Association of Petroleum Geologists. India
Registered under Societies Registration Act,No. 21 of 1860

GEO India 2022

A Synergistic Approach of Interpretation of Surface Geochemical Adsorbed Gas and Microbial Anomalies in G & G Framework: A Case Study of Sarkaghat, Himalayan foothills, India

Varun Chopra[1], Asim Samanta, Rakesh Tripathi, Rashmi Anand
[1]Email: Chopra_varun@ongc.co.in, Oil and Natural Gas Corporation Limited

Abstract

Geochemical and geomicrobial surface prospecting for hydrocarbon exploration has a worldwide appreciation in upstream oil industries. It is an unconventional, environment friendly, economical and direct hydrocarbon indicating tool which is based on the detection and identification of micro seepages at the surface and near surface sediments in respect of adsorbed hydrocarbon gases and propane and butane oxidizing bacterial abundances. The micro seepages, effusing/diffusing from the sub-surface accumulations, are mainly composed of lighter hydrocarbon gases (C_1-C_5) with traces of higher hydrocarbons which serve as hydrocarbon signatures at surface and induce changes in the micro environment of soils/sediments. These seepages serve as sole carbon source for specialized microbial growths like propane and butane oxidizing bacteria.

The present study attempts the analyses of micro seeps in terms of adsorbed hydrocarbon gases and enumeration of propane and butane oxidizing bacterial abundances in the sediment samples collected during 2D seismic survey in Sarkaghat area of Himalayan Foothills, Frontier Basin.

The study reveals that the micro seeps are of catagenetic origin and associated with sub-surface wet gas/gas condensate accumulations. Their hydrocarbon constituents are co-genetic and follow the descending concentration trend like $C_1>C_2>C_3>C_4$ and propane oxidizers > butane oxidizers, indicating thereby a petroliferous characteristics of the study area.

The adsorbed gas anomalies have shown a good deal of corroboration with propane and butane oxidizing bacterial anomalies, indicating a halo anomaly effect usually seen in a petroliferous area.

An integrated approach has been adopted for interpretation and evaluation of micro seeps profile of the study area by integrating geochemical and geo-microbial anomalies with surface and sub-surface geological data. The combined anomalies (C_2+ adsorbed gas and microbial) on superimposing on Surface geological map of Sarkaghat area of Himalayan Foothills and surface lineament have shown corroboration with the sub-surface structures. The presence of lineaments and sub thrust in anomalous area may be indicative of sub surface faults which may act as probable conduit for hydrocarbon seepages. The studies suggest that the northwestern and south western parts of study area are potentially significant in terms of hydrocarbon warmness. The integrated model of micro seepages has helped in understanding the mechanism of seeping gases and reducing exploration risk which in turn helped in the evaluation and prioritization of theprospective sub-surface structures for hydrocarbon exploration.

Introduction

Hydrocarbons generated and trapped beneath the surface seep or leak to the surface in varying but detectable quantities. These phenomena occur because processes and mechanisms such as diffusion, effusion and buoyancy allow hydrocarbons to escape from reservoirs and migrate to the surface where they may be retained in the sediments and soils or diffuse into atmosphere or water columns (Klusman, 1993; Schumacher and Abrams, 1996). Based on these assumptions, various techniques of surface geochemical prospecting for hydrocarbons have been developed to identify the surface or near-surface occurrences of hydrocarbons (Figure-1). Surface geochemical prospecting for hydrocarbons consists of direct and indirect methods to identify the micro-seepage. These methods include adsorbed soil gas surveys, microbial techniques, soil salts, bitumen, and trace element techniques etc. These techniques when integrated with G &G data help in delineating and prioritizing the hydrocarbon prospects of an area and thus reducing exploration risk. This technique is cost effective, environment friendly and risk reducing, involving search for chemically identifiable surface or near surface occurrences of micro-seeping light hydrocarbons (C_1 through C_5).

