Implication of Soil Gas Method for Prospecting of Hydrocarbon Microseepage

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Abstract: *The light hydrocarbons in soil are the guides to indicate the existence of reservoir through most Surface geochemical exploration. The light gaseous hydrocarbons (C_1 to C_5) in soils represent one of the widely accepted analytical approaches. The methodology involves the presence of surface manifestations of hydrocarbons, that are indicative of deep-seated petroleum reservoirs both onshore and offshore regions. The methodology approach is to collect the soil samples analyses of light hydrocarbon gases as methane, ethane, propane, butane and pentane. The contour maps of the analytical results are drawn and integrated with the geological, geophysical data to evaluate the hydrocarbon prospects and to prioritize the drilling locations thereby increasing success rate towards exploration. Thus, the surface geochemical surveys document the success ratio of nearly 82% of wells on prospects with a microseepage anomaly as resulted in oil and gas discoveries. The paper highlights the details of methodology adopted in terms of sample collection, processing, statistical data interpretation, identifying the anomalous zone as part of surface geochemical surveys.*

Keywords: *light hydrocarbon gases, surface geochemical prospecting, micro-seepage, petroleum exploration, integrated approach.*

1. INTRODUCTION

Geochemical exploration is the search for chemically identifiable surface or near-surface occurrences of hydrocarbons and their alteration products, which serve as clues to the undiscovered oil and gas accumulations. All such methods on the principle that hydrocarbons generated and trapped at depth, leaked to varying but detectable quantities to the surface. This is a phenomenal occurrences as the processes and mechanisms of diffusion, effusion, and buoyancy allow hydrocarbons to escape from subsurface to surface where they are retained in the soil sediments. Geochemical exploration techniques can be direct or indirect. Vertical migration of light gaseous hydrocarbons establishes an environment allowing the migration via buoyancy through micro fractures and micro pores. As the trap fills, the upward migration of hydrocarbons continues towards the surface along the highly conductive micro fracture systems and as a result of buoyancy rather than in solution or as colloidal fluid. This evidences that the hydrocarbon microseepage from the reservoirs involves buoyant colloidal size "microbubbles" of light hydrocarbons most likely C_1 to C_5 ascending rapidly through the water filled network of fractures, joints and bedding planes (Price, 1986). Bacterial consumption of these hydrocarbons creates carbon dioxide and hydrogen sulfide, which may get altered near surface, producing detectable modifications in geomorphic, seismic, magnetic and radiometric properties of soils.

Microseeps are recognized by the presence of anomalous concentrations of light hydrocarbons (C_1-C_5) in the near surface soils/sediments along with other surface manifestations in the form of microbial and trace element anomalies, mineralogical changes and altered electrical, magnetic and seismic properties. 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 diverse surface manifestations leading to the hydrocarbon seepage. These activities when coupled with long-term migration of hydrocarbons of near-surface oxidation-reduction zones favoring the formation of variable hydrocarbon-induced chemical and mineralogical changes. This alteration is highly complex, and its varied surface expressions leads to the development of an equally varied number of geochemical exploration techniques. Among these techniques some detect hydrocarbons directly in surface and seafloor samples, while others detect seep-related microbial activity, and few other

measures the secondary impact of hydrocarbon-induced alterations (Schumacher and Abrams, 1996). The figure 1 shows a generalized model of hydrocarbon microseepage and hydrocarbon-induced effects on soils and sediments. The existing near surface anomalies serve as clues to the nature and composition of sub-surface hydrocarbon occurrences and help to demarcate the anomalous hydrocarbon zones and grade the frontier basins. (Jones and Drodz, 1983; Klusman, 1993; Tedesco, 1995; Schumacher and Abrams, 1996).
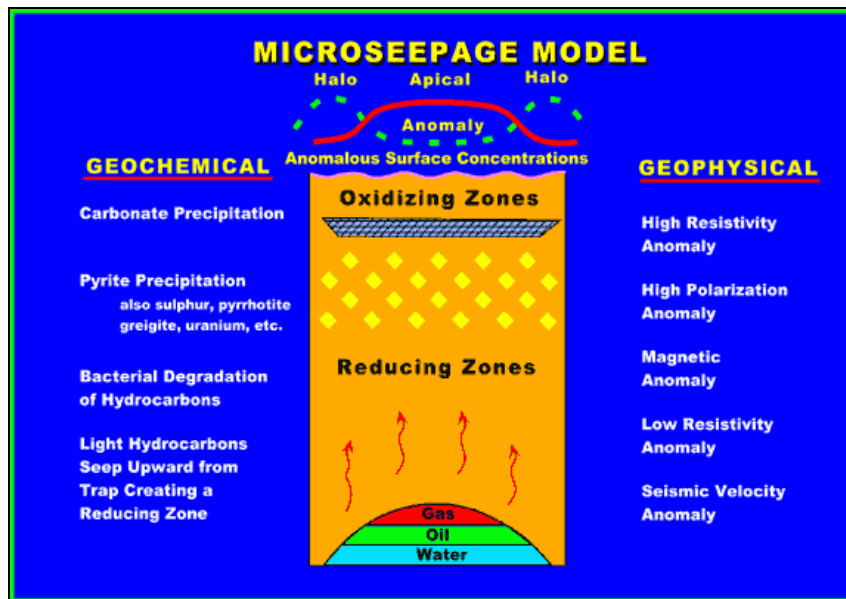

Fig. 1 *Hydrocarbon microseepage model and hydrocarbon-induced effects on soils and sediments (modified after Schumacher and Abrams 1996).*

