

Evaluation of Hydrocarbon Geochemical Anomalies in the Dailekh Region of Nepal

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Abstract: Analyzing the geochemical characteristics of hydrocarbons in Nepal is important to promote the exploration and development of hydrocarbons in Nepal. In this thesis, significant hydrocarbon geochemical anomalies in the Dailekh area of Nepal were revealed by comprehensive analysis of 12 indicators, including soil acid-dissolved hydrocarbons, post-generated carbonates (ΔC), conductivity (Ks), and adsorbed phase mercury (Hg). The analysis shows that the correlation between the indicators is good, and two anomalous zones are identified, located in the northwest and west-central part of the survey area, respectively, and the indicator anomalies in these zones show ring-in-ring top halo characteristics, especially Hg shows weak ring-strong top halo characteristics. These anomalies reflect the real geochemical activity information of the reservoir and verify the validity of this set of geochemical indicator combinations. The study further shows that these anomalies are mainly formed by the escape of underground oil and gas to the surface, and the favorable areas of anomalies No. I and No. II are presumed to be oil-type oil and gas reservoirs by the clustering analysis and hydrocarbon ratio method, indicating that this area has a good prospect for oil and gas exploration.

Keywords: Hydrocarbon Geology; Geochemical Characterization; Favorable Exploration Areas; Dailekh Region.

1. Introduction

Surface oil and gas geochemical exploration refers to the upward transportation of hydrocarbons from subsurface oil and gas reservoirs in various forms to form a series of responses in surface or near-surface media. The goal of oil and gas geochemical exploration is to search for the chemical characteristics of these hydrocarbons and their conversion products at or near the surface, which can serve as important clues to undiscovered oil and gas reservoirs [1-3]. In recent years, with the continuous improvement of geochemical investigation theories and research methods, the gradual improvement of analytical testing precision, and the corresponding improvement of data processing means and comprehensive interpretation level, soil oil and gas chemical prospecting has made remarkable achievements in production practice in several regions [4-6], showing good application prospects and high economic benefits.

Several gas seedling sites have been discovered in Dailekh region of Nepal, showing certain potential for hydrocarbon exploration. Nepal has developed the Laxharpata, Gondwana, Surkhet and Siwalik Groups in order from old to new, and different types and maturity of hydrocarbon source rocks are developed in these formations [7, 8]. However, scholars from different countries have not yet reached a definite conclusion on the genesis of these oil and gas seedlings through their studies, lacking carbon isotope tests and necessary analysis of influencing factors on the crude oil and hydrocarbon source rock systems. Research scholars Singh et al. analyzed by saturated hydrocarbon chromatography method concluded that the gas seedling points are the result of intense biodegradation of crude oil [9]; while Petro-Canada through carbon isotope method concluded that they may originate from mature hydrocarbon source rocks or reservoirs underlain by metamorphic rocks [10]. Although the petroleum geological conditions of the low Himalayan thrust belt in Nepal have been under study, hydrocarbon exploration has

not been able to make substantial progress due to the complexity of the geology and the insufficient degree of research, and the source of oil and hydrocarbon enrichment patterns are still unclear.

Based on the existing oil and gas geological data and research results, this paper carries out the oil and gas geochemical investigation in Dailekh area of Nepal, applies the detection of soil acid dissolved hydrocarbons, soil post-generated carbonates, soil conductivity, soil adsorbed phase mercury and other indexes, identifies the geochemical characteristics of oil and gas activities and the conditions of preservation of oil and gas aggregation in the Dailekh area, and predicts and evaluates the favorable areas for oil and gas aggregation. The study was conducted to identify the geochemical characteristics of oil and gas activities and the preservation conditions of oil and gas accumulation in Dailekh area, to predict and evaluate the favorable zones for oil and gas accumulation, and to identify the anomaly causes by combining the cluster analysis method and hydrocarbon ratio method. This study is of great significance for hydrocarbon exploration in the Dailekh area of Nepal under complex geological conditions.

2. General Geology

Nepal is tectonically located between the Lhasa Massif and the Indian Plate, separated from the Lhasa Massif by the Indo-Yarlung Tsangpo Suture Zone in the north and connected to the Indian Plate by the Ganges Foreland Basin in the south [11]. Influenced by the subduction of the Indian Plate to the Eurasian Plate, a series of north-dipping, north-west-south-east trending retrograde fault zones have been developed in the territory. There are four main fault zones, namely, the South Tibetan Demolition Zone (STD), the Central Main Tectonic Fault (MCT), the Border Main Tectonic Fault (MBT), and the Marginal Main Tectonic Fault (MFT), which have been developed from north to south, and their geologic

ages vary from old to new (Figure 1), the STD is the oldest, and the MFT is the newest [12, 13].

Regionally, stratigraphy from the Precambrian onwards is developed in Nepal. The Himal, Midland, Lakharpata, Gondwana, Surkhet and Siwalik Groups and the Quaternary are the main ones from the bottom up (Figure 1). The Himal Group contains only the Dailekh Group; the Midland Group is further divided into the Dubidanda Group and the Nabhisthan Group; the Lakharpata Group can be divided from the bottom up into the Sangram Group, the Ramkot Group, the Gawar Group, the Khara Group, the Katuwa Group, and the Aru Group; and the Gondwana Group includes the Sisneva Group in the Tansen area. Tansen region includes Sisne, Taltung and Amile Groups and in other regions only Charchare Group; Surkhet Group includes Melpani, Swat and Suntar Groups; Siwalik Group is further divided into Lower Siwalik Group, Middle Siwalik Group and Upper Siwalik

Group.

