Time-lapse geochemical exploration utilizing a multi-depth sampling design

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Abstract. The objective of this proposed surface geochemical exploration method is to design a sampling survey in a different way than has been done conventionally. Traditionally, surface sampling is carried out at a depth ranging from 0.5-1.0 meters. A new patented method is proposed to test different depth intervals to reach the optimum depth. The survey is then repeated to verify whether the same results are consistently obtained (time-lapse). A regional east-west transect was chosen to test whether 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. 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 were placed at 1, 5 and 10 meter depths using drilled cased holes along the transect. The sensors were collected after three weeks. 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 typical signature in the area. 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 modelled 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 and repeating the survey to confirm reproducibility of the results (time-lapse effects). 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. The survey can be conducted concurrently with seismic acquisition to prove the presence of a petroleum charge before making more expensive decisions whether in seismic acquisition or in exploration drilling.

1. Introduction
The aim of this paper is to test a new sampling design to detect hydrocarbon seepage, differentiate seepage patterns from known accumulations versus those from dry wells, determine the optimum depth for seepage detection, repeat the survey to examine time-lapse effects and complement other exploration methods\cite{1,2}. Several methods for surface and near-surface geochemical methods to detect hydrocarbon.
microseepage were discussed by [3-5]. As these methods are quite important in proving the existence of a petroleum charge in the subsurface, they can also be used to lower the exploration charge risk when prioritizing prospects for exploration drilling. The proposed multi-depth sampling along with other direct and indirect methods should always be integrated with other exploration tools (seismic and non-seismic) to give the optimum geologic results. A single method is never enough to prove the geologic success of a basin in terms of having a working petroleum system or a commercial presence of a trap.

1.1. Method
Three samples were chosen around the perimeter of each sampling location. A few locations were selected along a traverse containing wells and prospects to allow for calibration and validation of anomalies around the prospects. At each location shallow holes were drilled using a car-mounted rig to a depth ranging from 1-10 meters. The drilled hole was cased using steel pipes to eliminate contamination from hydrocarbon-containing casing material such as PVC pipes. The drilled locations were left for three to four weeks to allow for equilibration with the soil environment. All cased holes drilled nearby wells were located away from the well pad and upslope from the well, to avoid possible surface contamination.

Geochemical samplers were then placed in each drilled hole and left for about three weeks for in-situ adsorbent equilibration. Figure 1 shows a map of the study area with locations marked S1 to S19 as well as locations of wells and prospects [6-7]. The locations are spaced out at roughly 5 km. The samplers were placed in the shallow holes drilled to 1, 5 and 10 meters depth to test and validate the new patented technology [3].

![Surface Exploration Survey Line](image)

Figure 1. Location map of the study area. The numbers above each location indicate the number of shallow holes drilled, 1, 5, or 10 meters deep.

2. Analysis
Analysis of the samplers by automated thermal desorption GC/MS were carried out. Chemical compounds ranging from C2 to C20 were measured from about 160 plus samplers representing all locations in addition to duplicate samples, blanks and instrument calibration samples. Processing of the data allowed for removing noise and outlier detection. This was achieved by comparing the values obtained from each location with the average values obtained from other surveys conducted worldwide.

2.1. Interpretation
The data interpretation process went through several steps. Geochemical data were screened for noise and sample outliers. Samples that showed promising hydrocarbon response were then mapped to identify possible geochemical leads. The next step was geostatistical treatment of the data using multivariate statistical techniques such as principal component and factor analysis, hierarchical cluster analysis, linear discriminant analysis, canonical variates analysis and neural network analysis. This allowed for a geochemical model to be established. The compound ranges (C2 to C20) helped in identifying the petroleum phase followed by prospectivity determination of the lead.

The measured compound list includes napthenes, aromatics, aliphatics and nitrogen/sulfur/oxygen (NSO). There are about 86 measured compounds. Some anomalous values were detected at very high levels that are not normally associated with microseepage (several thousand nanogram). These values may represent either contamination from the surface sites or from the casing material. Additional work is needed to test this hypothesis. The anomalous values represent heavy compounds in varying locations and depths. These values were many folds higher than average values measured from other basins worldwide. These readings were, therefore, removed from the dataset to avoid sampling bias. Similarly, compound response values that were close to those of the blank ones were removed as noise. The anomalously removed samples were for the C11-C20 compounds. Approximately half of the 86 compounds were removed, either as noise or contamination. The compounds that were kept represented C2-C5 and C6-C10 ranges. Discriminant, factor and neural network analyses were then performed on the remaining compounds to look for patterns of hydrocarbon character.