The direct microseepage exploration techniques involve free air, headspace, de-absorption, acid extraction, groundwater and fluorescence methods detecting light hydrocarbons trapped near the surface soils. Direct methods comprise the detection of light and heavier hydrocarbons in soils. The indirect methods measure a secondary manifestation due to hydrocarbon microseepage, such as microbiological methods, remote sensing, soil calcite surveys, micromagnetic surveys, radiometric surveys, trace metal surveys, hydro geochemical and biogeochemical surveys (Tedesco, 1995).
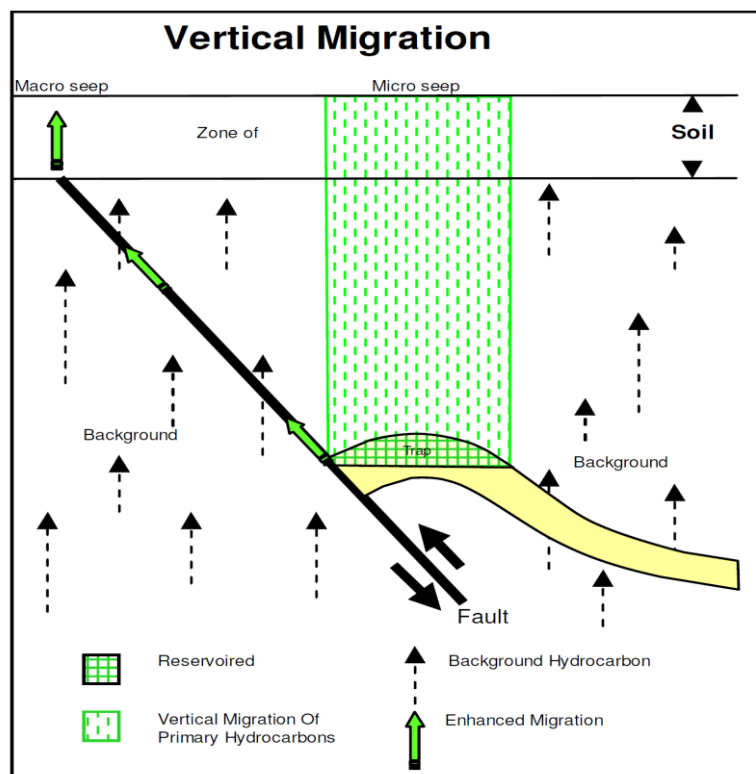

Fig. 2. *Concept of surface micro seepage (Adapted from Potter et al, 1996)*

2. MATERIALS AND METHODS

2.1 Soil sampling

The sampling methodology is crucial since the validity of the test results depend largely on the manner in which the samples are collected. There are two types of field surveys for collection of soil samples, one is reconnaissance pattern and the other is grid pattern. In reconnaissance surveys the samples are collected along the existing roads, usually with an interval of 3 to 5 km. The reconnaissance survey along the existing roads can help one to evaluate a large tract of land for its hydrocarbon resource potential and prioritize the areas for further exploratory studies. Here, the samples are usually collected nearly 40–50 ft away from the existing roads, avoiding the possible anthropogenic contaminations. The surveys are treated as an elementary tool to cover a large area of any basin as part of preliminary assessment of hydrocarbon accumulation. The grid surveys are designed based on the size of the survey area; usually the samples are collected in a close interval of 200 m× 200 m or 500m × 500m (~200–1000 m). These surveys are mainly used for locating hydrocarbon microseepage and also for probable oil or gas well drilling location following the correlation of the results with other geo-scientific studies.

Soil core samples are collected from a depth of top 2–6 m by using the hollow metal pipe by and by manual hammering to the required depth. About 500g of core soil samples are wrapped in aluminum foil and sealed in poly-metal packs. The samples then sealed in the resealable plastic bags with their sample numbers along with their locations marked through the Global Positioning System (GPS). The disturbed or excavated areas, soils contaminated with hydrocarbon, chemicals or animal waste, swamps and areas under watershed or water logged areas are avoided for sampling. Further, rocks, coarse materials, plant residues, and animal debris have been excluded (Rasheed et al, 2008).

Methods of microseepage detection

The collected samples are analysed as per the standards through the following procedures.

a. Detection of light hydrocarbons

The analysis of light hydrocarbons, methane to pentane in soils and soil gases represent one of the established geochemical methods used as part of geochemical surveys. The light hydrocarbons reside in soils and shallow sediments most likely as free gas in the effective porosity as; interstitial gas occluded in pore spaces between grains, as gas adsorbed onto sedimentary particles or trapped within carbonate cements and gas dissolved in water or present in the atmosphere

b. Detection of heavier hydrocarbons

Volatile and semivolatile heavier hydrocarbons as aromatic compounds, gasoline range hydrocarbons, and even normal or biodegraded oils can be traced particularly in the areas where migration occurs along fault and fracture pathways. These different manifestations lead to the development of different techniques for sampling and analyzing hydrocarbons. It is beyond the scope of this chapter to discuss the advantages and limitations of specific methods or sampling procedures; however, such information is available in publications by Abrams (1996).

c. Soil-probe method

This was the first documented method in Germany in 1929 used to measure hydrocarbons migrating through the well-connected pores of the soils. A hollow steel probe is driven to a depth of 1 to 2 meters, after purging the atmospheric gases, a fresh gas sample is drawn into a syringe and is ejected into a sample container and the gases are analyzed by a gas chromatograph.

d. Headspace method

The headspace technique measures hydrocarbons adsorbed onto, or loosely bound by, the clay and organic materials within the soil. Here, the samples are collected at one or two-meter depth and free gases of the sample are placed in a sealed container of measured volume. A measured amount of distilled water and a bacteriostatic agent are added to the container. The bacteriostatic agent prevents the microbiological oxidation of hydrocarbon gases prior to analysis. One or two glass marbles are added before the container rim is sealed for enhancement of sample agitation. The sample container is placed in a water bath and heated at a set temperature. Overtime, agitation of the soil liberates the gas that occupies the headspace. The headspace gas sample is extracted and then injected into a gas chromatograph for further analyses.