In terms of hydrocarbon geological conditions, the Sivalik Built-up Distribution Area (BDA) and Tarai Plain Area (TPA) in southern Nepal, which is the northern margin of the Indo-Gangetic Foreland Basin (IGFB), have better hydrocarbon geological conditions, with a total area of 38000km². The well-developed Cenozoic sediments in the area have good prospects for hydrocarbon exploration, especially for natural gas resources, and more favorable. Several oil and gas seedlings have been discovered in the above mentioned area such as Pakastan, Jawani, Dailekh, Sillasthan and within Kathmandu city. Seismic processing interpretation of the Terai plains indicates that the Siwalik sedimentary strata are in unconformable contact with the underlying meta-group, which corresponds to the Unnamed reservoir in northern India, which develops hydrocarbon source rocks and cap layers.

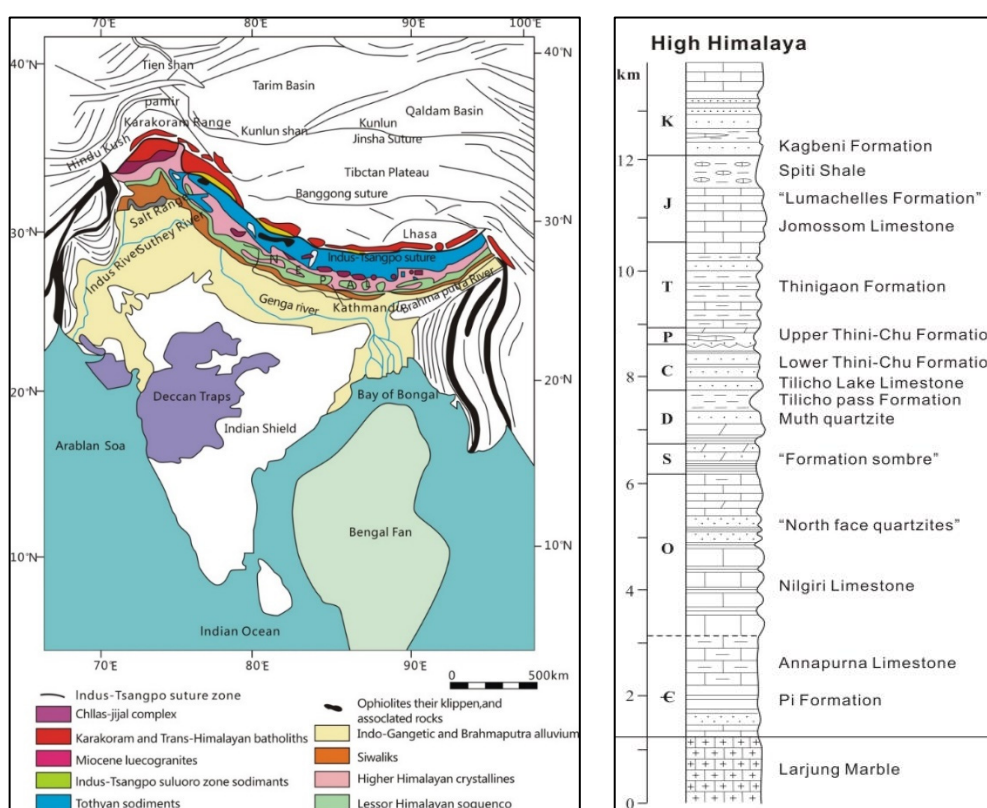


Figure 1. Comprehensive regional tectonic and stratigraphic histogram for the Nepal region.

3. Materials and Methods

3.1. Sample Collection and Testing

The geochemical landscape of the study area is hilly, with bedrock outcrops in some areas, and the location of the sample collection area is shown in the red boxed area A-H in Figure 2. The optimal sampling stratum is the C layer, and the optimal sampling depth is 30-80 cm. Because the C layer of the soil is thin in local areas, the B-C soil medium is taken according to the actual situation. Sampling must be collected from the same type of soil medium to ensure the consistency of the information obtained from the samples, and the samples are packed in cloth bags and the weight of the samples is not less than 500g.

The collection of 778 samples, oil and gas seedlings collected 23 samples. On the basis of sampling the samples were processed, the samples were processed by standard

stainless steel sieve, the samples larger than 40 mesh were discarded; the samples over 40 mesh sieve were encapsulated in cellophane bags and numbered for hydrocarbon index test and analysis; the samples that hadn't been sieved through the 120 mesh sieve (40-120 mesh particle size) were encapsulated in cellophane bags and numbered for non-hydrocarbon index test and analysis. And each processed sample number and sampling number consistent and indicate the particle size, each sample weight not less than 100g, and then the sample will be sent to the laboratory for testing and analysis. Sample analysis items of acid hydrocarbon, pyrolytic mercury, and post-generation carbonate (ΔC) were performed according to the method of "GB/T29173-2012 Methods for Determination of Oil and Gas Geochemical Exploration Specimens". Conductivity was analyzed according to the method of "HJ802-2016 Electrode Method for the Determination of Soil Conductivity". All samples were spiked with quality control samples at a ratio of 5% as required by the analytical basis.