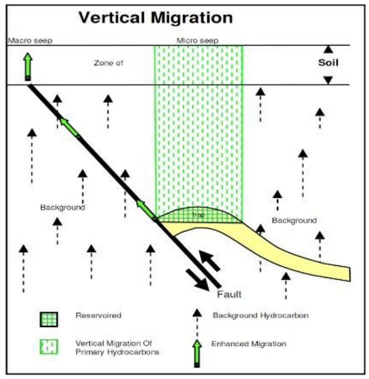

Figure 1: Concept of surface micro seepage (Adopted from Potter et al, 1996)

The adsorbed gas and microbial anomalies of soil samples have been integrated with geological framework in order to delineate and prioritize the prospects by correlating the surface anomalies with the sub-surface structures.

Geological Setting

Himalaya is a part of an arcuate orogenic belt extending over about 2500 km on the northern part of the Indian plate, resulting from a collision between the Indian and Eurasian plates. The tectonic setting of the Himalayan mountain belt can best be described in terms of four prominent structural breaks running along the entire length of the Himalayan strike, viz., The main frontal thrust (MFT), The main boundary thrust (MBT), The main central thrust (MCT) and The Indus Tsangpo Suture (ITS). Siwaliks are the Late Tertiary sediments deposited between the MFT and MBT and are present over almost the entire length of the Himalayan foothills. These sequences have been stratigraphically grouped into the Upper, Middle and Lower Siwaliks by Pilgrim (1913). Many thrusts and fold belts have developed in this region as a result of the post-collision compressional forces, which were subsequently covered by various sedimentary deposits brought down by the rivers and streams in this vast mountain chain. The Lambargaon syncline flanked by the Sarkaghat anticline on the NE and the Bahl anticline to the SW, is about 10 km deep. The generalized stratigraphy of the basin is depicted in figure-2

AGE	GROUP	FORMATION	LITHOLOGY	THICKNESS (m.) OUTCROP	THICKNESS (m.) SUB-SURFACE	GENERALISED DESCRIPTION	PRINCIPAL FOSSIL RECORDS	ENVIRON-MENT
HOLOCENE	ALLUVIUM					COARSE SAND AND CLAY WITH PEBBLES AND CALCAREOUS CONCRETIONS		
EARLY PLIOCENE TO PLEISTOCENE 5.5 - 1.5 Ma	SIWALIK	UPPER		600-2350	870-1640	PREDOMINANTLY CONGLOMERATE WITH MINOR SANDSTONE AND EARTHY BUFF AND BROWN CLAYSTONE	PLOSPORES ASSEMBLAGE TRILETE MONOCOLPATE	FLUVIAL BRAIDED PLAIN
LATE MIO. TO LATE PLIO 10.8 - 5.1 Ma	SIWALIK	MIDDLE		820-2830	268-1640	PREDOMINANTLY SANDSTONE MEDIUM TO COARSE GRAINED MASSIVE PEBBLE WITH SUBORDINATE VARIEGATED CLAYSTONE AND MINOR LENTICULAR CONGLOMERATE BANDS AT THE TOP	-DISACCITES -TRIPORATA -TRICOLPATE	BRAIDED FLUVIAL
MIDDLE MIOCENE 18.3 - 10.8 Ma	SIWALIK	LOWER		1000-3450	120-1500	ALTERNATIONS OF GREY TO GREENISH GREY, FINE TO MEDIUM GRAINED SANDSTONE AND MAROON TO REDISH BROWN, NODULAR CLAYSTONE AND SILTSTONE	-VERUCATO SPORITES USMENSIS -TRILOBATA -ZONOCOSTITES	BRAIDED FLUVIAL WITH BRACKISH INFLUENCE
EARLY MIOCENE 20.0 - 18.3 Ma	DHARMSALA / MURREE	UPPER		550-1625	1176-3270	GREENISH GREY, FN. GRAINED SANDSTONE WITH SUBORDIN-ATE GREEN MAUVE AND AT PLACES PURPLE CLAYSTONE	-SABAL MAJOR -UNIO SR. -DINOTHERIUM	BRAIDED MEANDERING FLUVIAL
EARLY MIOCENE 21.5 -20.0 Ma	DHARMSALA / MURREE	LOWER		1000-2270	538-2150	MAINLY ARGILLACEOUS, CONTAINS THICK SECTIONS DEEP PURPLE TO CHOCOLATE COLOURED CLAYSTONE AND SILTSTONE WITH SUBORD. FINE GRAINED, QUARTZOSE, MICACEOUS, HARD SANDST.	DINOCOTHERES CHALICOTHERES ANTHRACOTHERES PALMIDEMITES Sp. PINUSPOLIENTES	FLUVIAL BRACKISH
PALEOCENE TO MID. EOC	SUBATHU			35-840	417 ?	OLIVE GREEN AND GREY CALCAREOUS SPLINTERY SHALES WITH FOSSILLIFER-OUS LIMESTONE	NUMMULITES ASSILINA ROTALIA	MARINE MIXED BRACKISH
PRESENCE OF PALEOZOICS AND SALT RANGE FORMATION EQUIVALENT SEQUENCES EXPECTED IN JAMMU SUB-HIMALAYAS IN ANALOGY WITH POTWAR SUB-BASIN AND LIKELY TO BE PRESENT IN KANGRA RECESS HIATUS IN DUN RECESS AND NAHAN SALIENT BASED ON RECENT STUDIES AND DRILLED WELL DATA								
MESO-NEOPROTEROZOIC	WAISHNODEVI LIMESTONE/ SIRBAN			450-1220	~2500	DOLOMITES, LIMESTONE, CHERTY THIN SHALES, SALT AS LOKHAN OF PALE PURPLE AT MANDI-DRANG	STROMATOLITES	MARINE-INTERTIDAL (S)
MESO-NEOPROTEROZOIC	MOHAND			—	677	MARBLE, DOLOMITIC LIMESTONE SLATY SHALE, BLACK IN COLOUR AND QUARTZITE	KILDINOSPHAERA CHAGRINATA ZONE	INNER NERITIC
MESO-NEOPROTEROZOIC	JANAURI			—	25-237+	DOLOMITIC MARBLE, AND GY. & DIRTY WHITE AND SMOKY QUARTZITE WITH CHLORITE MICA SCHIST	ELLIPSALETES Sp.	RESTRICTED MARINE
ARCHEAN	GRANITE BASEMENT			—	25+			