e. Time-delay method:

A hole is augured to a specific depth and thoroughly cleaned of loose soil. The gravel or sand is placed in the lower one feet of the hole along with a small diameter copper tube that extends to the surface where bentonite or a low permeability material is placed on the top of the gravel to prevent atmospheric contamination. The end of the copper tube at the surface bears a rubber septum to draw the gas sample. The system is then purged with a syringe until an amount of gas equivalent to the volume present in the copper tube is extracted. The sample site is left intact ad over a period of time a sample is withdrawn from the copper tube and analyzed by a chromatograph.

f. Adsorbed Soil Gas

The present paper focuses on the adsorbed soil gas method which is a direct technique in which the trace amount of light hydrocarbons occurring in the pore space of soil and adsorbed on the fine grained portion of soil or that are incorporated in soil cements are analyzed. Trace amounts of light hydrocarbons collected near the earth's surface provide clues to present day subsurface fluid composition and migration from deep seated oil and gas reservoir (Gevirtz 1983).

g. Light hydrocarbon analysis using gas chromatography

The light gaseous hydrocarbons have been extracted from the soil samples using a gas extraction system (Horvitz, 1981). Here, 1 gm of 63 μ particle size soil sample was used to extract light gaseous hydrocarbons after acid treatment in glass degasification apparatus and subsequent analyses on gas chromatograph (GC) for the samples having higher concentrations (Fig 3).
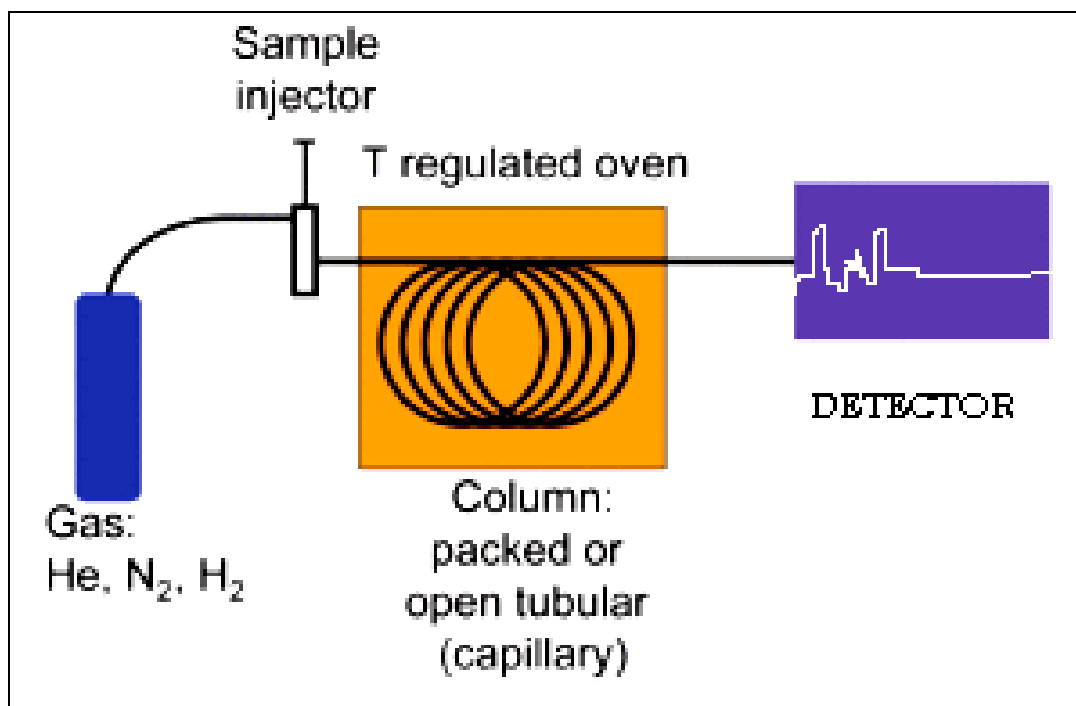

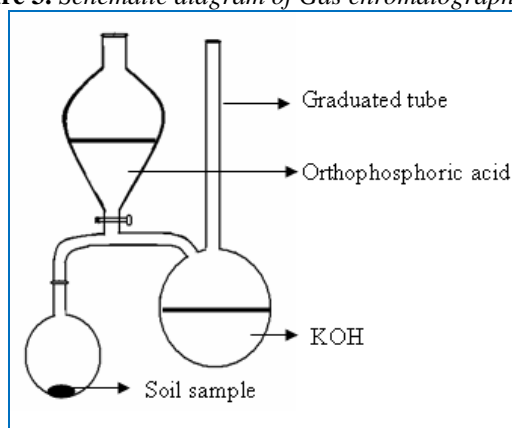**Figure 3.** *Schematic diagram of Gas chromatograph (GC)*

Fig. 4. *Degasification apparatus for desorption of hydrocarbon gases from soil.*

