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INTEGRATING HYDROCARBON MICROSEEPAGE DATA WITH SEISMIC DATA DOUBLES EXPLORATION SUCCESS

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ABSTRACT

It has been long known and well documented that most oil and gas accumulations leak hydrocarbons, that this leakage (or microseepage) is predominantly vertical, and that this leakage can be detected and mapped using any of a number of direct and indirect geochemical and non-seismic geophysical methods. It has also been documented that the areal extent of the surface geochemical anomaly can approximate the productive limits of the reservoir(s) at depth. How reliably this can be done depends on the geologic setting, the choice of hydrocarbon detection method, survey design and sample spacing.

Proponents of surface geochemical surveys contend that proper use of surface geochemistry -- and proper integration of geochemical results with conventional geologic and seismic data -- leads to better prospect evaluation and risk assessment. How can one quantify the value added by hydrocarbon microseepage data when it is integrated with conventional exploration methods? One way to do so is to compare survey results with results of subsequent drilling. The results of such a comparison are summarized here for more than 2700 U.S. and International wells, all drilled on conventionally developed prospects after completion of geochemical or non-seismic hydrocarbon detection surveys The prospects are located in both frontier basins and mature basins, onshore and offshore, and occur in a wide variety of geologic settings. Targets ranged in depth from 300 meters to more than 4900 meters and covered the full spectrum of trap styles. Prospects were surveyed using a variety of geochemical exploration methods including free soil gas, microbial, iodine, radiometrics, and micromagnetics.

Of wells drilled on prospects associated with positive microseepage anomalies 82% were completed as commercial discoveries. In contrast, only 11% of wells drilled on prospects without an associated microseepage anomaly resulted in discoveries. Had drilling decisions included consideration of the hydrocarbon microseepage data, exploration success rates would have more than doubled!

INTRODUCTION

Seismic data are unsurpassed for providing stratigraphic and structural information, and for imaging trap and reservoir geometry. However, in many geologic settings, seismic data yield little or no information about whether a trap is charged with hydrocarbons. In other settings, the acquisition of seismic data is difficult and extremely costly, or the quality of such seismic data is poor due to unfavorable geology or surface conditions. Detailed surface geochemical surveys document that hydrocarbon microseepage from oil and gas accumulations is common and widespread, is predominantly vertical, and is dynamic (Klusman, 1993; Schumacher and Abrams, 1996; Klusman, 2002).

The surface manifestations of hydrocarbon seepage can take many forms, including (1) anomalous hydrocarbon concentrations in soils, sediments, waters, and atmosphere; (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 (Schumacher, 1996; 1999). These varied expressions of hydrocarbon seepage have led to the development and marketing of an equally diverse number of hydrocarbon detection methods. Some of these methods are geochemical, some are non-seismic geophysical methods, and some come under the category of remote sensing.

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PROSPECT EVALUATION AND RISKING

Peter Rose (2001) discussed five critical geologic attributes that must be satisfied in order for a prospect to result in an oil or gas discovery: These risk factors are:

- Hydrocarbon source rocks
- Hydrocarbon migration and charge
- Reservoir rock
- Trapping (Closure)
- Containment (Preservation)

While each one of these factors or attributes must be properly developed in a prospect if one is to have a hydrocarbon discovery, there will be no oil or gas discovery without the presence of hydrocarbons in the trap and reservoir. According to Rose (2001), post-drilling evaluations of dry holes tend to attribute most failures to incorrect structural interpretation and/or unanticipated poor reservoir quality. Only rarely is failure attributed to lack of hydrocarbon charge.

One could argue, however, that the cause for most of these dry holes is in fact due to a lack of hydrocarbon charge, whether this is due to a failure of hydrocarbons reaching the trap, or because the trap could not retain those hydrocarbons. It is the absence of significant hydrocarbons from the trap that has resulted in the dry hole, whether that absence is due to a poor quality reservoir, or inadequate seal, or a lack of closure.

Hydrocarbon microseepage data can provide direct evidence not only for the presence of mature source rocks and for hydrocarbon migration, but more importantly for the probable hydrocarbon charge of the lead or prospect. Such microseepage data -- when properly acquired, interpreted, and integrated with conventional exploration data – can significantly reduce the exploration risk by focusing the explorer’s attention on those leads and prospects that show evidence of being charged with hydrocarbons.

