



Geochemical exploration to detect hydrocarbon seepage using an innovative sampling design

*Mahdi AbuAli, Khaled Arouri, Yin Xu, AbdulJaleel Abubshait, Maher Almarhoon and Alan Siliman**
Saudi Aramco; * Amplified Geochemical Imaging

Summary

An innovative sampling method was designed and employed to distinguish genuine anomalies from false geochemical anomalies. The method is based on a multi-depth sampling survey, where the signal from hydrocarbon seepage is measured from three different depth intervals and compared to each other, and to the real signature obtained from a known hydrocarbon reservoir in the area of interest. This new design has proven to be critical in reaching the optimum depth of investigation and in statistically differentiating real signals from noise (AbuAli et al., 2016). Designing an intelligent sampling method may account for the contamination effect and better reflect the actual hydrocarbon seepage pattern coming from the subsurface. The design can be implemented in two ways utilizing a grid similar to that used in seismic acquisition surveys. First, a geochemical survey would start by inserting gas-absorbing sensors into shallow boreholes at several depth intervals, which could eliminate the contamination effect by subtracting the signature measured at different depth intervals from the real seepage signal that is believed to be representing the actual accumulation. Second, the survey is repeated different times to investigate reproducibility and whether the same signals vary over time (time-lapse surface prospecting). This method can be applied both onshore and offshore. Onshore application would be through a gridded survey, while the offshore one would utilize a similar survey by sampling seabed cores at different depth intervals. The study will also attempt to identify other chemical compounds that were not typically analyzed before by conventional surface geochemical surveys (normally C2-C20 compounds). These include polar compounds and ratios of polar to non-polar compounds to come up with new seepage parameters.

Introduction

Exploring for hydrocarbon reserves is becoming increasingly difficult. Various geochemical methods exist for surface and near-surface exploration to detect signals that could be associated with microseeps (Schumacher and Abrams, 1996; Klusman, 1993). For example, sensitive instrumentation can be used for direct and indirect microseep detection. Improvements in technology and sensitivity of microseep detection methods may be beneficial in lowering the risk of hydrocarbon exploration and in locating subsurface hydrocarbon accumulations more efficiently. The compounds present in subterranean zones can include oil, water, gas and solids (e.g., coal deposits). A direct method to detect hydrocarbon seepage can include measuring reservoir hydrocarbons through soil-gas surveys. Near-surface prospecting technology offers an inexpensive tool to confirm the presence of subsurface hydrocarbons ahead of the drill bit.

This technology can also be used in prioritizing prospects and in inferring the nature of hydrocarbon accumulation (e.g., oil versus gas), potentially reducing the overall exploration risk quite substantially. Surface and near-surface prospecting technology can also be used as an ancillary and integral component of other exploration tools to enhance their resolution.

Theory and Method

Most sedimentary basins exhibit one form or another of hydrocarbon seepage. This seepage can be active or passive. Active seepage occurs in areas where active hydrocarbon generation or active migration pathways are taking place. Passive seepage occurs in areas that are not actively seeping. In the early days of hydrocarbon exploration, only macroseepage was detectable, and many early discoveries were made following macroseepage anomalies. Microseepage surveys were developed after advancements in analytical instrumentation. Surface exploration using soil gas samples was first applied in Russia and Germany in the 1930s (Fontana and Seneshen, 2014). Microseepage patterns are complex and can vary in space and over time.

For example, the microseepage patterns vary in intensity in producing areas, where gas concentration is expected to increase while fluid concentrations decrease away from the fields. Reservoirs that are over-pressured presumably leak more intensely than under-pressured reservoirs. Active seepage leads to higher concentrations of hydrocarbons at the surface that may be easier to detect by geochemical surveys, as opposed to passive seepage.