3. Results

The discriminant analysis model was run on the dry and producing well cases to establish a supervised classification scheme. The neural network classification was done using a single-layer node of logistic as activation functions. The classification included factor score data and depth of the sample. The factor scores represented separation of hydrocarbon influence from background character, which represents a difference from a producing and a dry well influence. The neural network classification was found to be more effective despite the sparsity of the dataset.

3.1. Factor Scores

Figures 2-5 show the different factor scores representing the conventional “in-sand” depth (less than 0.5 meter) and the newly designed method with drilled cased holes representing 1, 5 and 10 meter depth samples. High factor scores are represented in red and low scores in dark blue. The factor scores method did not reveal meaningful results over the area of interest. Mixed high and low scores were obtained in the area where producing and dry wells were located. Therefore, the factor scores were not considered representative in the interpretation of the dataset.

3.2. Linear Discriminant and Neural Network

Results showing the linear discriminant and neural network models are shown in Figure 6. Both models were generated in 2017. The image on the right is for the linear discriminant analysis while the left image shows the neural network model. While the linear discriminant model shows a strong anomaly around the control points, it does not show hydrocarbon influence to the west of the area. The neural network model shows clearly both the hydrocarbon influence around the control points as well as along the traverse with clear anomalies in different localities and depth of samples. The conventional “in-sand” sample (less than 0.5 meter) images the reservoir extent and identifies an anomaly at the end of the traverse. The 1 meter, cased-hole sample identifies the reservoir as well as the lead around the middle of the traverse. This depth sample does not extend to the west; therefore, no interpretation can be made. The 5 meter, cased-hole sample identifies the reservoir as well as the middle lead and the anomaly to the west. The 10 meter, cased-hole sample agrees with 1 and 5 meter samples in imaging the reservoir and the middle lead. It, however, does not extend to the west of the traverse due to sample unavailability.
Figure 2. Factor scores result for the conventional depth sample (less than 0.5 meter). Red represents high factor scores while dark blue represents low scores. Control locations are shown by arrows.

Figure 3. Factor scores result for the proposed sampling design of 1 meter, cased-hole depth sample. Red represents high factor scores while dark blue represents low scores. Control locations are shown by arrows.
Figure 4. Factor scores result for the proposed sampling design of 5 meter, cased-hole depth sample. Red represents high factor scores while dark blue represents low scores. Control locations are shown by arrows.

Figure 5. Factor scores result for the proposed sampling design of 10 meter, cased-hole depth sample. Red represents high factor scores while dark blue represents low scores. Control locations are shown by arrows.

Figure 6. Geochemical models for the linear discriminant (right) and neural network (left) analysis conducted in 2017. Red circles indicate high hydrocarbon influence and blue circles represent low influence.

3.3. Time-Lapse Effects
The survey was repeated in 2018 to investigate time-lapse effects. Selected cased-hole samples were re-sampled and analysed. Interestingly enough, the results showed remarkable similarity to the 2017 results. The conventional sample (less than 0.5 meter) images the reservoir, lead and anomaly very well. The 1 meter sample only reproduced the reservoir extent part of the surveyed traverse. The 5 meter samples gave very strong correlative associations to the 2017 survey. The reservoir extent, lead and anomaly to the west were very well imaged. Similarly, the 10 meter samples correlated well over the reservoir extent and the lead at the middle of the survey. The western part of the survey was not covered for the 10 meter depth due to sample unavailability. Figure 7 shows the time-lapse results only for the neural network model for both surveys conducted in 2017 and 2018.

![Figure 7. Time-Lapse geochemical models for the neural network analysis conducted in 2017 and 2018. Red circles indicate high hydrocarbon influence and blue circles represent low influence.](image-url)

4. Conclusions
Although the survey did not benefit from a detailed geochemical sampling, the available samples obtained in this survey confirmed that geochemical exploration using adsorbed soil-gas has good merits when conducted and integrated with other methods. This method provides a fast and non-expensive reconnaissance tool. The cased-hole samples provided another level of quality control compared with the conventional sampling methods. There were some samples that were not conformable to the rest of the dataset. Such findings are expected in all surveys and care has to be exercised to identify and remove outliers from the dataset to improve data interpretation. Data acquisition, sampling and analysis can be improved by providing more calibration samples, blanks and duplicates. Despite the results not conclusively favoring any particular depth of investigation due to sample sparsity, the deeper the sample depth the better the results maybe to avoid the zone of contamination near the surface. Finally, as long as such a survey is conducted in integration mode with other exploration methods, it will improve the assessment of any area at an early stage of exploration. Preferably, this survey should be conducted concurrently with a detailed seismic acquisition grid to highlight areas of future exploration potential. The results will always be timely, before major investment decisions are made whether in seismic acquisitions or in drilling.
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