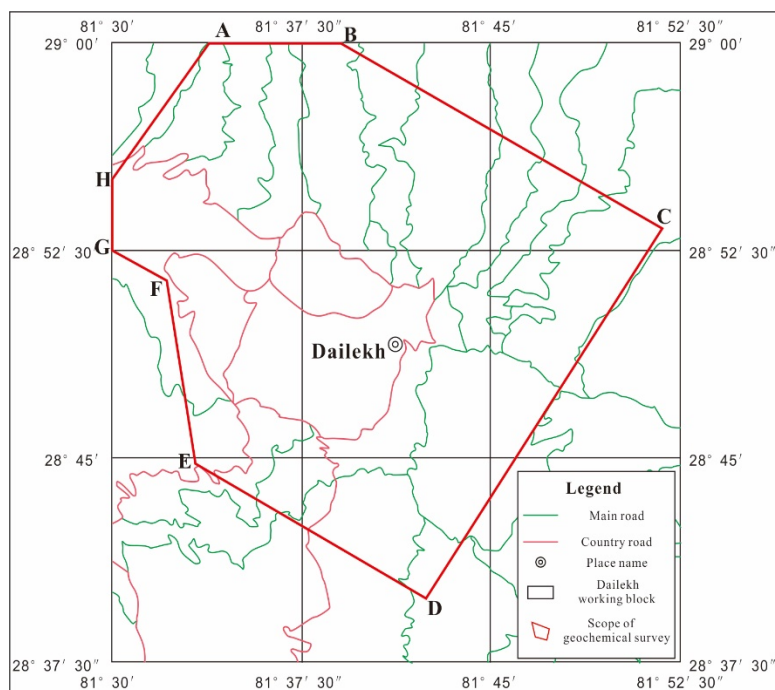


Figure 2. Location map of hydrocarbon geochemical survey in Dailekh area

3.2. Indicators for Geochemical Analysis of Oil and Gas

In oil and gas chemical exploration, the background value refers to the average value of the content of various oil and gas chemical exploration indicators (hydrocarbons, ΔC , Hg, Ks, etc.) in various natural materials (rocks, soils, groundwater, air, etc.) in non-oil and gas fields (reservoirs) or non-oil and gas activity zones in oil and gas-bearing basins. This analysis covered soil acidolyzed hydrocarbons (methane (CH_4), ethane (C_2H_6), propane (C_3H_8), n-butane ($n-C_4H_{10}$), isobutane ($i-C_4H_{10}$), n-pentane ($n-C_5H_{12}$), isopentane ($i-C_5H_{12}$), ethylene (C_2H_4), propene (C_3H_6)), soil post-generated carbonate (ΔC), soil adsorbed phase mercury (Hg), soil conductivity (Ks) 4 methods 12 indicators.

4. Analysis and Discussion

Based on the results of previous studies, multiple factors such as geology, tectonics, topography and soil media type of the Dailekh survey area, through an in-depth study of the geochemical field structure of the area, it was initially determined that three sub-tectonic units represent three different secondary oil and gas geochemical fields, and related studies were carried out on this basis.

4.1. Background Values and Lower Limits of Anomalies for Hydrocarbon Geochemical Anomalies

The background value of the integrated geochemistry of surface hydrocarbons is the average value of the non-anomaly content of various indicators (hydrocarbons, ΔC , Ks, Hg, etc.) in soils of non-hydrocarbon reservoir areas within hydrocarbon bearing basins. The form of distribution of indicators in geochemical processes of geological bodies obeys normal distribution. Due to many factors affecting the change of indicator content, the dispersion of each indicator content is high, and often it does not obey the (logarithmic) normal distribution, but the skewed distribution or even the

multi-peak distribution, which generates the "iterative background". Therefore, in order to obtain a reasonable background value, combined with the previous research results, it is more effective to use the iterative statistical method of probability distribution test to obtain the background value and the lower limit of anomaly. Thus, the characteristic parameters of anomalous zones of each index of hydrocarbon geochemistry are obtained (Table 1).

In summary, it is obtained that: (1) the background value of soil acid hydrocarbon components in the background area of Dailekh survey area has the characteristics of: $CH_4 > C_2H_6 > C_3H_8$; (2) the background value of post-generation carbonate (ΔC) has a large difference in the background area, and is characterized by I area > II area > III area; (3) the background value of adsorbed phase mercury (Hg) has a small difference between I and III area, and has a larger value in the background area of II, and overall. The background value is characterized by II area > I area > III area. The differences and patterns of change of background values and lower limits of anomalies of different indicators in each background area reflect that different geological tectonic units form three independent geochemical background fields, and the background values of post-generation carbonate and adsorbed-phase Hg show significant differences.

4.2. Background Values and Lower Limits of Anomalies for Hydrocarbon Geochemical Anomalies

4.2.1. Distribution Characteristics of Soil Acid Hydrocarbon Anomalies

The methane and propane anomalies in the whole region have formed 4 anomalous areas with more concentrated anomalies, which are coded as No.I, No.II, No.III and No.IV anomalous concentration zones, while the ethane anomalies have formed 3 anomalous areas with more concentrated anomalies, which are coded as No.I, No.II and No.III anomalous concentration zones, and the anomalous zones have been characterized as halo structure in the middle and at

the top of the ring (Table 2).

Table 1. Characteristic parameters of anomaly zoning for various indicators of hydrocarbon geochemistry

Index	Geochemical zoning	Background value	Standard deviation	Threshold value	Abnormal concentration zoning			Unit
					Abnormal outer band	Abnormal middle band	Abnormal inner band	
Methane	Not zoning	4.617	1.736	8.090	8.090-11.56	11.56-15.03	>15.03	μl/kg
Ethane	Not zoning	0.350	0.224	0.800	0.800-1.244	1.244-1.691	>1.691	μl/kg
Propane	Not zoning	0.208	0.154	0.516	0.516-0.824	0.824-1.130	>1.130	μl/kg
Isobutane	I,II	0.035	0.035	0.083	0.083-0.153	0.153-0.222	>0.222	μl/kg
	III	0.036	0.024	0.067	0.067-0.116	0.116-0.165	>0.165	
N-butane	I,II	0.120	0.148	0.320	0.320-0.616	0.616-0.912	>0.912	μl/kg
	III	0.113	0.111	0.260	0.260-0.481	0.481-0.702	>0.702	
Isopentane	I,II	0.029	0.031	0.071	0.071-0.132	0.132-0.194	>0.194	μl/kg
	III	0.029	0.027	0.065	0.065-0.199	0.119-0.174	>0.174	
Pentane	I,II	0.073	0.070	0.164	0.164-0.304	0.304-0.443	>0.443	μl/kg
	III	0.076	0.061	0.155	0.155-0.276	0.276-0.397	>0.397	
Ethylene	I,II	1.203	1.040	2.573	2.573-4.654	4.654-6.735	>6.735	μl/kg
	III	1.171	0.820	2.229	2.229-3.868	3.868-5.507	>5.507	
Propylene	I,II	0.613	0.660	1.477	1.477-2.98	2.798-4.188	>4.118	μl/kg
	III	0.541	0.415	1.074	1.074-1.905	1.905-2.736	>2.736	
Metagenetic carbonate	I	0.938	0.481	1.42	1.42-1.90	1.90-2.38	>2.38	%
	II	0.739	0.387	1.126	1.126-1.513	1.513-1.90	>1.90	
	III	0.518	0.290	0.80	0.80-1.09	1.09-1.38	>1.38	
Absorbed mercury	I	3.874	3.054	9.98	9.98-16.09	16.09-22.20	>22.20	10 ⁻⁹
	II	5.161	3.380	11.92	11.92-18.68	18.68-25.64	>25.64	
	III	3.709	1.701	7.11	7.11-10.50	10.50-13.90	>13.90	
Electric conductivity	Not zoning	3.75	1.05	4.80	4.80-5.85	5.85-6.90	>6.90	μc/km

