Minimizing Exploration Risk: The Impact of Hydrocarbon Detection Surveys for Distinguishing Traps with Hydrocarbons from Uncharged Traps

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Summary

The application of surface geochemical prospecting methods to oil and gas exploration has resulted in varied success and considerable controversy despite advances in technology and an improved understanding of migration mechanisms. Few people question that hydrocarbons can migrate to the surface in amounts that are detectable, but many remain skeptical of how such information is best integrated into exploration and development programs.

It has been 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 several geochemical and non-seismic geophysical methods (Klusman, 1993; Schumacher and Abrams, 1996; Klusman, 2002).

The surface expressions of hydrocarbon 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 both direct and indirect surface geochemical methods, and non-seismic geophysical methods such as magnetic and electrical methods, radioactivity-based methods, and satellite remote sensing methods.

What are the benefits of using geochemical and non-seismic 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 hydrocarbon detection surveys – documents that more than 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 use of such hydrocarbon detection surveys has significant economic benefit. Although these geochemical and non-seismic methods cannot replace conventional exploration methods, they can be a powerful complement to them and add value to such conventional data and methods. The need for such an integrated exploration strategy cannot be overemphasized.

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, and the hydrocarbon data may be the only expression of subtle stratigraphic traps.

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 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 (Klusman, 1993; Schumacher, 1999; Schumacher and LeSchack, 2002). A detailed discussion of these methods is beyond the scope of this presentation, but a list of the more commonly used hydrocarbon detection methods are listed 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 the shallow subsurface

SOIL GAS, ACID EXTRACTED SOIL GAS, FLUORESCENCE

Measures concentration and composition of gases and aromatics in soils and sediments

MICROBIOLOGICAL

Measures concentration and distribution of hydrocarbon-utilizing bacteria

BIOGEOCHEMICAL, GEOBOTANICAL

Measures concentration of trace elements; vegetation stress

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, and more importantly for the probable hydrocarbon charge of the exploration 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 and dollars on the most promising targets.

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 (Schumacher et al., 2010). 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 microseepage survey methods including free soil gas, integrative soil gas, microbial, iodine, radiometrics, and micromagnetics. The majority of these 2700 wells were drilled on conventionally developed prospects after completion of geochemical or non-seismic hydrocarbon detection surveys.

An example from one of these studies is illustrated in Figure 1. Meyer et al. (1981) 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 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, and included the full range of trap styles. 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 (i.e., no anomaly), and 42 wells encountered no hydrocarbons. Of the 98 wells drilled in positive geochemical anomalies, 90 encountered reservoired hydrocarbons, and 74 of these (76%) were completed as commercial discoveries.

The results are summarized on Table 1 in Schumacher et al. (2010) are displayed graphically in the form of a pie chart on Figure 2. The cited surveys resulted in the drilling of 2774 wells of which 45% were completed as discoveries. Of the wells drilled on prospects associated with a positive hydrocarbon seepage anomaly, 82% resulted in discoveries. In contrast, only 11% of wells drilled on prospects without a microseepage anomaly yielded a discovery. In other words, the hydrocarbon survey results correctly predicted 82% of the subsequent discoveries and about 90% of the subsequent dry holes!

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 presentation, we have compared the hydrocarbon survey results with results of subsequent drilling. The results of this comparison are summarized for more than 2700 wells, all drilled on conventionally developed prospects after completion of geochemical or non-seismic hydrocarbon detection surveys. Prospects were surveyed using a variety of geochemical and non-seismic exploration methods including probe soil gas, microbial, radiometrics, and micromagnetics. Of wells drilled on prospects with positive microseepage anomalies, 82% were completed as commercial discoveries. In contrast, on 11% of wells drilled on prospects without an associated hydrocarbon microseepage anomaly resulted in discoveries. Had drilling decisions included serious consideration of the hydrocarbon microseepage data, exploration success rates would have more than doubled, and in some cases resulted in a ten-fold increase.