During acid treatment, the dominant gas released is CO_2 which is trapped in KOH solution (Fig 4). The light gaseous hydrocarbons are collected by water displacement in a graduated tube fitted with rubber septa. The volume of desorbed gas was recorded and 500 µl of desorbed gas sample was injected into gas chromatograph (Varian CP 3380) fitted with a Porapak Q column, equipped with a flame ionization detector. The gas chromatographs are calibrated using external standards with known concentrations. The quantitative estimation of light gaseous hydrocarbon constituents in each sample was made using peak area measurements and a correction for moisture content on a wet basis was also applied. The hydrocarbon concentration values of individual hydrocarbons from methane through pentane (Fig. 5a & 5b) are expressed in parts per billion (ppb) (Kumar et al., 2003).
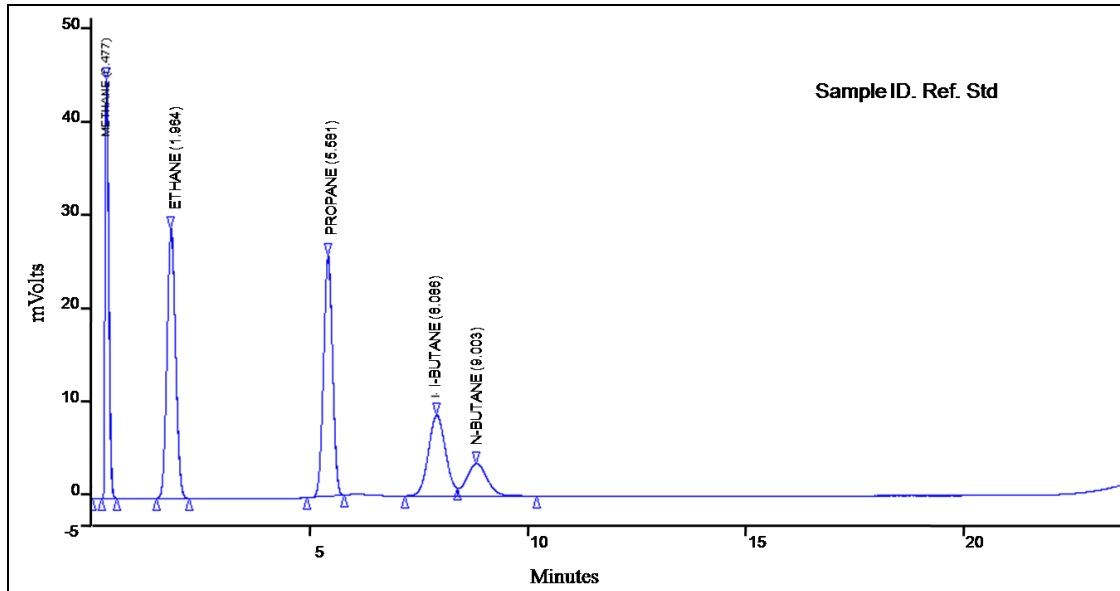

Fig. 5 (a) *Gas Chromatograph of light gaseous hydrocarbons in reference standard.*
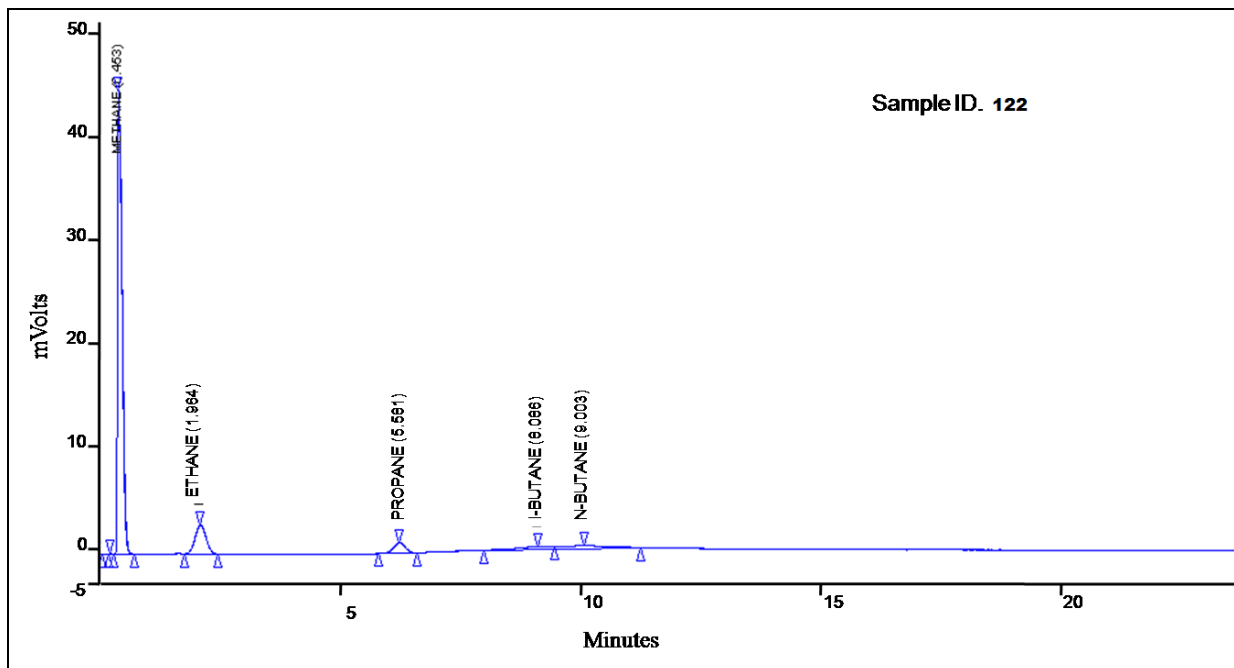

Fig. 5 (b). *Gas Chromatographs of light gaseous hydrocarbons in soil sample.*

Evaluation of adsorbed soil gas data

Evaluation of adsorbed soil gas data comprises graphical representation and statistical analysis to identify the anomalous population of samples (Abrams, 2005). The histograms and probability diagrams of C1 and ΣC2+ (C2+C3+iC4+nC4+iC5+nC5) are plotted to identify the different sample concentration in a data set and to identify anomalous and background values. Subsequently, C1 to C4 data is interpreted using hydrocarbon cross plots and their correlation coefficients that are excellent

statistical tools for numerically determining how well the grouped hydrocarbon pairings correlate to each other and also help in determining their sources (Schumacher, 2003).