From Table 2, it can be seen that the size order of anomaly mean and average lining in the four anomaly concentration areas is basically III>IV>II>I, showing good consistency. As for the anomalous maximum value and maximum lining, CH₄, C₂H₆ and C₃H₈ are different.

4.2.2. Characterization of the Distribution of Soil Post-Growth Carbonate (ΔC) Content

The anomaly parameters of the four anomaly groups of ΔC are shown in Table 3. On the whole, the ΔC anomalies and hydrocarbon anomalies have good similarity, but there are also obvious differences, and the soil post-growth carbonate (ΔC) anomalies in the whole region form four anomalies with

more concentrated anomalies, and some of the ΔC anomalies are more sporadic than the hydrocarbon anomalies, and the strength of the anomalies is also much lower. Due to the poor continuity of the anomalies, it is difficult to see the obvious anomaly group boundaries of ΔC in some areas, and some areas with hydrocarbon anomalies have ΔC anomalies. In order to facilitate the correspondence with hydrocarbon anomalies I, II, III and IV anomalies concentration areas, ΔC anomalies are also coded as I, II, III and IV anomalies concentration areas respectively (concentration areas), but the anomalies of the ΔC are obviously inferior to hydrocarbon anomalies in terms of their scale, continuity and anomalies intensity.

Table 2. Characteristic parameters of hydrocarbon anomalies in Dailekh area block

Index	Anomalous group	Abnormal points	Anomaly	Abnormal average/abnormal maximum	Coefficient of variation	Anomalous average lining/anomalous maximum lining
CH ₄	I	North western part of the survey area	57	12.78/28.99	0.41	1.58/3.58
	II	West central part of the survey area	72	14.40/42.42	0.53	1.78/5.24
	III	Eastern part of the survey area	7	26.37/41.64	0.41	3.26/5.15
	IV	Eastern part of the southern part of the survey area	8	20.87/30.04	0.29	2.58/3.71
C ₂ H ₆	I	North western part of the survey area	53	1.90/5.50	0.60	2.37/6.88
	II	West central part of the survey area	69	2.19/6.89	0.63	2.74/8.61
	IV	Eastern part of the southern part of the survey area	8	3.40/5.72	0.48	4.25/7.15
C ₃ H ₈	I	North western part of the survey area	62	1.11/3.58	0.62	2.16/6.93
	II	West central part of the survey area	81	1.26/4.41	0.68	2.45/8.55
	III	Eastern part of the survey area	7	2.79/4.55	0.44	5.41/8.83
	IV	Eastern part of the southern part of the survey area	10	2.05/3.87	0.54	3.96/7.51

Table 3. Characteristic parameters of non-hydrocarbon anomalies in Dailekh area block

Index	Anomalous group	Abnormal points	Anomaly	Abnormal average/abnormal maximum	Coefficient of variation	Anomalous average lining/anomalous maximum lining
Hg	I	Northwestern part of the survey area	13	40.97/96.93	0.66	5.76/13.63
	II	Northwest central part of the survey area	14	79.18/940.5	3.13	11.14/132.28
ΔC	I	Northwest part of the survey area	28	1.53/4.38	0.49	1.37/3.91
	II	Western part of the survey area	29	1.25/2.61	0.37	1.56/3.26
	III	Northeast part of the survey area	24	1.75/3.11	0.33	1.23/2.19
	IV	Southwestern portion of the survey area	25	1.60/4.33	0.51	2.0/5.41
Ks	I	Northwest part of the survey area	36	6.77/21.00	0.40	1.41/4.375
	II	Western part of the survey area	41	6.90/11.55	0.256	1.44/2.41
	III	North central part of the survey area	20	6.40/10.61	0.21	1.33/2.21
	IV	Southern part of the survey area	21	6.93/17.46	0.4	1.44/3.64

Among the ΔC anomalies, the I and II anomaly clusters have a high degree of agreement with the hydrocarbon anomaly clusters, and are located in the northwest and west of the survey area, indicating that the I and II zones have the potential to search for hydrocarbons. Anomalies No. III and No. IV do not match with the hydrocarbon anomaly group, indicating that the hydrocarbon field in the No. III and No. IV areas belongs to the low abundance background field, with relatively high degree of oil and gas fugitive and poor preservation conditions.

