Geochemical Exploration in Mature Basins: New Applications for Field Development and Production

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ABSTRACT

Detailed surface geochemical surveys and research studies document that hydrocarbon microseepage from petroleum accumulations is common and widespread, is predominantly vertical (with obvious exceptions in some geologic settings), and is dynamic (responds quickly to changes in reservoir conditions). These characteristics create a new suite of applications for surface geochemical surveys: 1) early delineation of field limits, 2) finding by-passed oil or gas, 3) evaluation of in-fill and step-out well locations, 4) contributions to reservoir characterization studies, 5) documentation of hydrocarbon drainage over time, and 6), monitoring of waterflood operations. Combined with more established uses of surface geochemistry such as high-grading leases, leads, and prospects, these new geochemical applications show great promise for better prospect evaluation and risk assessment in mature basins.

Because hydrocarbon microseepage is nearly vertical, the extent of an anomaly at the surface can approximate the productive limits of the reservoir at depth. The detailed pattern of microseepage over a field can also reflect reservoir heterogeneity and distinguish hydrocarbon-charged compartments from drained or uncharged compartments. Additionally, since hydrocarbon microseepage is dynamic, seepage patterns change rapidly in response to production-induced changes. Evidence for such changes are identified with detailed microbial and soil gas surveys. When such surveys are acquired at different stages during the life of a field or waterflood project, the changes in seepage patterns can reflect patterns of hydrocarbon drainage. Applications such as these require close sample spacing, and are most effective when results are integrated with subsurface data, especially 3-D seismic data. The need for such integration cannot be overemphasized. Seismic data will remain unsurpassed for imaging trap and reservoir geometry, but only detailed soil gas or microbial surveys can reliably image hydrocarbon microseepage from those same reservoirs.

INTRODUCTION

Geochemical exploration for petroleum is the search for analytically identifiable surface or near-surface occurrences of hydrocarbons as clues to the location of undiscovered oil and gas. Observations range from clearly visible oil and gas seepage at one extreme to the identification of minute traces of hydrocarbons or hydrocarbon-induced changes at the other.

The past decade has seen a renewed interest in geochemical exploration which, when coupled with developments in analytical and interpretive methods, has produced a new body of data and insights. Many of these developments and new insights are published in AAPG Memoir 66, "Hydrocarbon Migration and Its Near-Surface Expression" (Schumacher and Abrams, 1996). The volume critically examines the process of hydrocarbon migration from the deep subsurface to the near-surface; documents the varied geological and geophysical expressions of this leakage in soils and sediments; discusses some of the surface exploration methods based on these phenomena; and the implications for their use in exploration. Individual contributions to this volume document that hydrocarbon microseepage from oil and gas accumulations is real, is predominantly vertical (with obvious exceptions in some geological settings) and is dynamic – all characteristics which establish the foundation for the field development and production applications discussed in this presentation.

BACKGROUND

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 shown to be an established fact, and the close association of surface geochemical anomalies with faults, productive fairways, and leads and prospects is well known (Horvitz,1985; Jones and Drozd, 1983; Price, 1986; Schumacher, 1999). It is further assumed, or at least implied, that the anomaly at the surface can be reliably related to a petroleum accumulation at depth. The success with which this can be done is greatest in areas of relatively simple geology and becomes more difficult as the geology becomes more complex**.** Proper interpretation of surface geochemical data requires integration of seepage data with geological, geophysical, and hydrologic data. Understanding geology, and hence petroleum dynamics, is the key to proper use of seepage data.

Microseepage is defined as high concentrations of analytically detectable light hydrocarbons in soils, sediments, or waters. These largely invisible seeps are recognized only by the presence of anomalous concentrations of light hydrocarbons (principally C_1 - C_5), hydrocarbon-oxidizing microbes, or hydrocarbon-induced alteration products. High molecular weight hydrocarbons may be present in ever-wet or intermittently-wet environments, however, only light hydrocarbons are expected above the water table. Most surface geochemical methods, including both direct and indirect methods, are designed to detect microseepage.