Figure 2: Generalized Stratigraphy of Himalayan Foothills (modified after DGH-ONGC-OIL)

Experimental methodology

The study involved broadly two parts: (i) Geochemical adsorbed gas and microbial (Propane and Butane oxidizers) studies and (ii) Integration of adsorbed gas and microbial anomalies with sub-surface G&G framework.

Laboratory analysis of soil samples

The soil samples were dried at room temperature and sieved through 63µm sieve to remove the coarse grain fraction. One gm fine grained portion (≤ 63µm, ASTM) of the sample was disintegrated with ortho-phosphoric acid under vacuum condition to desorb the adsorbed hydrocarbons from soil particles. The liberated carbon dioxide was removed by using potassium hydroxide solution. The desorbed hydrocarbons gases (C_1–C_5) were analyzed by CHEMITO GC-1000 gas chromatograph and computed with respect to the standard gas mixture. The data were acquired by using IRIS-32 LITE software and plotted through surfer and Arc-GIS software.

The propane and butane oxidizers were studied for substrate utilization. Each isolate was grown on its carbon source i.e., alcohol derivative (propanol and butanol). Liquid media plates were prepared by first preparing the Mineral-Agarose medium and adding the respective liquid carbon source (alcohols) after cooling the medium to 40-45°C. The decimal dilution of original soil sample was worked out by carrying out initial experiments with the whole range of dilution (10^{-2} to 10^{-7}), depending upon the initial bacterial load in the samples. After inoculation of the required dilution plates in duplicate, the plates were incubated for 3 days at 37+1ºC and the colonies were counted ("Microbiological method of prospecting for hydrocarbon exploration", KDMIPE patent application no. 3295/DEL/2011 dated 18.11.2011).
The experiments were carried out in duplicate / triplicate to ensure precision and repeatability.