4.2.3. Characterization of Anomalous Distribution of Soil Pyrogenic Mercury (Hg) Content

The characteristic parameters of the Hg anomalies are shown in Table 3, from which it can be seen that the two anomalies in the Hg concentration area are all II>I. On the whole, the Hg anomalies are similar to the hydrocarbon and ΔC anomalies, but also have great differences. The similarity is manifested in the macroscopic features: that is, the Hg anomaly can be roughly divided into two anomaly concentration areas, located in the central and western parts of the country. The differences are more prominent, and the Hg anomalies can only map two anomaly clusters, while the rest of the individual anomaly blocks are more scattered, failing to be divided into obvious concentration boundaries.

4.2.4. Characterization of Soil Conductivity (Ks) Distribution

The anomalous parameters of the four anomaly groups of Ks are shown in Table 3. On the whole, the Ks anomalies and hydrocarbon anomalies have good similarity, but there are obvious differences, the soil conductivity (Ks) anomalies in the whole region form four anomalies more concentrated anomalies, and some of the Ks anomalies are more sporadic than the hydrocarbon anomalies, and the strength of the anomalies is also much lower. Due to the poor continuity of the anomalies, it is difficult to see the obvious anomaly group boundaries of Ks in some areas, and some areas with hydrocarbon anomalies have Ks anomalies. In order to facilitate the correspondence with hydrocarbon anomalies I, II, III and IV anomalies concentration areas, Ks anomalies are also organized as I, II, III and IV anomalies concentration areas, respectively. However, the anomalies of Ks are not as big as hydrocarbon anomalies in terms of scale, continuity and strength.

The anomaly concentration areas of Ks No.I and No.II have high degree of integration with hydrocarbon anomalies and are located in the northwestern and western parts of the survey area, indicating that No.I and No.II have better potential for finding hydrocarbons; while the anomaly concentration areas

of No.III and No.IV do not integrate with hydrocarbon anomalies, and the hydrocarbon indexes have not formed obvious anomaly groups there, which indicates that underground hydrocarbon sources are not abundant in the area or the preservation conditions are poor.

4.3. Comprehensive Anomaly Evaluation

4.3.1. Anomaly Area Delineation

Geological conditions are indispensable for the generation, transportation, aggregation and preservation of hydrocarbons. The hydrocarbon geochemical anomalies caused by oil and gas are closely related to the geological conditions and are evaluated by synthesizing the geology and various indicators (elements). Tectonically the Dailekh region of Nepal can be divided into Dailekh region tectonically located mainly in the High Himalayan Belt, Low Himalayan Belt and Sub-Himalayan Belt (Sivalik Belt). Among the lithologies within the hydrocarbon geochemical survey are mainly Precambrian metamorphic rocks. Combined with the analysis of the plane distribution characteristics, combination patterns and causes of the 12 indicators of soil acid hydrocarbon, soil post-generated carbonate (ΔC), soil adsorbed phase mercury (Hg), and soil conductivity (Ks), the methane anomalies are preferably selected as 4 favorable zones, ethane anomalies as 3 favorable zones, propane anomalies as 4 favorable zones, soil post-generated carbonate (ΔC) anomalies as 4 favorable zones, and adsorbed phase mercury (Hg) anomalies as 4 favorable zones. (ΔC) anomalies, two favorable zones for adsorbed mercury (Hg) anomalies, and four favorable zones for conductivity (Ks) anomalies.

The oil and gas reservoir is complex geologic body, containing rich hydrocarbon components and associated components. Due to the similarity in the origin of the components and the same geological process, regular ring anomalies and top anomalies are formed on the surface above the oil and gas reservoir. Therefore, the complete combination of each index anomaly, complete morphology and structure, and high degree of coincidence are the important features of chemical exploration anomalies above oil and gas reservoirs. Based on the determination of the degree of coincidence of indicators in the oil and gas geochemical anomaly map of Dailekh work area, two favorable zones of oil and gas anomalies can be circled in Dailekh area, which are No.I and No.II favorable zones, respectively.

In the study area, the comprehensive mapping of each index (Figure 3) shows that the hydrocarbon anomalies of No. I favorable area are characterized by ring-in-ring anomalies, with a large range of top halo, which is mainly concentrated in the north-central part of the anomalous area, but the

anomaly intensity is not high, and is mainly dominated by low and medium-value anomalies, and the high-value anomalies only have one ethane and two propane, and the area of the high-value anomalies is relatively small; and the hydrocarbon anomalies of No. II favorable area are characterized by ring-in-ring anomalies in the planar surface. Among the non-hydrocarbon indicators, ΔC anomaly and Ks anomaly are more consistent with hydrocarbon anomalies and are ring anomalies, and the anomalies are displaced on the surface due to the disturbance of tectonic activities; Hg anomaly is a halo

anomaly at the top, and it is integrated in hydrocarbon ring anomalies. Therefore, the correspondence between the indicators (elements) in the anomaly concentration area No. I and the favorable area No. II indicates that the non-hydrocarbon indicator anomalies are closely related to the hydrocarbon indicator anomalies; the extensive development of all the indicator (elemental) anomalies in the two anomaly concentration areas indicates that there are extensive oil and gas activities in the area, which has a good prospect of oil and gas searching.