METHODS

Due to the varied surface expressions of hydrocarbon seepage and microseepage, a number of different methods have been developed over the years for detecting and mapping hydrocarbon microseepage. Some of these methods are surface geochemical methods, some are microbiological, some are geophysical, and some are classified as remote sensing (Klusman, 1993; Tedesco, 1995; Schumacher, 1999; Schumacher and LeSchack, 2002). A detailed discussion of these methods is beyond the scope of this paper, but a list of the more commonly used hydrocarbon detection methods appears below:

- Remote sensing, satellite imagery analysis.
  Detect hydrocarbon-induced alteration of soils and sediment; oil slicks; atmospheric anomalies

- Aeromagnetics, micromagnetics.
  Detects seep-induced magnetic anomalies in shallow subsurface

- Soil gas, adsorbed soil gas.
  Measures concentration and composition of hydrocarbon gases in soils and sediments

- Microbiological.
  Measures concentration and distribution of hydrocarbon-utilizing bacteria

- Biogeochemical, geobotanical.
  Measures trace elements, vegetation stress

RESULTS

In order to quantify the benefit of integrating hydrocarbon microseepage data with conventional geological and geophysical exploration data, we have compiled published microseepage survey results with the results of subsequent drilling. A preliminary report of this study was presented at the AAPG International meeting in Perth, Australia (Schumacher, 2007). Updated results of this comparison are summarized on Table 1 for more than 2700 exploration wells. The majority of these wells were drilled on conventionally developed prospects after completion of geochemical or non-seismic hydrocarbon detection surveys, however, the statistics for R. S. Foote’s micromagnetic surveys include both pre-survey and post-survey wells. These prospects are located in both frontier basins and mature basins, onshore and offshore, and occur in a wide variety of geologic settings. Targets ranged in depth from 300 meters to more than 4900 meters and covered the full spectrum of trap styles. Prospects were surveyed using a variety of microseepage survey methods including free soil gas, integrative soil gas, microbial, iodine, radiometrics, and micromagnetics.

An example from one of these studies is illustrated in Figure 1. Meyer et al. (1983) published an excellent but little known case history documenting vertical hydrocarbon microseepage from undisturbed structural traps. In the early 1980s, a series of microseepage surveys were conducted over 49 proposed well locations in the Denver Basin, U.S.A. Each prospect displays good four-way dip closure on a Cretaceous horizon, and each is located in a basin that has produced oil and gas for many decades. Soil samples were collected at 160m intervals within 800m of each proposed drilling site and analyzed for hydrocarbon-oxidizing microbes. All samples were analyzed prior to drilling, The 39 wells subsequently drilled, yielded three producers, three wells with non-commercial shows, and 33 dry holes. When compared with the drilling results, the soils overlying productive reservoirs contained microbial populations that were clearly anomalous and readily distinguishable from samples from non-productive sites. Of the ten prospects illustrated in Figure 1, only one was associated with a positive microseepage anomaly; it was the only one of the ten shown that resulted in a commercial discovery. Each of the 33 dry holes was associated with a negative microseepage anomaly.

A second well-documented study from among those on Table 1 is by Potter et al. (1996). Their exploration program involved soil gas geochemical surveys of 139 prospects located in both frontier basins and mature basins, onshore and offshore, and in a variety of geologic settings and environments. Targets ranged in depth from 300m to 4500m, and included the full spectrum of trap styles; survey areas ranged from as small as a few hundred acres to regional surveys covering more than 2500 square kilometers. The 139 geochemical surveys led to the drilling of 141 wells in previously undrilled prospects. A total of 43 wells were drilled on prospects with negative microseepage anomalies, and 42 wells encountered no hydrocarbons. Of the 98 wells drilled in positive geochemical anomalies, 90 encountered reservoired hydrocarbons, and 74 of these wells (76%) were completed as commercial discoveries.