The existence of microseepage is supported by a large body of empirical evidence (Price, 1986; Klusman, 1993; Klusman and Saeed, 1996; Brown, 2000). This includes (1) increased concentration of light hydrocarbons and hydrocarbon-oxidizing microbes in soils and sediments above hydrocarbon reservoirs, (2) an increase in key light hydrocarbon ratios in soil gas over oil and gas reservoirs, (3) sharp lateral changes in these concentrations and ratios at the edges of the surface projections of these reservoirs, (4) similarity of stable carbon isotopic ratios for methane and other light hydrocarbons in soil gases to those found in underlying reservoirs, and (5) the disappearance and reappearance of soil gas and microbial anomalies in response to reservoir depletion and repressuring.

Microseepage rates and surface hydrocarbon concentrations can vary significantly with time. Soil gas and microbial anomalies appear and disappear in relatively short times – weeks to months to years. Results from studies of natural seeps and underground storage reservoirs, as well as repeat surveys of producing fields, indicate that the rate of hydrocarbon migration and microseepage varies from less than one meter per day to tens of meters per day (Jones and Burtell, 1996; Mathews, 1996a; Klusman and Saeed, 1996; Brown, 2000). Empirical observations and computer simulations suggest that the mechanism for microseepage is a buoyancy-driven, continuous-phase gas flow through water-wet pores and microfractures.

ANOMALY RECOGNITION

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

To optimize the recognition of an anomaly, the sampling pattern and sample number must take into consideration the objectives of the survey, the expected size and shape of the anomaly (or geologic target), the expected natural variation in surface measurements, and the probable signal-to-noise ratio (Matthews, 1996b). Defining background values adequately is an essential part of anomaly recognition and delineation; Matthews suggests that as many as 80% of the samples collected be obtained outside the area of interest. We concur with these recommendations for reconnaissance and prospect evaluation surveys, however, for field development surveys optimum results are obtained when numerous samples are collected in a closely spaced grid pattern over the feature of interest (Tucker and Hitzman, 1994; Schumacher and others, 1997; Schumacher, 1999). Sample spacing for such surveys is routinely 100 meters (330 feet) or less. Grid designs keep the spatial density of sampling approximately constant and enable more direct correlation with subsurface data, an essential objective in field development or production applications.

APPLICATIONS FOR FIELD DEVELOPMENT AND PRODUCTION

The detailed geochemical and geomicrobiological surveys and research studies referred to have documented that hydrocarbon microseepage is a dynamic and predominantly vertical process which responds quickly to changes in reservoir conditions.These characteristics make possible a new suite of applications for soil gas and microbial surveys including (1) early delineation of field limits, (2) finding by-passed oil and gas, (3) evaluation of infill and step-out well locations, (4) contributions to reservoir characterization studies, (5) documentation of hydrocarbon drainage over time, and (6) monitoring of waterflood operations.

Because hydrocarbon microseepage is nearly vertical, the extent of a soil gas or microbial anomaly at the surface can approximate the productive limits of the reservoir at depth. Furthermore, the detailed pattern of microseepage over a field can reflect reservoir heterogeneity and distinguish hydrocarbon-charged compartments from drained or uncharged compartments. Additionally, since hydrocarbon microseepage is dynamic, seepage patterns can change rapidly in response to production-induced changes. These applications require close sample spacing and are most effective when results are integrated with subsurface data, especially 3-D seismic data. The need for such integration cannot be overemphasized. Seismic data will remain unsurpassed for imaging trap and reservoir geometry, but, especially onshore, only detailed microbial or soil gas surveys can reliably image hydrocarbon microseepage from those same reservoirs.