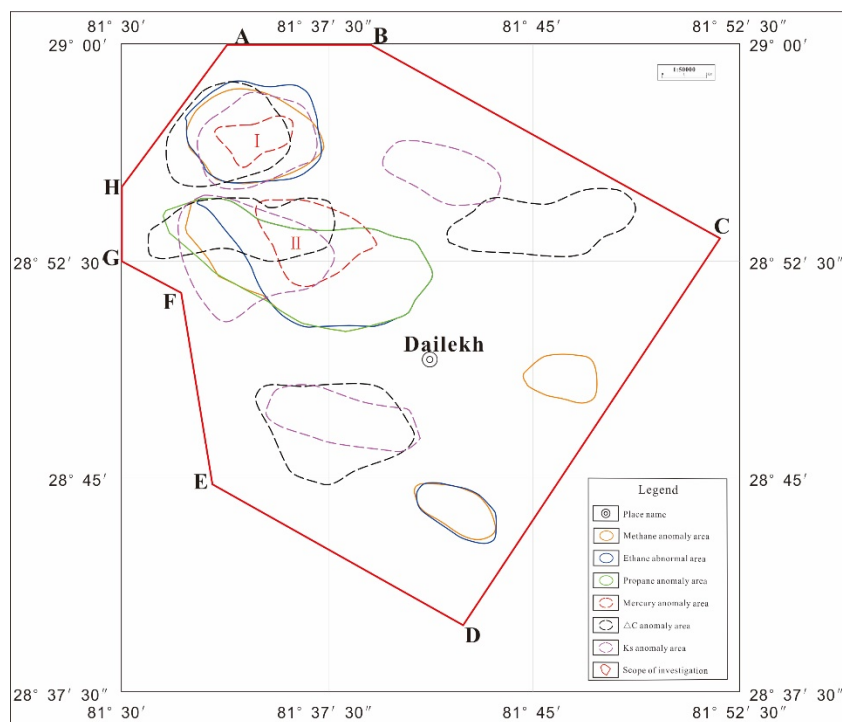


Figure 3. Composite anomaly map of Dailekh district, Nepal

4.3.2. Analysis of Anomaly Causes

(1) Analysis of hydrocarbon anomaly cause types

Statistical analysis of anomalies higher than the lower limit of anomalies shows that anomalies in the work area are formed both by the escape of underground hydrocarbons to the surface, and some of the anomalies are caused by inorganic or biological genesis, but they are mainly formed by the escape of underground hydrocarbons to the surface, and it can be concluded that there are underground hydrocarbon reservoirs in the work area. As different sources of hydrocarbons transported to the surface, will form different forms. If the hydrocarbons diffuse from the reservoir to the surface, they usually form a ring or semi-ring halo on the surface, and if the oil and gas are transported to the surface along the fractures, they are mostly distributed along the faults and are in the form of strips; if the hydrocarbons of inorganic or biological causes form anomalies on the surface, they are mostly in disordered and irregular forms.

(2) Analysis of raw carbonate genesis types

The anomalous characteristics of soil post-generation carbonate (ΔC) reflect the formation and evolution of the reservoir to a certain extent. The distribution of soil-derived carbonate (ΔC) anomalies is mainly along the periphery of the work area, and the anomalous features are not obvious in the central area. This is mainly due to the fact that the tectonic structure around the working area is more developed, and the fractures and cracks are more developed, which is conducive

to the upward diffusion of hydrocarbons and the formation of more post-growth carbonate, while the central part of the area has a slower diffusion rate due to better preservation conditions, and the area is undergoing the Himalayan period of reversed thrusting and overturning, and the bottom of the hydrocarbons are shorter than the time of transporting to the surface, and the cumulative effect of post-growth carbonate is poor, which results in post-growth carbonate anomalies of the area with better preservation conditions. The result is that the post-generation carbonate anomaly is weak in areas with good preservation conditions.

(3) Analysis of the types of causes of mercury

The morphology of mercury anomalies caused by oil and gas reservoirs is closely related to the morphology of oil and gas reservoirs, which are mostly round and oval, and usually form the top of the ring with the hydrocarbon ring anomalies. Mercury anomalies formed by fractures are related to the fracture patterns, mostly distributed along the fractures, and if there are hydrocarbons escaping along the fractures, they mostly coincide with the hydrocarbon anomalies. Mercury anomalies caused by strata are related to the lithology of the strata, and there is no obvious rule for the anomaly pattern, mostly spreading along the strata. Through the statistical analysis of mercury anomalies in the working area, the average value of anomalies in different layers in the working area varies greatly, but the influence of soil properties is not obvious. The anomalies in the working area are formed by oil

and gas reservoirs and strata, and the strata is one of the important factors affecting the mercury anomalies.

(4) Analysis of the types of conductivity causes

The range and intensity of conductivity anomalies reflect the connection between the surface and the subsurface, and to a certain extent, the underground oil and gas preservation conditions in the region. Fracture zones are prone to form strip-like and sheet-like anomalies due to the direct transport of highly mineralized groundwater to the surface. In the oil field water area, due to the better closure of the stratum, its anions and cations form anomalies in the electromagnetic field, concentration difference, pressure difference, and with a small amount of groundwater infiltration to the surface, which are mostly ring-shaped and semi-ring-shaped. It can be seen that the conductivity anomalies in the working area are in the form of rings and bands, which are mainly caused by the combined effects of faults and oil and gas reservoirs. The anomalies in the central part of the working area are weaker than those in the peripheral part of the working area, which reflect that the preservation conditions in the peripheral part of the working area are poorer than those in the central part.

4.3.3. Identification of the Causes of Anomalies

Discriminate the attributes of oil and gas chemical exploration anomaly genesis based on cluster analysis method and hydrocarbon ratio method.

(1) R-type cluster analysis method

Hydrocarbons are transported upward from oil and gas reservoirs, and since the hydrocarbon sources are the same and the transportation channels are consistent, the hydrocarbons usually maintain a high correlation when anomalies are formed on the surface. Therefore, based on the magnitude of correlation coefficient and R-type clustering spectrogram of each indicator, the affinity relationship between indicators can be determined, and the surface anomalies can be preliminarily determined whether the anomalies are related to oil and gas activities or not. We performed R-type clustering analysis on six indicators, including C1, C2, C3, Hg, ΔC and Ks, in the three anomalous favorable areas identified, and the results are shown in Figure 4 and Table 4.