The results summarized on Table 1 are displayed graphically in the form of a pie chart on Figure 2. Figures 3 and 4 are pie chart summaries for microseepage surveys using two of the more commonly used microseepage methods, soil gas and microbial. The surveys listed on Table 1 resulted in the drilling of 2774 wells of which 45% were completed as discoveries. Of the wells drilled on prospects associated with a hydrocarbon seepage anomaly, 80% resulted in discoveries. In contrast, only 11% of wells drilled on prospects without a microseepage anomaly yielded a discovery.

The studies listed on Table 1, with one exception, are grouped by microseepage method and summarized on Table 2; the Argentina study is not included because no wells were drilled on prospects with negative anomalies. Of the 2610 wells drilled, 42% resulted in discoveries. For wells drilled on prospects with a microseepage anomaly, success rates ranged from 73-87% with an average of 80%. Wells drilled on prospects without an associated hydrocarbon anomaly had success rates ranging from 2-29% with an average of 11%. It is clearly apparent from Table 2 that wells drilled on prospects associated with a positive microseepage anomaly are 2-10 times more likely to result in a commercial discovery than wells drilled on prospects without an associated hydrocarbon anomaly.

CONCLUSIONS

Hydrocarbon microseepage data – when properly acquired, interpreted, and integrated with conventional geologic and seismic data -- leads to better prospect evaluation and risk assessment. How can one quantify the value added by hydrocarbon microseepage data when it is integrated with conventional exploration methods? In this paper, we have compared microseepage survey results with results of subsequent drilling. The results of such a comparison are summarized for more than 2700 wells, all drilled on conventionally developed prospects after completion of geochemical or non-seismic hydrocarbon detection surveys The prospects are located in both frontier basins and mature basins, onshore and offshore, and occur in a wide variety of geologic settings. Targets ranged in depth from 300 meters to more than 4900 meters and covered the full spectrum of trap styles. Prospects were surveyed using a variety of geochemical exploration methods including probe soil gas, microbial, radiometrics, and micromagnetics.

Of wells drilled on prospects associated with positive microseepage anomalies 82% were completed as commercial discoveries. In contrast, only 11% of wells drilled on prospects without an associated hydrocarbon microseepage anomaly resulted in discoveries. Had drilling decisions included consideration of the hydrocarbon microseepage data, exploration success rates would have more than doubled, and in some cased resulted in a ten-fold increase.

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TABLE 1 - PRE-DRILLING MICROSEEPAGE SURVEYS AND POST-SURVEY DRILLING RESULTS

Results of post-survey wells drilled on prospects associated with negative and positive geochemical anomalies. "Dry" means dry or non-commercial; "Discovery" means the well resulted in a commercial discovery.

Location	Negative Anomalies	Positive Anomalies
Brazil, Amazon Basin	**18/19 wells dry**	**6/16 wells discoveries**
(Petrobras, microbial)	**95%**	**38%**
M. R. Mello et al., 1996, AAPG Memoir 66, p.401-411		
USA – Denver Basin	**33/33 wells dry**	**3/6 wells discoveries**
(Barringer, microbial)	**100%**	**50%**
W. T. Meyer et al., 1983, Applied Geochemistry in the 1980s, p. 86-102		
Western Canada	**30/38 wells dry**	**10/14 wells discoveries**
(Canadian Hunter, soil gas)	**79%**	**71%**
R. E. Wyman, 2002, Foreword to AAPG Studies in Geology, No. 48		
USA – Kansas	**14/24 wells dry**	**9/10 wells discoveries**
(Axem/Murfin, soil gas)	**58%**	**90%**
V. Jones III and R. LeBlanc, 2004, AAPG Search and Discovery		
USA – Kansas	**55/68 wells dry**	**13/18 wells discoveries**
(Phillips Petroleum, microbial)	**81%**	**72%**
F. W. Beghtel et al., 1987, APGE Bulletin, v. 3, p. 1-14		
USA - Williston Basin	**43/54 wells dry**	**30/39 wells discoveries**
(Sun Oil, radiometrics)	**80%**	**77%**
R. C. Weart and G. Heimberg, 1981, SMU Unconventional Methods Symp. 2, p. 116-123		
USA – Powder River Basin	**18/31 wells dry**	**50/60 wells discoveries**
(W. Curry, radiometrics)	**58%**	**83%**
W. H. Curry III, 1984, SMU Unconventional Methods Symp. 3, p. 25-39		
USA and International	**42/43 wells dry**	**74/98 wells discoveries**
(Santa Fe Minerals, soil gas)	**98%**	**76%**
R. W. Potter et al., 1996, AAPG Memoir 66, p. 431-439		
Argentina, San Jorge Bsn.	**0 wells drilled**	**155/164 wells discoveries**
(Vintage Petroleum, soil gas)		**95%**
Personal communication, R. W. Potter, Vintage Petroleum		
USA – CO, WY, ND, IL	**53/58 wells dry**	**27/31 wells discoveries**
(Thomasson Partners, iodine)	**91%**	**87%**
J. Leaver and M. Thomasson, 2002, AAPG Studies in Geology No. 48, p. 41-57		
USA and International	**20/23 wells dry**	**109/128 wells discoveries**
(GMT, microbial)	**87%**	**85%**
J. Lopez et al., 1994, OGJ; D. Hitzman et al., 2002, AAPG Studies 48; GMT files		
Northwest Europe	**112/117 wells dry**	**83/103 wells discoveries**
(Several companies, microbial)	**96%**	**81%**