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USA, Denver Basin, Colorado

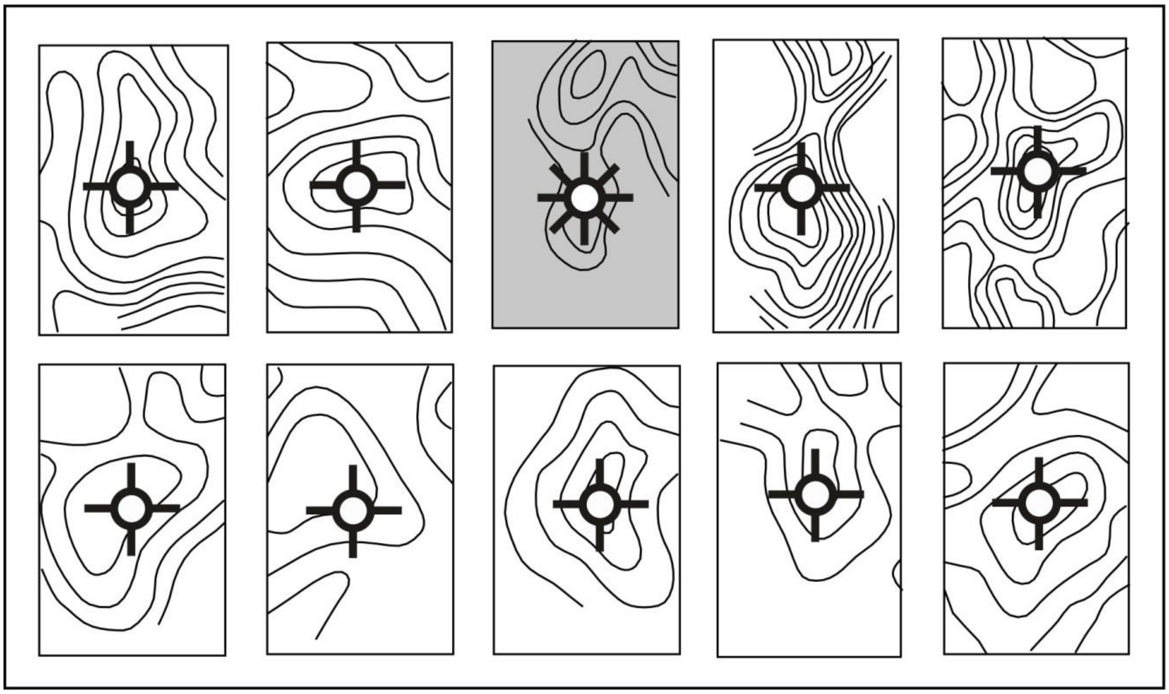

Figure 1. This figure illustrates ten seismic prospects from the Denver Basin in the western U.S.A. Each prospect displays good 4-way dip closure on a Cretaceous horizon, and each prospect was surveyed before drilling for evidence of hydrocarbon microseepage using a microbial method. Only one p[rospect 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)

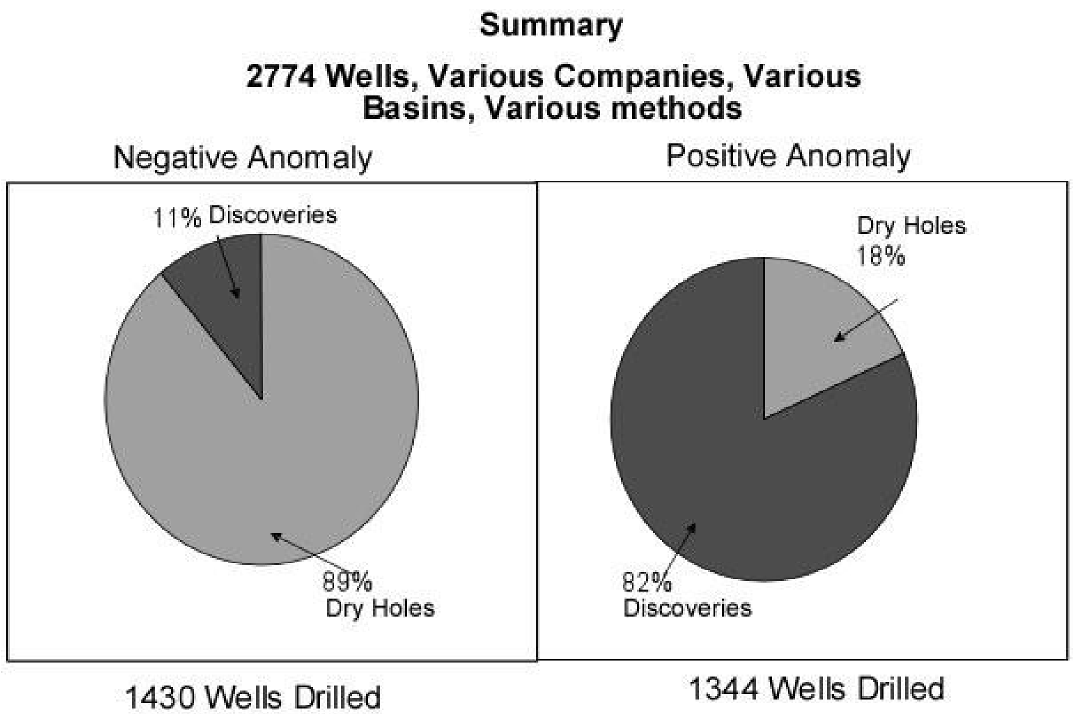

Figure 2. This figure displays graphically in the form of a pie chart the exploration success rates summarized in Table 1. Wells drilled on prospects associated with a positive hydrocarbon microseepage anomaly resulted in commercial discoveries 82% of the time; in contrast, only 11% of the wells drilled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