Results and Discussion

All samples showed presence of light gaseous hydrocarbons viz. methane, ethane, propane, i-butane, n-butane, i-pentane and n-pentane (C_1, C_2, C_3, iC_4, nC_4, iC_5 and nC_5), whereas more than 90% of soil samples showed the propane and butane oxidizers. The ranges of concentration of the constituent's hydrocarbon are shown below in Table-1:

Hydrocarbons	Concentration Range
Methane (C_1)	0.358-3434.54 ppm
Ethane (C_2)	0.015-16.77 ppm
Propane (C_3)	0.004-4.94 ppm
iso-Butane (iC_4)	0.002-1.65 ppm
n-Butane (nC_4)	0.0009-0.55 ppm
Ethane plus (C_2+)	0.015-16.77 ppm

Table 1: Concentration ranges of hydrocarbons

The concentration of the hydrocarbons in soil samples has been observed to follow the trend $C_1>C_2>C_3>C_4$ (Table-1) and generally this is the characteristic feature of gases from petroliferous areas. Beside this various gas ratios, have been calculated to observe the nature of the seeped gases and given in Table-2.

Gas Ratios	Value
C_1/C_2	310
C_1/C_2+C_3	9.91
C_2/C_3	4.18
$(C_3/C_1)*1000$	208
$C_1/\sum(C_1-C_5)\%$	96.57

Table 2: Gas ratios calculation

As the value of $C_1/\sum(C_1\text{-}C_5)\%$ is more than 95 and $(C_3/C_1)*1000$ is more than 60 suggests that the micro seeps are of catagenic in origin and associated with wet gas/gas condensate/oil accumulation (V.T. Jones and R. J. Drozd et al., B. B. Bernard et al.).

	$C_1/\Sigma C_n$	C_1/C_2	$(C_3/C_1) \times 1{,}000$
Dry gas	100-95	100-20	2-20
Gas condensate or oil and gas	95-75	20-10	20-60
Oil	5-50	10-4	60-500

Very high value of C_1 /C_2 may be due to mixing of local biogenic gas along with micro seeped gases.
Out of 185 samples more than 90% of soil samples showed the propane and butane oxidizers. The range of concentration of the constituents hydrocarbon and propane and butane oxidizers are shown below in Table-3

Hydrocarbons	Concentration Range
Propane Oxidizers	500-6800000count/g soil
Butane Oxidizers	500-6000000count/g soil

Table3: Concentration ranges of propane and butane oxidizers

Frequency distribution of hydrocarbons

In general, a non-productive survey area is usually represented by a histogram of normal frequency distribution, i.e., a normal bell shaped curve (Koch and Link). However, in productive areas or prospects, with increase in carbons numbers the lowest concentration generally shifts towards the lower value and the frequency distribution shows a bimodal distribution or, more commonly is skewed to the right (Tedesco SA). Histograms have been prepared by using half of the standard deviation as class interval to get meaningful interpretation. The frequency distributions of hydrocarbon yield for C_{2+} (Figure 3a) and Propane oxidizers (Figure 3b) showed the skewness trend mainly towards the right, indicating petroliferous nature of hydrocarbons.

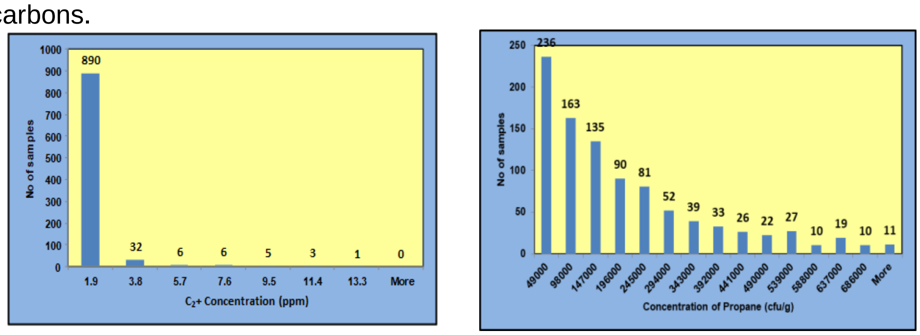

Figure 3a: Frequency distribution of C2+ (ppm) (3b) Frequency distribution of Propane oxidizers (Cfu/g)