M. Wagner et al., 2002, AAPG Studies in Geology, No. 48, p. 453-479

Canada - Alberta **8/11 wells dry** **35/37 wells discoveries**
(Topaz , micromagnetics) **73%** **95%**
L. A. LeSchack and D. Van Alstine, 2002, AAPG Studies in Geology, No. 48, p. 67-156

USA – Colorado, Kansas **353/404 wells dry*** **212/283 wells discoveries***
(Foote, micromagnetics) **87%** **75%**
R. S. Foote, 1996, AAPG Memoir 66, p. 111-128

USA – Oklahoma **127/146 wells dry*** **88/99 wells discoveries***
(Foote, micromagnetics) **87%** **89%**
R. S. Foote, 1996, AAPG Memoir 66, p. 111-128

USA – Utah **20/21 wells dry *** **19/21 wells discoveries***
(Foote, micromagnetics) **95%** **90%**
R. S. Foote, 1996, AAPG Memoir 66, p. 111-128

USA – Alabama **297/312 wells dry*** **52/67 wells discoveries***
(Foote, micromagnetics) **95%** **78%**
R. S. Foote, 1996, AAPG Memoir 66, p. 111-128

USA – Gulf of Mexico **27/28 wells dry*** **125/150 wells discoveries***
(Foote, micromagnetics) **96%** **83%**
D. Schumacher and R. S. Foote, 2006, AAPG Annual Meeting, Houston, abstract volume, p. 96

***Note: R. S. Foote's statistics include both pre-survey wells and post-survey wells**

SUMMARY OF RESULTS **1267/1430 wells dry** **1097/1344 wells discoveries**
FOR ALL 2774 WELLS **89%** **82%**

TABLE 2 - SUMMARY OF EXPLORATION SUCCESS RATES FOR WELLS DRILLED ON PROSPECTS WITH AND WITHOUT HYDROCARBON MICROSEEPAGE ANOMALIES

Results of wells drilled on prospects associated with negative and positive microseepage anomalies. "Dry" means dry or non-commercial; "Discovery" means the well resulted in a commercial discovery.

SURVEY METHOD ANOMALY	**GEOLOGY AND GEOPHYSICS ONLY**	**WELLS WITHIN SEEPAGE ANOMALY**	**WELLS OUTSIDE SEEPAGE**
RADIOMETRIC	**104/184 Discoveries 57%**	**80/99 Discoveries 81%**	**24/85 Discoveries 28%**
IODINE	**32/89 Discoveries 36%**	**27/31 Discoveries 87%**	**5/58 Discoveries 9%**
SOIL GAS (Probe)	**37/86 Discoveries 43%**	**19/24 Discoveries 79%**	**18/62 Discoveries 29%**
SOIL GAS (Petrex)	**75/141 Discoveries 53%**	**74/98 Discoveries 76%**	**1/43 Discoveries 2%**
MICROBIAL (GMT)	**112/151 Discoveries 74%**	**109/128 Discoveries 85%**	**3/23 Discoveries 13%**
MICROBIAL (Non-GMT)	**124/380 Discoveries 33%**	**105/143 Discoveries 73%**	**19/237 Discoveries 8%**
MICROMAGNETICS	**621/1579 Discoveries 39%**	**531/658 Discoveries 81%**	**90/921 Discoveries 10%**
ALL DATA Discoveries	**1105/2610 Discoveries 42%**	**945/1181 Discoveries 80%**	**160/1429 11%**

