Petroleum Exploration in Environmentally Sensitive Areas: Opportunities for Non-Invasive Geochemical and Remote Sensing Methods

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ABSTRACT

The petroleum potential of environmentally sensitive areas -- such as tundra and wetlands, national forests and grasslands, tropical reefs and lagoons -- is often poorly known due to restrictions limiting the use of conventional exploration methods like seismic surveys and exploratory drilling. For such areas, surface geochemical and remote sensing methods provide an opportunity to reliably detect and map the elevated hydrocarbon concentrations and hydrocarbon-induced changes commonly associated with undiscovered oil and gas accumulations, while having minimal impact on the surface environment.

There is now a general consensus that (1) all petroleum basins exhibit some type of near-surface hydrocarbon leakage, (2) that petroleum accumulations are dynamic and their seals imperfect, (3) that hydrocarbon seepage can be active or passive, and that it can be visible (macroseepage) or only detectable analytically (microseepage). The surface and near-surface expressions of hydrocarbon migration and seepage can take many forms ranging from elevated hydrocarbon concentrations in soils to complex mineralogic, microbial, and botanical changes.

Advances in surface exploration methods, coupled with an improved understanding of hydrocarbon migration processes, have led to an increased usage of various remote sensing and surface geochemical methods to detect and map the small but significant concentrations of hydrocarbons, or hydrocarbon-induced changes, that occur above oil and gas accumulations. The noninvasive, low impact nature of some of these techniques makes them ideally suited for use in an early stage evaluation of environmentally sensitive areas. The results of such surveys can quickly identify those parts of the area possessing the highest petroleum potential. Use of such an exploration strategy protects the greater part of the area from more invasive exploration methods by focusing attention and resources on a relatively small number of high potential sites.

INTRODUCTION

Surface indications of oil and gas seepage have been noted for thousands of years. Historically, such seeps have led to the discovery of many important oil-producing areas. The surface expression of hydrocarbon migration and seepage can take many forms, including (1) anomalous hydrocarbon concentrations in soil, sediment, water, and even atmosphere; (2) microbiological anomalies and the formation of "paraffin dirt"; (3) mineralogical changes such as formation of calcite, pyrite, uranium, elemental sulfur, and certain magnetic iron oxides and sulfides; (4) bleaching of red beds; (5) clay mineral changes; (6) electrochemical changes; (7) radiation anomalies; and (8) biogeochemical and geobotanical anomalies

Bacteria and other microbes play a profound role in the oxidation of migrating hydrocarbons, and their activities are directly or indirectly responsible for many of the surface manifestations of hydrocarbon 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 a variety of hydrocarbon-induced chemical, mineralogical and geophysical changes (Figure 1). This hydrocarbon-induced alteration is highly complex and its varied surface expressions have led to the development of an equally varied number of surface exploration techniques. These include soil gas and soil microbial methods, soil iodine and soil trace metal methods, soil carbonate methods, magnetic and electrical methods, radioactivity-based methods, and remote sensing methods.

BASIC ASSUMPTIONS

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, fractures, and productive petroleum fairways is well known (Jones and Drozd, 1983; Horvitz, 1985; Price, 1986; Klusman, 1993). 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 of this relationship 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 and others, 1996). Relationships between surface geochemical anomalies and subsurface accumulations can be complex; proper interpretation requires integration of seepage data with geological, geophysical, and hydrologic data. Understanding geology, and hence petroleum dynamics, is the key to using seepage data in exploration.

GEOCHEMICAL AND REMOTE SENSING METHODS

Advances in surface exploration methods, coupled with an improved understanding of hydrocarbon migration processes, have led to an increased use of remote sensing and surface geochemical methods to detect and map the small but anomalous hydrocarbon concentrations, or hydrocarbon-induced changes, associated with oil and gas accumulations. Some of these methods are geochemical, some are geophysical, and some come under the category of remote sensing.

In general, direct hydrocarbon detection methods such as soil or soil gas analysis are preferable to indirect methods such as iodine or soil alteration methods, or non-seismic geophysical methods. Although this is not the place to discuss the advantages and limitations of each of the many commercially available methods, it should be noted that of the many indirect geochemical methods, only the microbial method is uniquely associated with the presence of light hydrocarbons in soil. Other indirect methods, such as iodine or soil alteration anomalies or geobotanical anomalies, form in response to the reducing conditions (or redox boundary) often associated with strong hydrocarbon seepage. However, factors other than hydrocarbon seepage can produce similar reducing environments and, even if due to hydrocarbons, could result from biogenic methane and thus be unrelated to deep oil or gas potential (Schumacher, 1996, 1999)).

Indirect effects that are detectable using satellite imagery. aeromagnetic data, or other airborne sensors do, however, have an essential place in reconnaissance surveys of large and often inaccessible areas, areas such as arctic forests and tundra, tropical jungles, coastal waters and lagoons, etc. Remote sensing methods such as these enable rapid yet reliable screening of large areas for the presence of hydrocarbon-induced alteration of soil and vegetation. Non-invasive surface geochemical methods such as soil gas and microbial surveys are then used to ground-truth these remotely sensed anomalies, as well as for the direct detection of hydrocarbon microseepage where remote sensing methods may not be applicable

GEOCHEMICAL SURVEY OBJECTIVES

The principal objective of a geochemical exploration survey is to establish the presence and distribution of hydrocarbons in the area of exploration interest and, more importantly, to determine the probable hydrocarbon charge to specific exploration leads and prospects.