Histograms

Log histograms for the adsorbed gases (C1-C5) show the presence of different populations in the data at a glance. In general, the frequency distribution pattern shows more than one modal peak with positive skewness in all the hydrocarbon components. The lowest concentrations shift towards smaller values with an increase in carbon number. These characteristics are commonly observed for hydrocarbon gases derived from thermogenic processes (Klusman, 1993).

Scatter plots

The gases of thermogenic origin generally show a trend of decrease in concentration from methane to pentane i.e. C1>C2>C3>C4>C5 (Klusman, 1993; Tedesco, 1995). The correlation coefficient between C1, C2, C3, $\Sigma C4+$ (iC4+nC4) and $\Sigma C2+$ are given in Table 1. Figures 6 & 7 illustrates the scatter plots of C1−C2 and C1−$\Sigma C2+$ which follows a linear trend. The linear correlation between all the gas species suggests that they all originate from the same source/origin and migrate under the same condition. High correlation of C1 with $\Sigma C2+$ indicates that the C1 in the samples have been derived from thermogenic source.
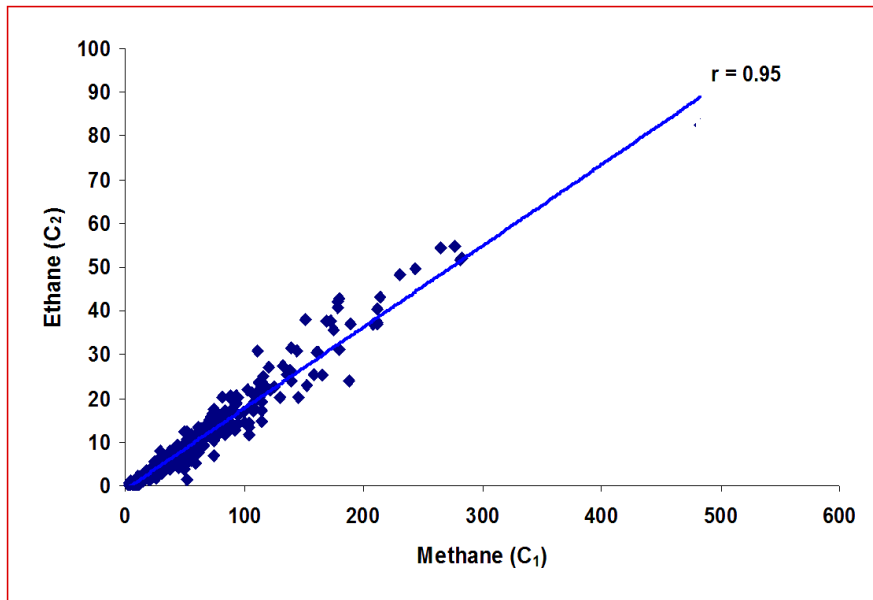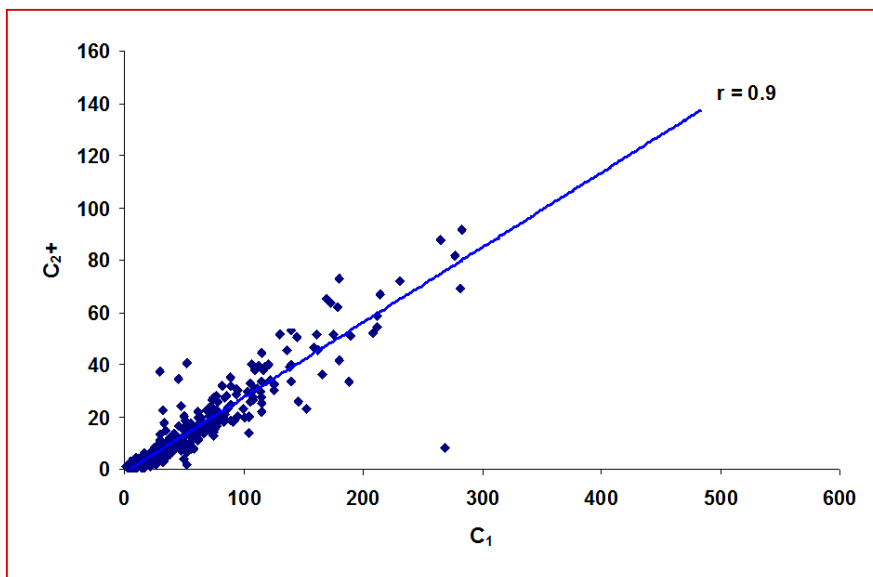