MICROBIAL OIL SURVEY TECHNIQUE (MOST)

The Microbial Oil Survey Technicque (MOST) used in the following case histories was first developed by Phillips Petroleum Company in the 1950’s (Beghtel and others, 1987), and since 1985 has been available to industry from GMT. The technique is based on analyzing shallow surface soil samples for a specific suite of hydrocarbon-oxidizing microbes. These unique microbial populations are in dynamic equilibrium with their hydrocarbon seepage environment. Where elevated clusters of these specific microbial populations are identified, anomalous hydrocarbon microseepage from oil and gas reservoirs is indicated (Tucker and Hitzman, 1994, 1996). There is a direct, positive relationship between light hydrocarbon concentrations in soil and these microbial populations, a relationship that is easily measurable and reproducible. Surface contamination by produced oil and changing soil types have a minimal effect on these hydrocarbon-indicating microbial population distributions. High microbial population distributions are therefore reliable indicators of light hydrocarbon migration pathways and/or leakage from petroleum accumulations.

PRODUCING FIELD EXAMPLES

High-resolution microbial surveys (MOST) conducted over active and abandoned fields have identified drainage patterns, in-fill locations, step-out potential, and possible re-drill potential of repressured abandoned fields. The hydrocarbon microseepage trends observed will be affected by the actual hydrocarbon withdrawal, reservoir heterogeneities, and bypassed pockets of oil and gas.

Sacramento Basin Field, California: In this example from the Grimes gas and condensate field, previously described by Tucker and Hitzman (1994), all of the expected microbial patterns have been identified (Figures 1). Clusters of low microbial values over and adjacent to many of the producing wells reflect the reservoir drainage radius around the wells. Some of the patterns are more radial while others are more elongate. Areas of high microbial values found between producing wells are believed to represent the undrained portions of the reservoir (Figures 1). The large microseepage anomaly in the northeast part of the map represents an undrained portion of the reservoir; the two wells within the anomaly are directional wells and are draining a part of the reservoir outside the survey area.

Kingfisher County, Oklahoma: In this example, a 19x17 grid of soil samples was collected over an old field producing chiefly from the Devonian Hunton group. The principal microseepage anomalies are seen as clusters of microbial highs located between existing wells (Figure 2). A successful Hunton in-fill well has been drilled within one of these anomalies since the completion of the survey.

Middle Magdalena Valley, Colombia: A gridded microbial survey of a 3-well oil field in Colombia's Middle Magdalena Valley basin using a 660-foot (200 meter) sample interval. The objective of the survey was to identify areas with potential by-passed pay that might offer in-fill drilling opportunities. The most extensive microseepage anomaly occurs along the east side of the field, between the southern and central wells (Figure 3). Geochemical fingerprinting of oils from the field indicate that the fault between these two wells is a sealing fault, and that there is no fluid communication across the fault.

Time Lapse Monitoring of Reservoir Drainage: There is widespread interest in our industry in conducting repeat 3-D seismic surveys at intervals during the life of a field, in order to follow fluid movement through the seismic expression of reservoir and pressure changes within the field (Anderson and others, 1997). This application, known in the industry as 4-D seismic, is most effective with marine seismic data. Results of repeat microbial surveys over several producing fields and one waterflood operations will be shown during the presentation. These results suggest great potential for such time lapse monitoring of reservoir drainage using high-resolution microseepage surveys. Unlike 4-D seismic surveys, microseepage surveys are most effective on land and may thus represent a viable alternative to more costly 4-D seismic data in some situations.