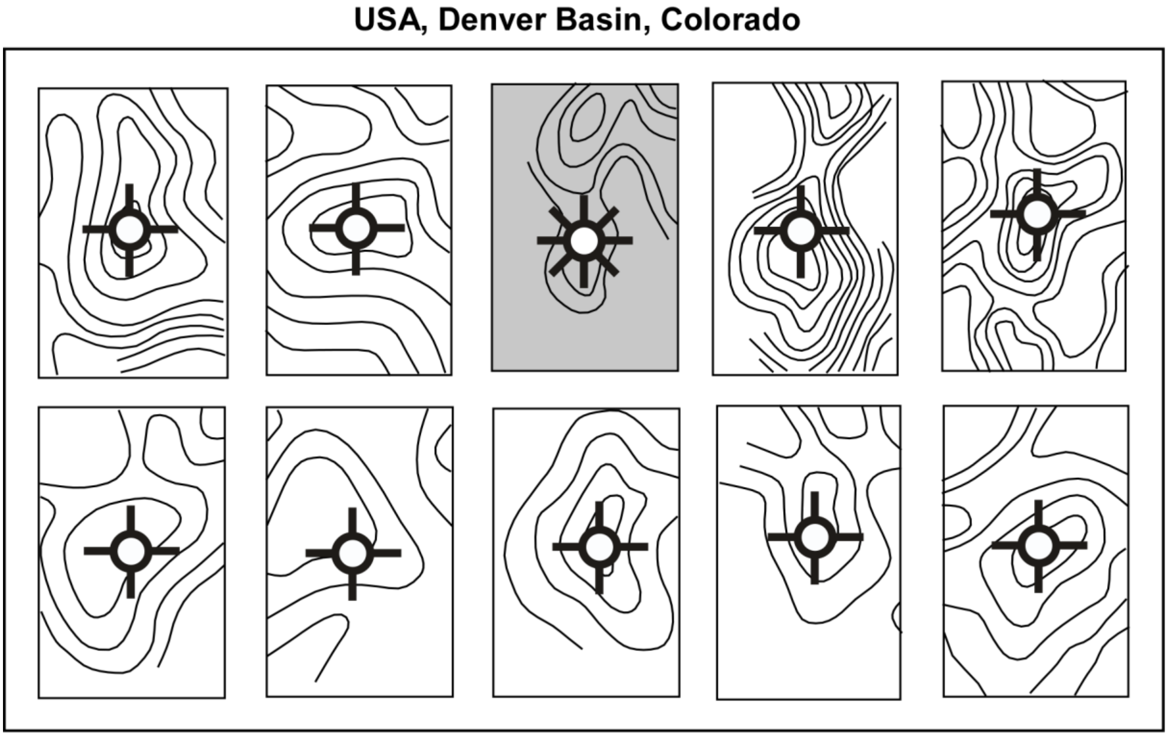

Figure 1 - This figure illustrates ten seismic prospects from the Denver Basin in the western U.S.A. Each prospect displays good 4-way dip closure on a Cretaceous horizon, and each prospect was surveyed before drilling for evidence of hydrocarbon microseepage using a microbial method. Only one prospect was associated with a positive microseepage anomaly, and it was the only one of the ten prospects shown to result in a commercial discovery. (Based on Meyer et al., 1983, and courtesy of Barringer Technologies)