Fig. 6. *Cross plot between C_1 and C_2*

Fig. 7 *Cross plot between C_1 and ΣC_{2+}*

Pixler plot

Pixler (1969) defined the compositional signatures displayed by methane to ethane (C_1/C_2); methane to propane ratios (C_1/C_3) to determine the geochemical signature (oil, oil/gas, gas). Ratios below ~2 or above 200 indicated that the deposits were of no-commercial importance or value. The upper-limit ratios for dry-gas reservoir C1/C2<350, C1/C3<900, C1/C4<4500. Based on the Pixler plot (Fig. 8), the samples fall in three zones (oil, oil/gas and gas zones) but majority of samples belongs to Oil & Gas zones.
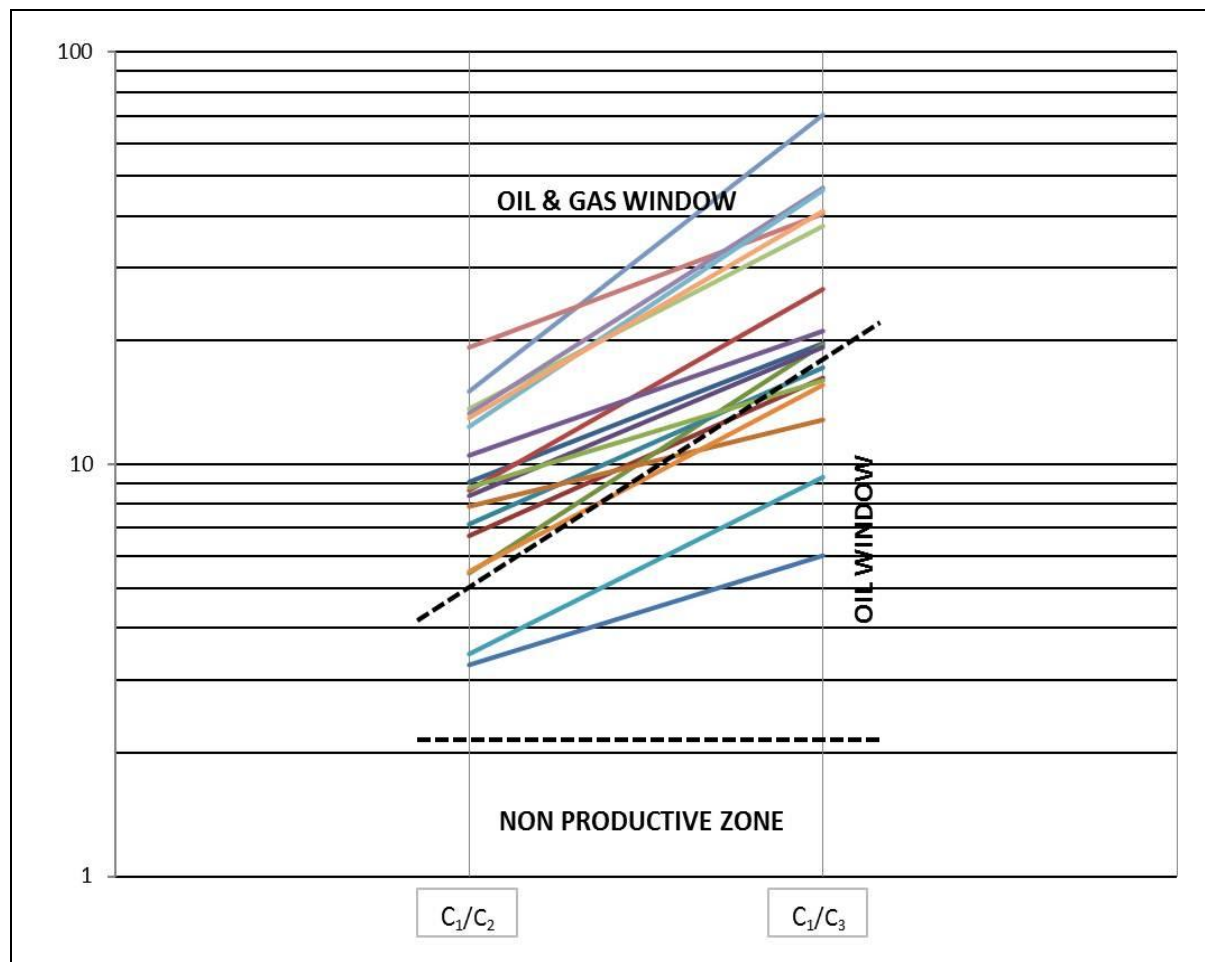

Fig 8. *Pixler plot of adsorbed light hydrocarbon gases.*

The geochemical signature (gas, gas condensate or oil) is determined using ratios of hydrocarbon constituents detected in the soil-gas sample (Table 3). The percent methane (%C1) and the percent gas wetness (Jenden et al., 1993; Jones et al., 2000) may further quantify the compositional signature of a soil gas. The values of hydrocarbon constituent ratios provide an identifying compositional signature for each sample (Table 3), may also indicate the most probable source of light hydrocarbons (Jones et al., 2000).

Table 1. *Approximate Empirical Range of Microseep Compositional Ratio for Gas, Gas condensate, and Oil (adapted from Jones and Drozd, 1983).*

Hydrocarbon Composition	C1/C1-C4 or %C1	C1/C2	(C1/C2)X10	(C3/C1)X10
Gas	100 -90	100-20	25-50	2-20
Gas condensate	90-75	20-10	16.5 – 25	20-60
Oil	50-5	10-4	10-16.4	60-500

Bernard plot

A Bernard plot can be used to differentiate light hydrocarbon gases derived from thermogenic or bacterial sources (Bernard *et al*., 1976). The carbon isotopic composition of methane (δ 13C1), The origin of the gases and possible processes of gas generation are investigated first with the help of the