SUMMARY

High-resolution microseepage surveys offer a flexible, low-risk and low-cost technology that naturally complements more traditional geologic and seismic methods. Properly integrated with 3-D seismic data, their use has led to the addition of new reserves, drilling of fewer dry or marginal wells, and optimization of the number and placement of development or secondary recovery wells

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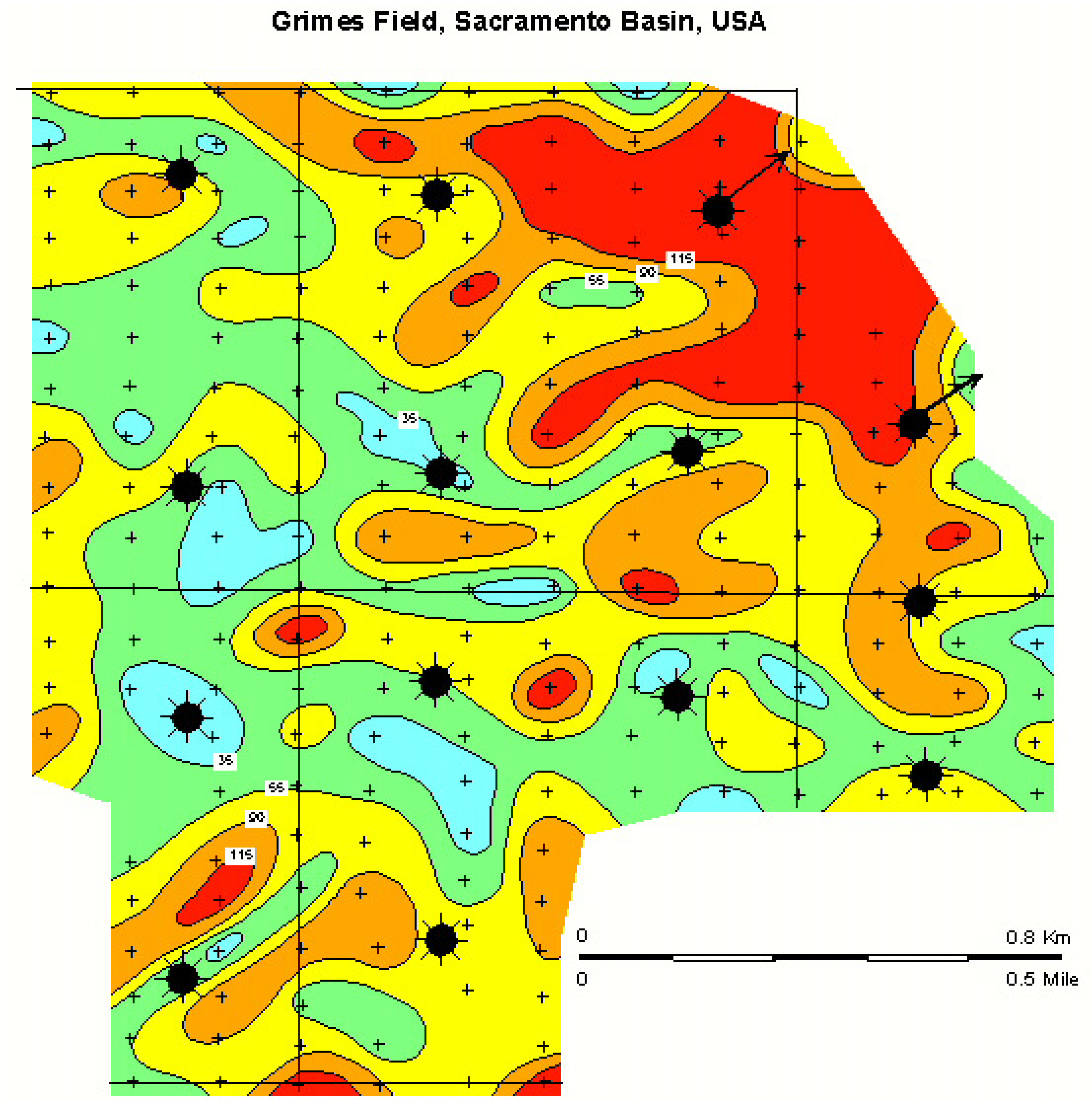

Figure 1. High-resolution microbial survey of Grimes Field, Sacramento Basin, California, using a 330-foot (100 meter) sample grid. Low microseepage values, shown in blue and green, near wells probably reflect pressure depletion due to production. The large microseepage anomaly in the northeast part of the map represents an undrained portion of the reservoir. The two wells within the anomaly are directional wells draining a part of the reservoir outside the survey area.