Genetic correlation of hydrocarbon constituent gases in micro seeps

Genetically, near surface hydrocarbon gases can be of bacterial, early digenetic, thermo-genic or of mixed origin. These may be generated in shallow sediments and soil, or at the greater depths associated with oil and gas generation. Additionally, soil moisture, soil mineralogy and microbiological activities can variably affect different soil gas survey methods.

The composition of migratory light hydrocarbons can be inferred from selected light hydrocarbon ratios, cross plots or gas ratios (Jones & Drozd et al.; Bernard et al., and Deitmar Schumacher). Cross plots of C_1 vs C_2 (Figure 4a) has showed non-linear trend among the hydrocarbon constituents which may be due to

The cross plot of ratio C_1/C_2 vs $C_1/(C_2+C_3)$ (Figure 4b) shows the linear relationship (R^2 value 0.95). This suggests that all the hydrocarbon constituents in micro seeps are genetically related and least influenced by secondary alteration during upward migration from the sub- surface deposit to the surface and their subsequent adsorption on the surface soil.

mixing with other gases (may be local biogenic gases present in some areas).

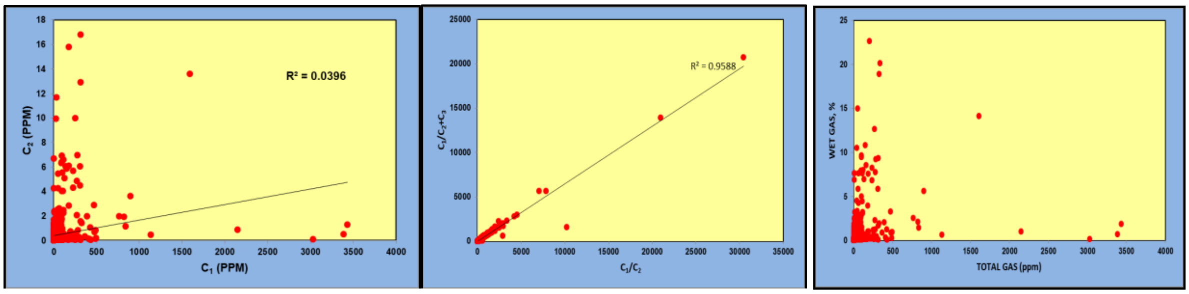

Figure 4a: Cross plots of C_1 vs C_2 (b) Cross plots of C1/C2 and C1/C2+C3 (c) Cross plots of Total Gas vs Wet Gas %

In the Total Gas versus Wet Gas % cross plot, (Figure 4c), it is observed that, majority of samples are have wetness below 5% which is actually showing the presence of biogenic gases along with thermo genic gases.

Statistical treatment of adsorbed gas and microbial data

The analytical data have been processed statistically to calculate the arithmetical mean (M) and standard deviation (σ) of all the hydrocarbon constituents present in the soil samples by using iterative extreme elimination method (Saunders) to find true background concentration value. In the present study, value of $M+1\sigma$ has been considered to eliminate background for all the hydrocarbon constituents. Anomalous areas having values equal to or greater than mean plus two standard deviation ($M+2\sigma$) becomes more reliable to prioritization of prospects for hydrocarbon exploration. It has been recognized that among the light hydrocarbon gases, C_2 and higher hydrocarbons are mainly thermo-genic in nature. So, in this paper we have mainly considered concentration anomaly map ethane to pentane (C_2+), propane and butane oxidizers for integration purpose. The map is depicted in figure 5.