For **reconnaissance surveys**, seeps and microseeps provide direct evidence that thermogenic hydrocarbons have been generated, that is, 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 pre-seismic 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.

If the objective is to **evaluate individual exploration leads and prospects**, the results of geochemical surveys can identify those which are 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 or concessions to renew and which ones don't warrant additional expense. Detailed seepage surveys can also generate geochemical leads for evaluation with geologic and seismic data, leads which might otherwise go unnoticed.

For **development projects in environmentally sensitive areas**, detailed microseepage surveys can help evaluate in-fill or step-out drilling locations, delineate productive limits of undeveloped fields, and identify by-passed pay or undrained reservoir compartments. The ability of high-resolution geochemical surveys to identify the approximate field limits of a wildcat discovery before those limits are determined by geophysical surveys and drilling, can significantly reduce development time while minimizing environmental impacts.

SUMMARY

Remote sensing methods enable rapid yet reliable screening of large areas for the presence of hydrocarbon-induced alteration on soils and vegetation. Non-invasive surface geochemical exploration methods such as soil gas and soil microbial surveys are effective methods for ground-truthing the remote sensing anomalies, as well as to detect hydrocarbon-induced changes where remote sensing methods may not be applicable. The results of such surveys would provide considerable insight into the oil and gas potential of the environmentally sensitive area, and could quickly and reliably dentify those portions of the regiont with the greatest petroleum potential. Furthermore, the use of surface geochemical and remote sensing methods would protect the greater part of the region from more invasive exploration methods since their use would be focused on a small number of high-potential areas.

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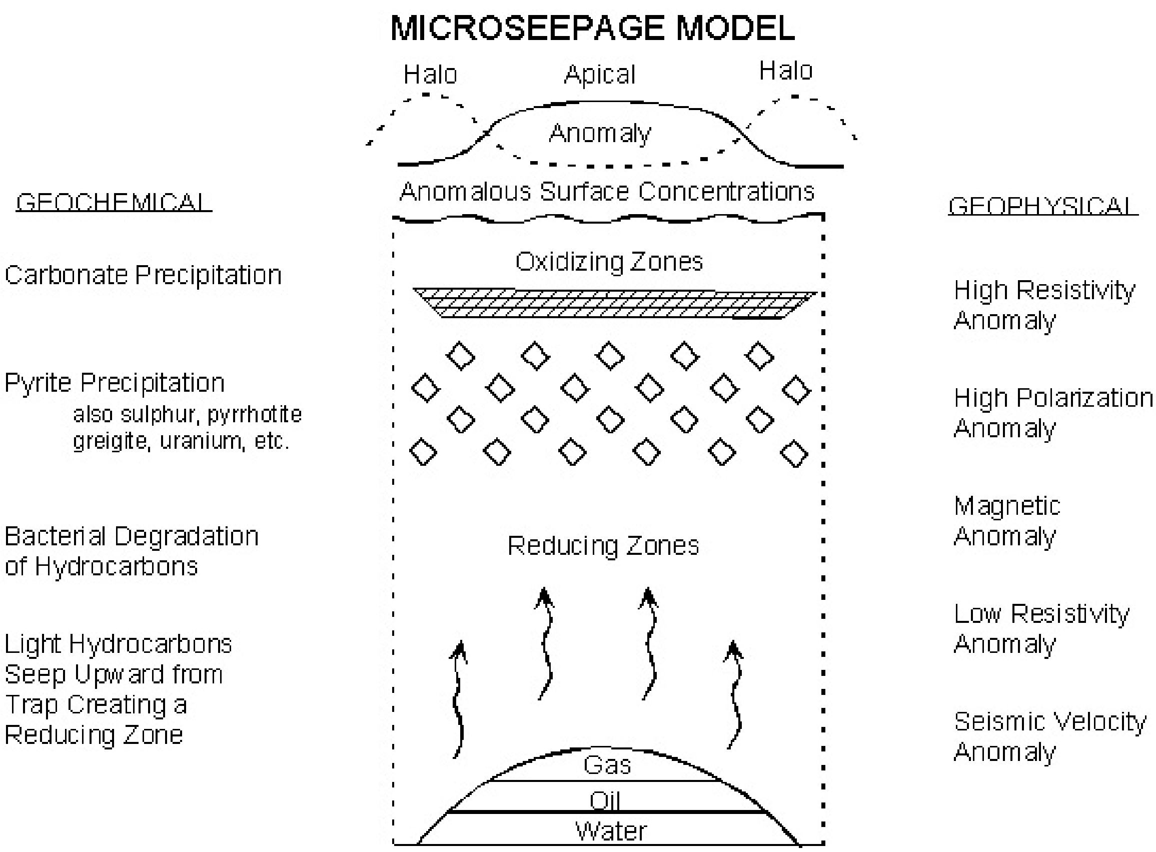

Figure 1. Generalized model of hydrocarbon-induced geochemical, mineralogical,a nd geophysical alteration of soils and sediments (from Schumacher, 1996; reprinted with permission)