Fresh seepages may suggest an active migration system induced by faulting/fracturing (or reactivation of pre-existing structures) and subsequent leakage from an old accumulation. Passive seepage may indicate a non-migrating system, resulting in weaker geochemical expression at the surface. It is assumed that the surface geochemical signature primarily reflects the type of accumulation (oil vs gas), although the original composition and primary signal can be altered by other geological factors such as seal type, depth of accumulation (or length of migration pathway), and structural reactivation, among other factors. Knowledge of microseepage parameters including the concentration as a function of space and time can aid efficient operation of the detection device used. Likewise, prior knowledge of basin architecture and its structural elements and their distribution can enhance surface prospecting by helping to correctly place the detection devices. Surface prospecting has matured from indirectly measuring the presence of subsurface hydrocarbons through microbial methods, soil reduction-oxidation techniques and gas sniffing, to directly measuring reservoir hydrocarbons through soil-gas surveys by placing special sensors that adsorb hydrocarbons.

Particular specifications of the proposed multi-depth profiling method can be implemented so as to realize one or more of the following advantages. The accuracy and reliability of the proposed method to detect microseepage is independent of the amount of gas fraction. The method accounts for spatio-temporal variability and the non-stationary nature of the signal. The described method can be coupled with other subterranean exploration tools. Multi-depth profiling can also be installed offshore or onshore downhole locations as part of a permanent or retrievable system. The method allows for enhancement of the seepage signal by measuring at multiple depths at the same test location and could, therefore, reduce the noise/contaminant (from a single measurement) by identifying new seepage-sensitive parameters. While this method is independent of other remote sensing methods such as seismic and satellite imagery, it could be integrated with these methods to simultaneously measure both the seepage concentration as well as the seismic reflection times through combined installations of geochemical sensors and geophones. Such integration would be invaluable in lowering the overall exploration risk.

Examples

A regional, east-west transect in central Saudi Arabia was chosen to test whether or not the multi-depth approach would reveal a depth-seepage relationship. The area of interest is ideal for such a study because of its relatively simple petroleum system setting. Paleozoic hydrocarbons are derived from a single source and trapped in a single reservoir, thereby minimizing or eliminating the risk of confusing signals from multiple reservoirs. The transect runs through a producing well and a dry well for calibration purposes. The geochemical sensors/sorbers were placed at 1, 5 and 10 meter depths using drilled cased holes along the transect (AbuAli et al., 2016). Some lead targets along the transect were selected for testing after they were drilled. Additional sensors or sorbers were placed in the sand (non-cased hole) at less than one meter depth following the routine soil-gas sampling technique of Amplified Geochemical Imaging (AGI).

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The sensors were collected after three weeks. Additionally, either full 10-meter long cores (where possible) or core/cuttings samples from 1, 5, and 10 meter depths were taken for comparison with the sorbers at the same depths. A regional trend was established and a comparative model was created, which allowed for contrasting the different depth profiles and validating the resultant geochemical signatures with the Paleozoic signature in the area. In some instances the geochemical signature was partially obscured by contaminants from the cased hole steel pipes, and their effect was removed by using pattern separation techniques. An optimal geochemical profiling depth was achieved based on the study area conditions.

Conclusions

Geochemical exploration using conventional soil-gas surveys has existed for many decades. Application of this technology has evolved as a response to the advancement in analytical capabilities. Unconventional methods, including a multi-depth sampling design and the use of other airborne and automated technologies, such as satellite images and UAVs, could have a huge impact on hydrocarbon seepage detection. Encouraging results were achieved from multi-depth seepage profiling in the field, but they were limited by the relatively sparse, transect sample pattern. Distinct conclusions were apparent when using both light and mid-range compounds (C2-C5 and C6-C10). The geochemical anomalies suggested an optimal sampling depth for seepage detection based on this study. In some instances positive anomalies were present over undrilled leads in the area. The dataset was modeled using both neural network and linear discriminant techniques. More follow-up work is underway to validate the results by varying the depth profiles, using cased holes vs. non-cased holes, sampling air blanks, repeating the survey to confirm reproducibility of the results (time-lapse effects), and investigating different methods such as biogeochemical and airborne surveys. The results from this study require validation and future development to improve the technology of multi-depth geochemical profiling, before these techniques can be made routine in hydrocarbon exploration.

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