Adsorbed gas and Microbial (C_2+, propane and butane oxidizers) Anomaly

The concentration of sum of C_2 to C_4 (i.e. C_2+), propane and butane oxidizers ranged from 0.034 ppm to 22.61 ppm, 500-6800000 count/g and 500-6000000 count/g. The C_2+, Propane and butane oxidizers sample population has standard deviation of 1.722 ppm, 460455.9 count/g and 436787.1 count/g soil and mean concentration as 0.64 ppm, 294272.9count/g and 282071.1 count/g respectively. 219 (19%), 310 (27%) and 321 (28%) samples have C_2+, propane and butane oxidizers concentration greater than mean value respectively. The value $M+2\sigma$ is calculated are 4.089 ppm, 1215185 count/g and 1155645 count/g respectively. Hence concentrations ≥ 4.089 ppm are considered as anomalous. Combined concentration map (Figure 5) indicates the presence of two anomalous areas in the north-western and south western part of the study area. The map indicates that the adsorbed gas (C_2+), propane and butane oxidizers anomalies are confined in the Northwestern and south-western parts with some scattered microbial anomalies in the central part of the study area have been observed. For the purpose of demarcation of anomalous areas, Adsorbed gas and microbial anomalies are superimposable and formed a halo pattern of anomalies in both zone ‘A’ and ‘B’ which indicates presence of micro seepages in the anomalous areas.

Zone ‘A’ has higher concentration of the microbial count than Zone ‘B’ where as adsorbed gas count is higher in zone ‘B’ to that Zone ‘A’.

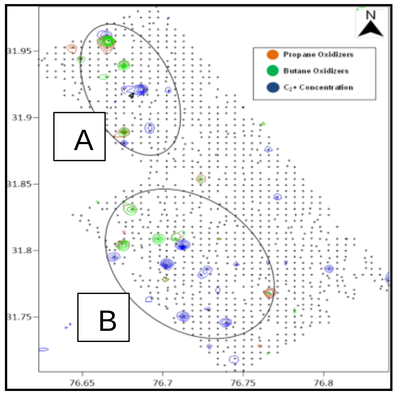

Figure 5: Combined Anomaly Map (C2+ adsorbed gases, Propane and Butane Oxidizers)

Integration of geochemical anomalies with geological data

The integration of geological and geochemical data provides a wider perception of prospect delineation and prioritization in hydrocarbon exploration. Signature of hydro carbons in the form of adsorbed gas anomalies are correlated with the sub-surface geological features/structures for better understanding of prospect evaluation.

The C_{2+} adsorbed gas anomalies have been superimposed on Surface geological map of Sarkaghat area of Himalayan Foothills and following observation have been observed. In Fig.-6. The map shows that the C_{2+} adsorbed gas anomalies fall on the younger Siwalik Formation but found very less concentration in Dharamsala Formation. The anomalous area 'B' has high lineament density in compare to area anomalous area 'A'. It has been also been observed that the anomalous area 'B' lies on anticlinal axial trace which is highly fractured zone and shown in Fig.-8.

In the thrust map Fig.-8 both the anomalous area is at the sub thrust of palampur thrust.

The presence of lineaments and sub thrust in anomalous area 'A' and 'B' may be indicative of sub surface faults which may act as probable conduit for hydrocarbon seepages. Higher concentration of adsorbed gas microbial count in anomalous area 'B' in compare to Anomalous area 'A' may be due to presence of higher lineament density in Area 'B' in compare to area 'A' and presence of anticline axial trace in area 'B'. It has been observed that surface geochemical and microbial anomalies are corroborating with the geological studies.