Bernard diagram (Bernard et al., 1978), which uses the molecular composition, namely the $C1/(C2+C3)$ ratio and the $\delta13C$ values of methane. Molecular ratios $C1/(C2+C3)$ less than 50 are typical for thermogenic hydrocarbon gases with the $\delta13$ C values between –25‰ to –55‰ PDB. This suggests that most of the samples fall in the thermogenic range (Figure 9).
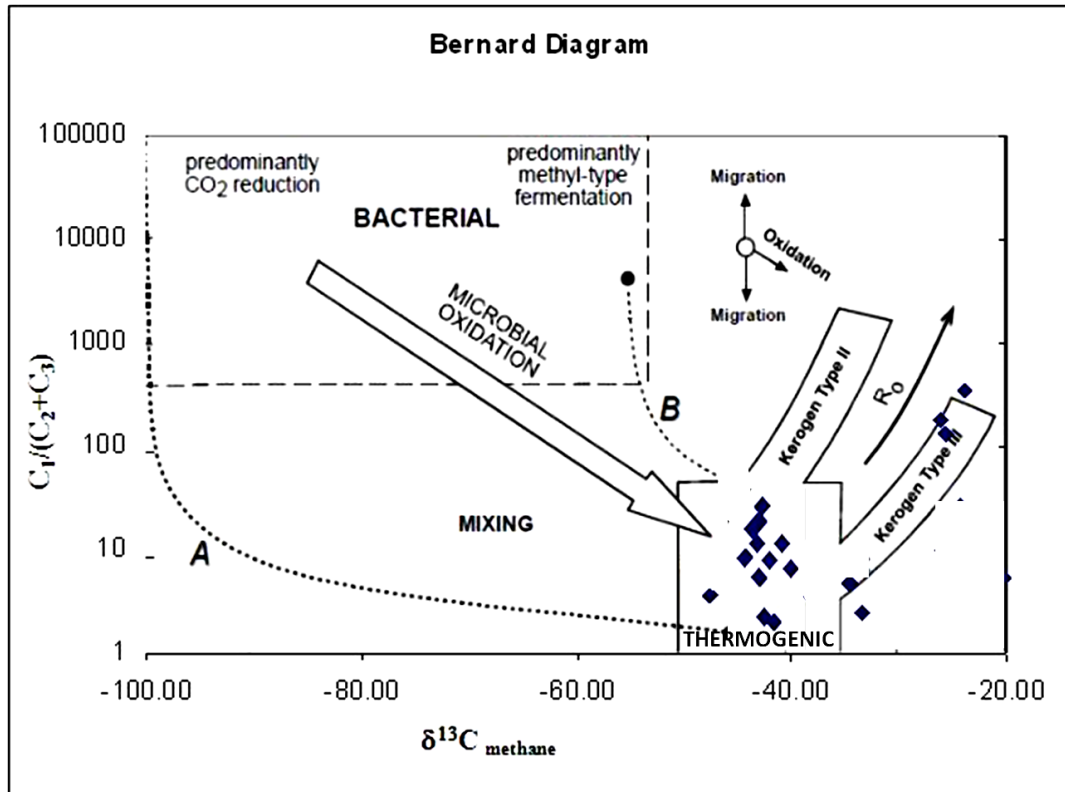

Figure 9. *Bernard diagram suggests that most of the samples fall in the thermogenic range.*

Concentration distribution maps

The concentration distribution and anomaly maps for individual constituents (C1 to $\sum$C2+) can be plotted on the surveyed map using Arc GIS (Geographical Information System) or Golden Surfer Software's etc. A statistical approach has been followed and the values above mean plus standard deviation value is taken as a background value for the demarcation of anomalous zones. Light gases hydrocarbon distribution map showing anomalous regions in figure 10.
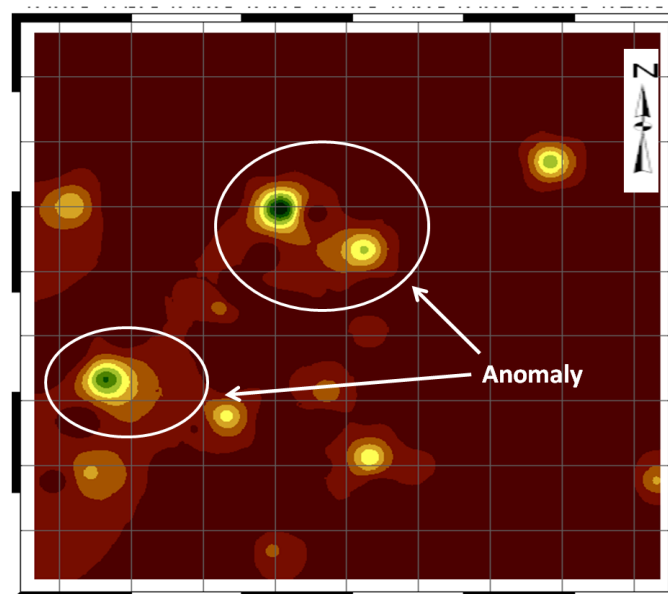

Fig. 10. *Light gases hydrocarbon distribution map showing anomalous regions.*
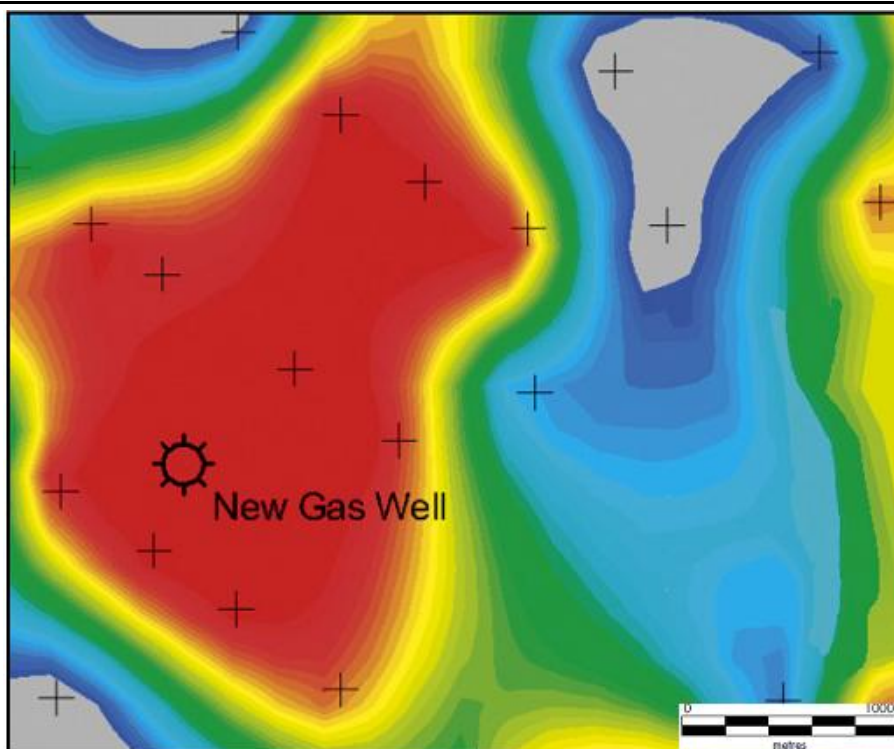
Fig. 11. *Case History from Permafrost – Arctic North America Location of new gas discovery within the geochemical feature (anomalous area shown in red color) defined by the GORE Survey. (Source: GORE Surveys)*