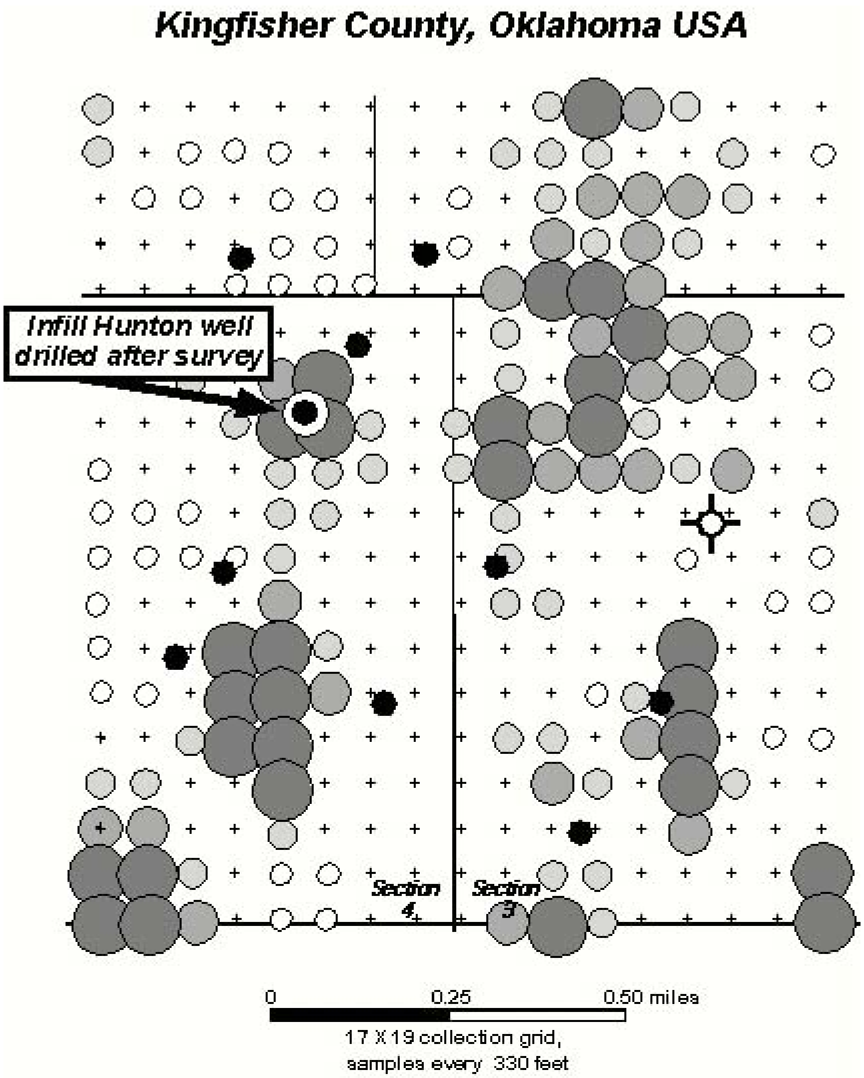

Figure 2. Detailed microbial survey of an old field in Kingfisher County, Oklahoma, using a 330-foot (100 meter) sample grid. Microseepage anomalies are shown in bubble map format and represent either by-passed pay or pay in an undrilled reservoir interval. A successful Devonian Hunton in-fill well was drilled after the survey.