From the figure, it can be seen that these anomalous favorable zones have the following clustering characteristics: the correlation coefficients among the indicators of C1, C2 and C3 in the anomalous favorable zones of No. I and No. II are high, ranging from 0.939 to 0.993, and obviously clustered into one group, indicating that hydrocarbon components have a common parent source, i.e., hydrocarbon activities in the deep subsurface; and ΔC in the anomalous favorable zones of No. I and No. II have a close relationship with Ks (Table 4).

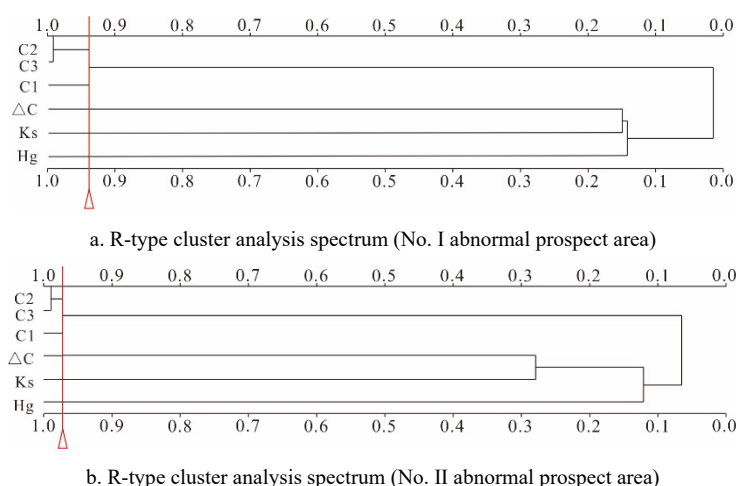


Figure 4. R-type correlation map of favorable zones I and II in Dailekh work area, Nepal

(2) Hydrocarbon ratio method

There are large differences in the hydrocarbon composition of hydrocarbons of different genesis in the subsurface, and the hydrocarbon compositions of the same type of genesis are more similar, so by statistically analyzing the ratio of hydrocarbon compositions, we can determine the genesis type and source of hydrocarbons.

To identify the genesis of soil acid hydrocarbon anomalies, the relationship between the humidity coefficient and CH_4/C_2H_6 , $C_3H_8/CH_4 \times 100$, $CH_4/(C_2H_5 + C_3H_8)$ was plotted (Figure 5), and the anomalies can be clearly seen in the figure are mainly located in the red circle, which belongs to Oil type oil, gas; the anomalies are basically in the Inorganic There is no distribution of genetic gas, Coal-type gas or biogenic gas, so the cause of soil acid hydrocarbon anomaly identification belongs to Oil type oil, gas.

Table 5 shows the table of hydrocarbon genesis parameters in the known areas and the average values of anomaly parameters of Dailekh work area I and II in Nepal.

From Table 5, it can be seen that the dryness coefficients of the anomalous favorable areas of Dailekh working area No. I and No. II in Nepal are 62.2 and 59.8 respectively, ranging from 50 to 75, and the humidity coefficients are 37.80 and 40.18 respectively, ranging from 25 to 50, and the values of the cyclic coefficients of methane/ethane, propane/methane, and methane/(ethane+propane) are within the range of the values of the oil-type oil and gas. Therefore, it is assumed that the anomalous favorable area of No.I and No.II are oil-type oil and gas reservoirs.

5. Conclusion

Based on the comprehensive analysis of 12 indicators, including soil acidolytic hydrocarbons (including methane, ethane, propane, ethylene, propylene, n-butane, isobutane, isopentane, n-pentane), post-generated carbonate (ΔC), conductivity (Ks), and adsorbed phase mercury (Hg), it is found that the hydrocarbon geochemical anomalies in the

Dailekh region of Nepal are characterized by significant correlation between the various indicators. The specific

conclusions are as follows:

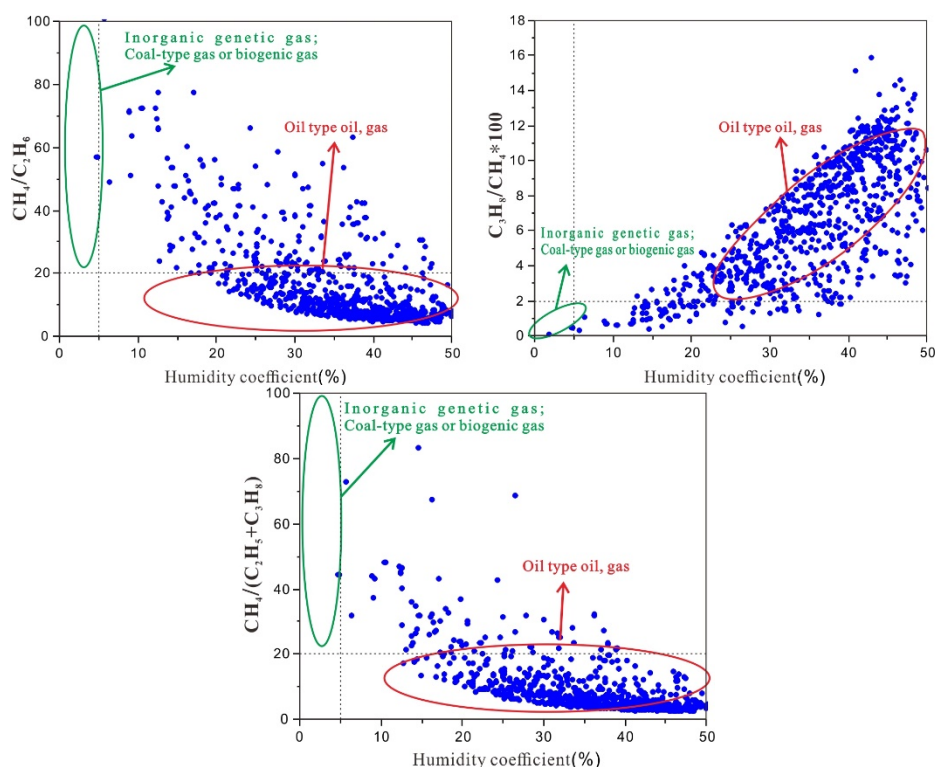


Figure 5. Identification of the causes of soil acid hydrocarbon anomalies

Table 4. R-type cluster analysis results table

Abnormal favorable block	Related indicators				
	C2-C3	C1-C2	ΔC-Ks	Hg-ΔC	Ks-C1, C2, C3
I	0.993	0.939	0.151	0.142	0.016
II	0.989	0.970	0.277	0.121	0.063