Success ratio

The contribution of geochemical surveys to increased discovery ratios can only be ascertained by comparing geochemical results with subsequent drilling. A review from U.S. and international for 2774 numbers of exploration wells, all these wells were drilled after completion of micro seepage surveys, which documents that 82% of wells on prospects with a microseepage anomaly are completed as oil or gas discoveries; in contrast only 11% of wells drilled on prospects with no seepage anomaly resulted in a discovery (Fig. 12). When hydrocarbon microseepage data is properly acquired and interpreted, it can significantly reduce exploration risks and costs by improving success rates and shortening development time (Schumacher, 2012).
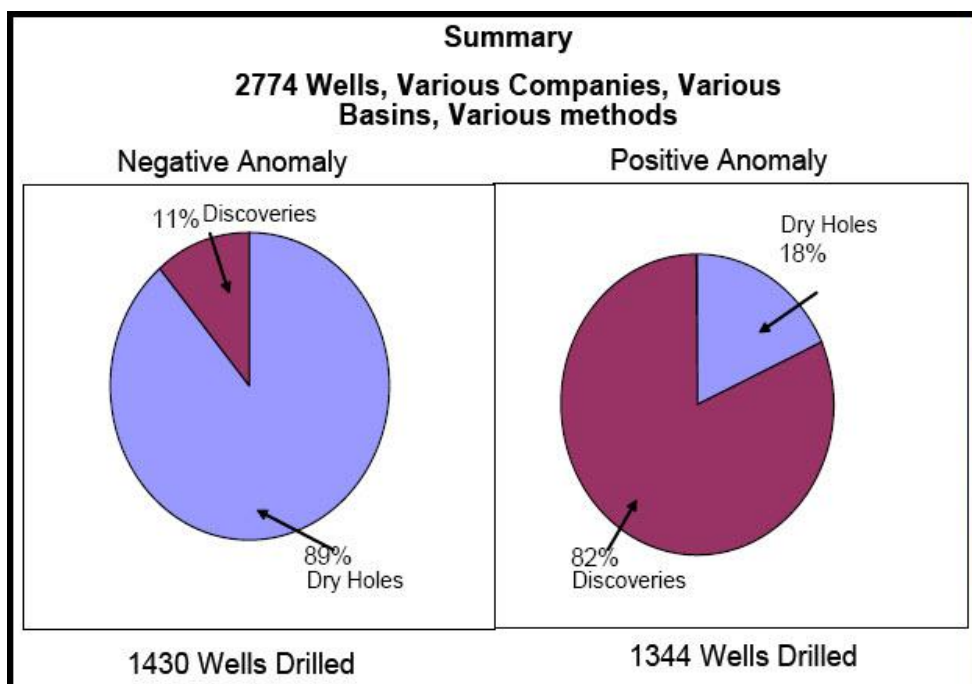

Fig. 12 *Summary of 2774 wells drilled and its stastics (Schumacher, 2012).*

Advantages of surface geochemical method

The following are the advantages of surface geochemical prospecting method, which as significant role and considered as an important tool in petroleum exploration (Schumacher, 2012).

- Surface geochemical prospecting methods are generally used for reconnainace surveys and considered to be the best and cost effective tool for identification of hydrocarbon prospects.

- The anomalous concentrations of C_1–C_5 in the surface soils are used for: i) grading of basins; ii) distinguishing productive/non-productive basins; iii) predicting oil and gas association of the basin and iv) assessment of hydrocarbon generation potential of a basin.

- Adsorbed soil–gas surveys are rapid and cost-effective for initial evaluation of a frontier basin for hydrocarbon exploration

- Directly detect hydrocarbons and/or hydrocarbon-induced changes in soils, near surface sediments, and/or on the sea floor. Document the presence of a working petroleum system in the area of interest. Permit high-grading of basins, plays, or prospects prior to acquiring leases or before conducting detailed seismic surveys.

- Permit post seismic high-grading of leads and prospects; generate geochemical leads for further geological or geophysical evaluation. Evaluate areas where seismic surveys are impractical or are ineffective due to geological or environmental factors.

- Provide methods applicable to both stratigraphic traps and structural traps, with the ability to locate invisible traps or poorly imaged with seismic data.

- The surface geochemical methods have no negative environmental impact.

- Surface geochemical anomalies provides direct indication of hydrocarbon seepage in the survey area. As the drilling operations are costly, it is essential to use appropriate and efficient exploratory methods, either singly or in combination, in order to cut down the drilling cost of dry holes as well as wild cats with unprofitable recovery. Surface Geochemical prospecting methodology is a valuable and less expensive value addition exploration tool to evaluate the valuable seismic prospects.

- It is a good supplementary tool for hydrocarbon prospecting and on proper integration with geological and geophysical data, can contribute to the success of exploration and helps in risk reduction of dry wells.

- The surface geochemical prospecting method can also be used independently and basically no geological or seismic data is required to carry out Surface geochemical prospecting surveys. In areas that have not yet been investigated geophysically, this technique can be applied as wildcat prospecting tool.

Acknowledgements

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