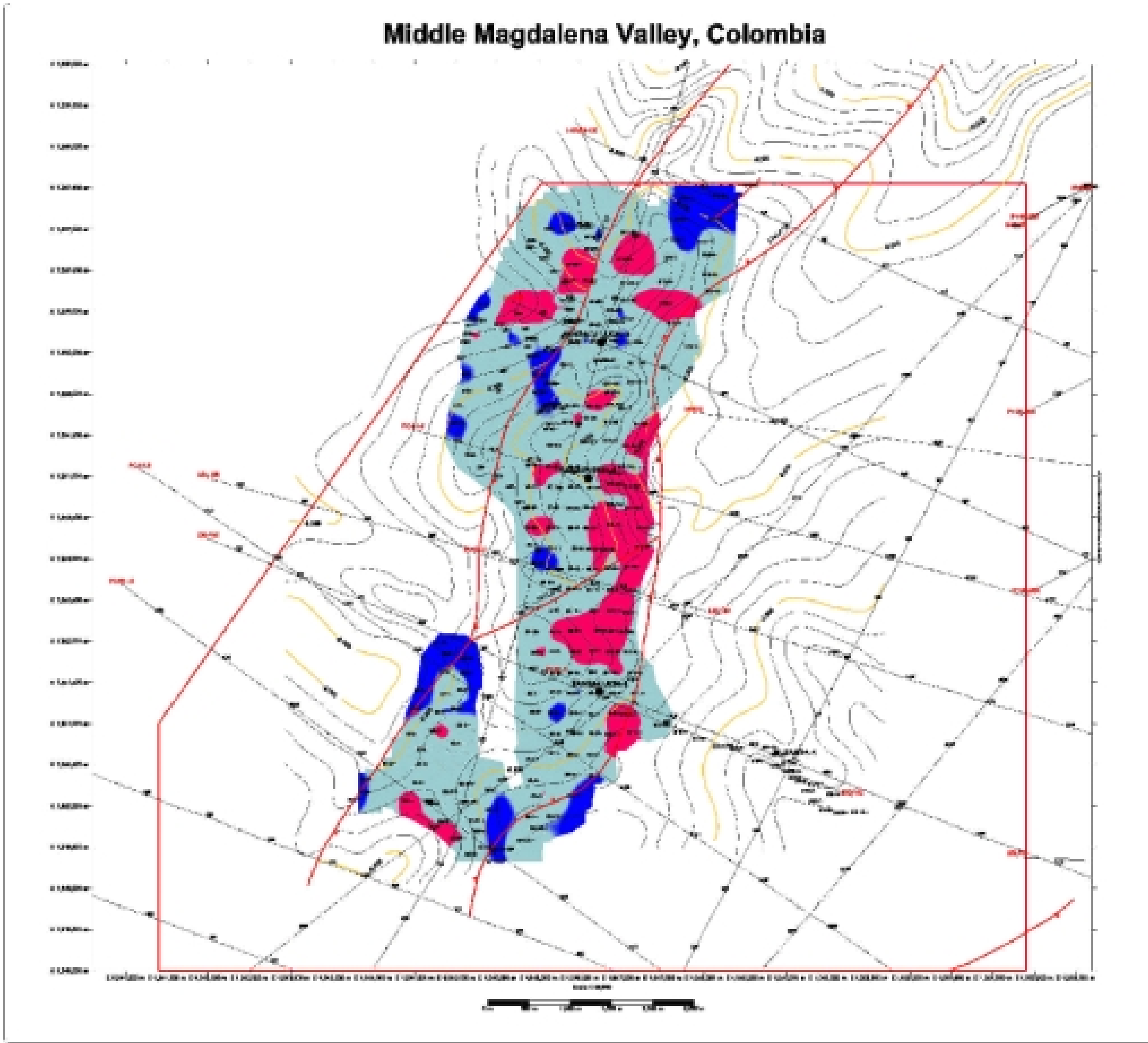

Figure 3. Gridded microbial survey of a 3-well oil field in the Middle Magdalena Valley, Colombia, using a 660-foot (200 meter) sample interval. The highest 20% and lowest 15% of the data are highlighted in red and dark blue respectively. It is these extreme values that sometimes convey the most geologic information. The main area of bypassed pay occurs along the eastern margin of the field between the southern and central wells.