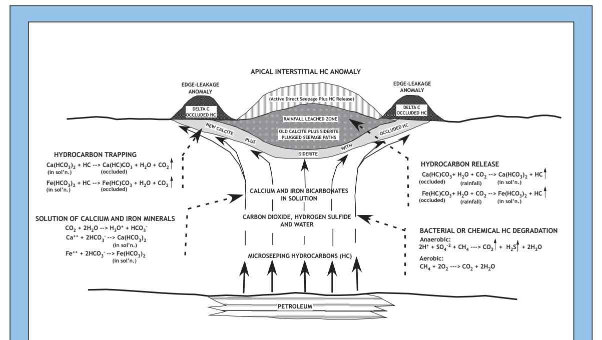
In-field analysis of microseepage data when possible

Expand use of drones (UAVs) for acquisition of micorseepage data

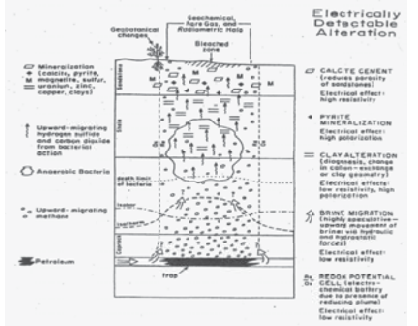
OTHER EXAMPLES OF CURRENT MICROSEEPAGE MODELS



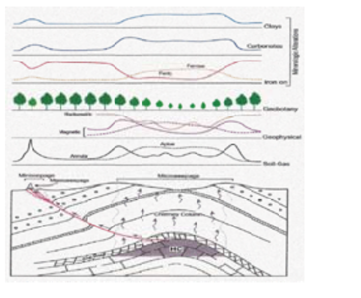
Idealized model for the hydrocarbon-induced alteration associated with microseepate (Saunders et al., 1999)



Possible model for the edge-leakage soil hydrocarbon and delta-C anomalies (Saunders et al., 1999)



Idealized illustration of seep-induced alteration, with emphasis on electrically-detectable alteration (Hughes et al., 1986)



Schematic representation of seepage and microseepage concept and the various associated hydrocarbon-induced alterations (Asadzadeh & de Souza Filho, 2017)

ACKNOWLEDGMENTS

My thanks to members of E&P GeoField Services and GeoMicrobial Technologies who participated in many of these surveys, and to colleagues both in academia and with exploration companies who generously share the results of their work with others in our profession. Special thanks are due to Ms Lesta Morrison for preparing these poster panels.

A list of references cited will be provided upon request. For more information contact deetschumacher@gmail.com