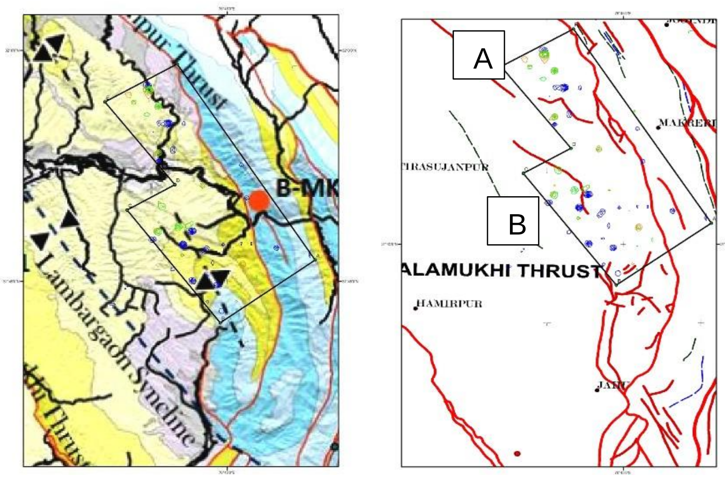

Figure 6 a: C_{2+} adsorbed gas anomalies superimposed on Geological of Sarkaghat area, HF Block (b)Thrust map showing the anomalous area is in the sub thrust of Palampur thrust

Conclusion

The study suggests that the micro seeps are catagenetic in origin and are associated with gas condensate/light oil and wet gas accumulation. Their hydrocarbon constituents are co-genetic and follow the concentration trend C1>C2>C3>C4, indicating petroliferous nature. Very high concentration of methane gasas compared to that of the other hydrocarbon gases in some areas may indicate the mixing of other local gas pools along with seeped gases(may be Biogenic) in those areas.

The integrated anomaly map of C2+ hydrocarbons, propane oxidizing bacteria and butane oxidizing bacteria indicates that the northwestern and south western part of the study area are significantly warm with hydrocarbon.

The presence of lineaments, sub thrust and anticlinal axial trace in anomalous areas in the study area, maybe indicative of sub surface faults which may act as probable conduit for hydrocarbon seepages. It is seenthat surface geochemical and microbial anomalies are corroborating with the geological studies.

References

Bernard, B. B., Brooks, J. M. and Sackett, W. M., (1977): Natural gas seepage in the Gulf of Mexico. Earth Planet. Sci. Letters, V (32): pp. 48-51.

Bernard, B. B. (1978): Light hydrocarbons in marine sediments, Ph.D. dissertation, Texas A and M University, USA, pp.144.

Horvitz, Leo (1980): Near surface evidence of hydrocarbon movement from depth, Robert, W.H.III and Cordell, R.J. (eds.), Problems of Petroleum migration, studies in Geology, AAPG, (10): pp. 241-269.

John, Phillip and Sountar, Ian, 1976: Identification of crude oils by synchronous excitation spectrofluorimetry. Anal chem., vol. 48, No.3, March 1976, 520-524.

Jones, V. T. and Drozd, R. J., (June 1983): Predictions of Oil or Gas Potential by Near Surface Geochemistry. AAPG, V (67): No. 6, pp. 932-952.

Koch, G.S and R.F.Link (1971): Statistical Analysis of Geological data, John Wiley and Sons, New York.

Price, L.C., (1986): A critical overview and proposed working model of surface geochemical exploration, in M. J. Davison, ed., Unconventional methods of exploration for petroleum and natural gas, IV: Southern Methodist University Press, Dallas, Texas, TX, pp. 245-304.

Saunders, D. F., Burson, K.R. and Thompson C. K., (1991): Observed relation of soil magnetic susceptibility and soil gas hydrocarbon analysis to subsurface hydrocarbon accumulations. AAPG Bulletin, V (75): No.3, pp. 389 – 408.

Schumacher, Deitmar "Deet", (2003): Geochemical exploration for oil and gas. Strategies for success – An Exploration short course at International Symposium on Geochemical Prospecting, National Geophysical Research Institute (NGRI), Hyderabad, India.

Tedesco S A (1995) Surface Geochemistry in Petroleum Exploration: New York, Chapman and Hall, Inc., pp.1 -206.

Rasheed, M.A., Aviral, B., Surabhi, N., Santhosh, D., Srinivas, K., Hasan, S. Z., and Rao, P.H (2013): Integrated Surface Geochemical and 3D Seismic Studies to understand the Hydrocarbon Seepage Pattern

Rasheed, M. A., Lakshmi, M., Kalpana, M. S., Patil, D. J., Dayal, A. M. (2017): Recognition of hydrocarbon

microseepage using microbial and adsorbed soil gas indicators in the petroliferous region of Krishna–Godavari Basin, India