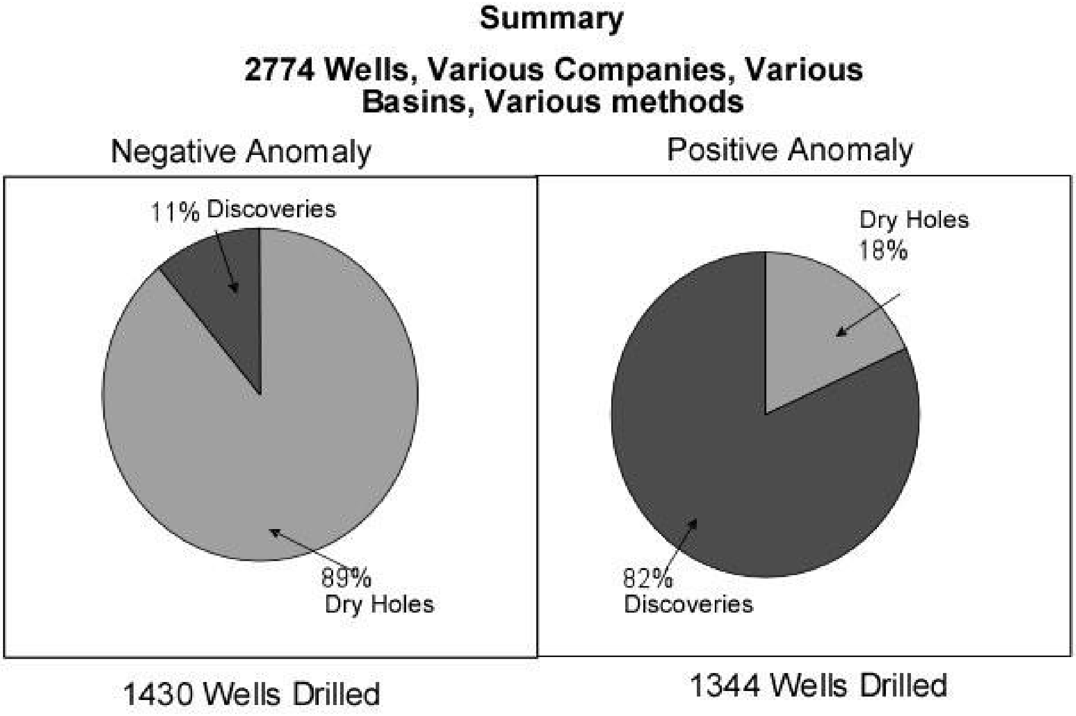

Figure 2 - This figure displays graphically in the form of a pie-chart the exploration success rates summarized on Table 1. Wells drilled on prospects associated with a positive hydrocarbon microseepage anomaly resulted in commercial discoveries 82% of the time. In contrast, only 11% of wells drilled on prospects without a microseepage anomaly resulted in discoveries.