Table 5. Comparison of deep hydrocarbon attributes of Dailekh anomaly favorable zone with hydrocarbon genesis parameters of known zones

Type		Geochemical genesis kinetic parameters of oil and gas					Genetic types of oil and gas reservoirs
		Dry coefficient (%)	Humidity coefficient (%)	Methane/ethane	Propane/methane (%)	Methane/ (ethane + propane)	
Genesis parameters of oil and gas in known area		>95	<5	20-100	0.2-2.0	20-100	Inorganic genetic gas
							Coal-type gas or biogenic gas
		75-95	5-25	10-20	2-6	10-20	Oil type oil, gas
Dailekh		50-75	25-50	4-10	6-50	4-10	
	I	62.2	37.80	7.45	9.22	4.51	Oil type oil, gas
	II	59.8	40.18	6.69	10.11	4.04	Oil type oil, gas

(1) By analyzing the anomalous consistency of each indicator, two anomalous zones were identified, which are located in the northwestern and central-western parts of the survey area. Comprehensively analyzing the characteristics of these two anomalous areas, the anomalies of each index show the ring-medium top halo characteristics, especially the mercury shows the weak ring-strong top halo characteristics. These anomalies reflect the real geochemical activity information of the reservoir.

(2) The results strongly prove the validity of the 12 indicators of four methods: soil acid hydrocarbon, post-generation carbonate, electrical conductivity and adsorbed phase mercury. This combination of hydrocarbon geochemical indicators is validated as an effective exploration technique and sampling method for hydrocarbon geochemical surveys in the Dailekh area of Nepal.

(3) The anomalies of each indicator are widely distributed in two anomaly concentration areas. Combined with the analysis of anomaly genesis types, it is found that these anomalies are mainly formed by the escape of underground oil and gas to the surface. By identifying the genesis attributes of the hydrocarbon geochemical anomalies through the cluster analysis method and hydrocarbon ratio method, it is presumed that the favorable areas of anomalies No. I and No. II are oil-type oil and gas reservoirs, which indicates that the area has good prospects for hydrocarbon exploration.

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References

- [1] W. J. Duchscherer, "Geochemical methods of prospecting for hydrocarbons," *oil & Gas Journal*, vol. 78, no. 48, pp. 194-208, 1980.
- [2] G.Z. Li, H.J. Yin, Z.Y. Yuan, et al., "Petroleum Geological Significance of Five Occurrence Modes of Light Hydrocarbon in Related Oil and Gas Reservoirs in China," *Geophysical and Geochemical Exploration*, vol. 34, no. 6, pp. 772-777, 2010.
- [3] J.M. Song, W. Li, B. Hu, "Identification of aromatic hydrocarbon in oil and gas geochemical exploration," *Geophysical and Geochemical Exploration*, vol. 30, no. 1, pp. 45-47, 2006.
- [4] W. Xie, Y. Gao, P. Han, "Application of multi-objective geochemistry data to oil and gas exploration: A case study of the oil field in Yanchi County of Ningxia," *Geology and Exploration*, vol. 47, no. 3, pp. 524-530, 2011.
- [5] Z. C. Chen, T. J. Cheng, Y. P. Tang, "Application results of oil and gas geochemical technique in oil and gas exploration in Tarim Basin," *Natural Gas Geoscience*, vol. 16, no. 1, pp. 59-63, 2005.
- [6] X. D. Suo, D. Y. Yu, "Application of geochemical exploration in the on-going development of Dawanqi oil field, Xinjiang, China," *Natural Gas Geoscience*, vol. 16, no. 1, pp. 64-68, 2005.
- [7] P. Yang, F. W. Tan, M. F. Shi, "Oil source correlation and hydrocarbon accumulation in the Lesser Himalayan belt of Nepal," *Acta Geologica Sinica*, vol. 95, no. 11, pp. 3426-3441, 2021.
- [8] F. W. Tan, P. Yang, Z. H. Wang, "Petroleum geological conditions in Dailekh area, western Nepal," *Sedimentary Geology and Tethyan Geology*, vol. 40, no. 3, pp. 87-95, 2020.
- [9] W. J. Stahl, "Compositional changes and $^{13}\text{C}/^{12}\text{C}$ fractions during the degradation of hydrocarbons by bacteria," *Geochimica et Cosmochimica Acta*, vol. 44, pp. 1903-1907, 1980.
- [10] Department of Mines and Geology of Nepal and Petro-Canada, *Hydrocarbon Prospecting Assessment of Southern Nepal*, 1993.
- [11] Z. Q. Xu, J. S. Yang, H. B. Li, "On the tectonics of the India-Asia Collision," *Acta Geologica Sinica*, vol. 85, no. 1, pp. 1-33, 2011.
- [12] P. Copeland, T. M. Harrison, K. V. Hodges, "An Early Pliocene thermal disturbance of the main central thrust, central Nepal: Implications for Himalayan tectonics," *Journal of Geophysical Research*, vol. 96, pp. 8475-8500, 1991.
- [13] P. G. DeCelles, D. M. Robinson, J. Quade, "Stratigraphy, structure, and tectonic evolution of the Himalayan fold-thrust belt in western Nepal," *Tectonics*, vol. 20, no. 4, pp. 487-509, 2001.