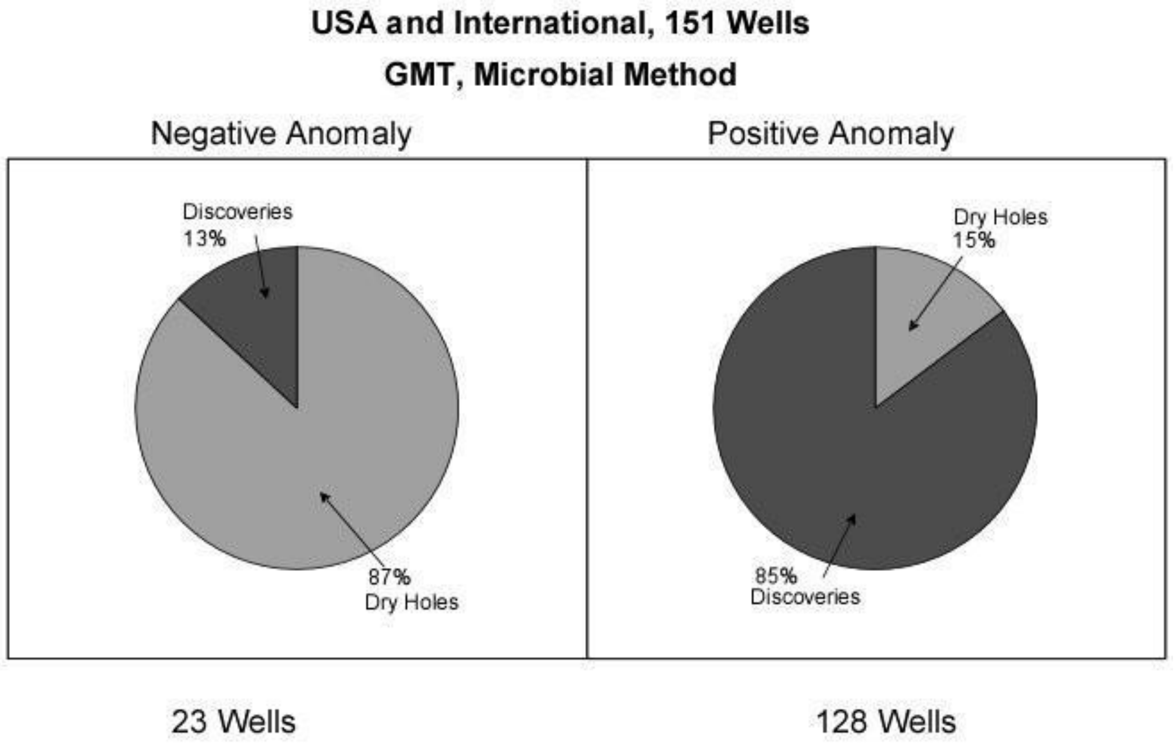

Figure 3 - This figure is a pie-chart display of exploration success rates for prospects surveyed before drilling using Geo-Microbial Technologies (GMT) microbial method (Table 2). Of the 151 prospects surveyed and subsequently drilled, 85% of wells drilled on prospects with a positive microseepage anomaly resulted in discoveries; in contrast, only 13% of wells drilled on prospects without an associated microseepage anomaly resulted in discoveries.

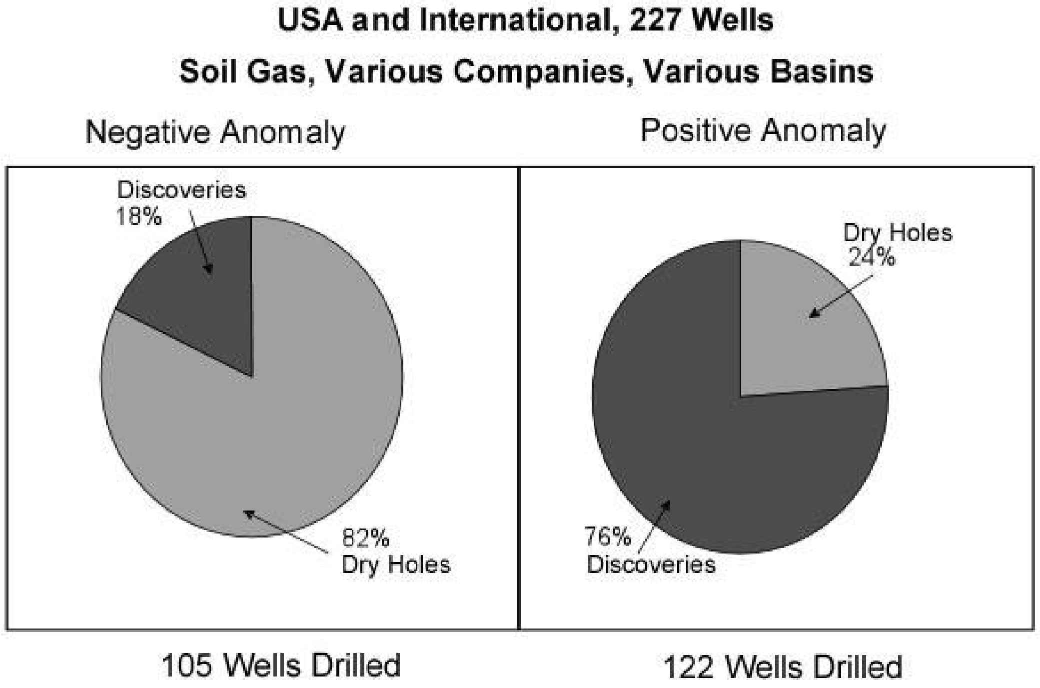

Figure 4 - This figure is a pie-chart display of exploration success rates for prospects surveyed before drilling using one of several available soil gas methods (Table 2). Of the 227 prospects surveyed and subsequently drilled, 76% of wells drilled on prospects with a positive soil gas anomaly resulted in discoveries; in contrast, only 18% of wells drilled on prospects without an associated microseepage anomaly resulted in discoveries.