Research and Application of New Methods to Oil-Gas Geochemical Exploration

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Abstract Based on the results of researches and applications for many years, it has been discovered that new methods and techniques for geochemical exploration of oil and gas such as ΔC, altered carbonate, Hg in absorption phase, Ks, Fe^{2+}, $\delta^{13}C$, fluorescence in two and three dimensions, and N_2 and O_2 in heat release can give full play in the following five fields: (1) optimization of the favourable target or hollow zones and structural zones in a region; (2) evaluation of oil traps and delineation of prospective oil and gas areas; (3) prediction of deep-seated oil-bearing horizons; (4) evaluation of the genesis of oil and gas geochemical anomalies and determination of the types of oil and gas accumulations; (5) forecast of the burial depths of oil and gas pools.

Key words: geochemical exploration for oil and gas, new method, field of application

1 Introduction

Oil-gas geochemical exploration, as a non-seismic exploration technique, has aroused great interest to petroleum geologists for its advantages of rapidness, effectiveness and economy, and has been arranged in the procedure of regional oil and gas reconnaissance and exploration by many countries (Li et al., 1994; Zhao Yongjun, 1994). After having studied its applications to more than sixty districts of thirteen petroliferous basins (Du et al., 1998; Zhao Changyi et al., 1998; Zhao Wenzhi et al., 1999; Zhou Jingao et al., 1999), it was discovered that new geochemical methods such as ΔC and Hg in absorption phase, Ks, Fe^{2+}, $\delta^{13}C$, fluorescence in two and three dimensions, and N_2 and O_2 in heat release can give full play to the following fields of oil and gas exploration.

2 Optimization of Advantageous Target or Hollow Zones and Structural Zones in a Region

In some poorly studied basins or large depressions, after comparisons with the average content, deviation, percent anomaly and average contrast of different indicators of hydrocarbons, ΔC and Hg in the absorption phase, Ks and Fe^{2+} among hollow zones and structural zones in regional cross sections, some advantageous target or hollow zones and structural zones can be selected.

For example, the Linqing depression, located west of the Shengli oil field with an area of 18,000 km^2, consists of 18 second-order structural units (6 hollow units, 9 structural zones and 3 raised units, see Fig. 1). Since 1958, many geologic and seismic surveys and more than 30 exploratory wells have been finished in that region by Shengli Petroleum Administrative Bureau. But, a great breakthrough has not been made because of the complexity of tectonics, the variability and small size of trap structures and reservoirs. So, we decided to carry out a regional oil-gas geochemical exploration in that region in 1993. The results are shown in Tables 1 and 2. The comprehensive evaluation is based on the geochemical and geologic indicators. Values of the former are obtained by normalization of the variation characters of the component average content, variance, anomaly percentage and average contrast; those of the latter are based on the area of the hollow zones, thickness of the dark-coloured mudstones and maximum burial depths of the major source rocks. It is clear from the tables that (1) based on geochemical exploration, among the six hollow

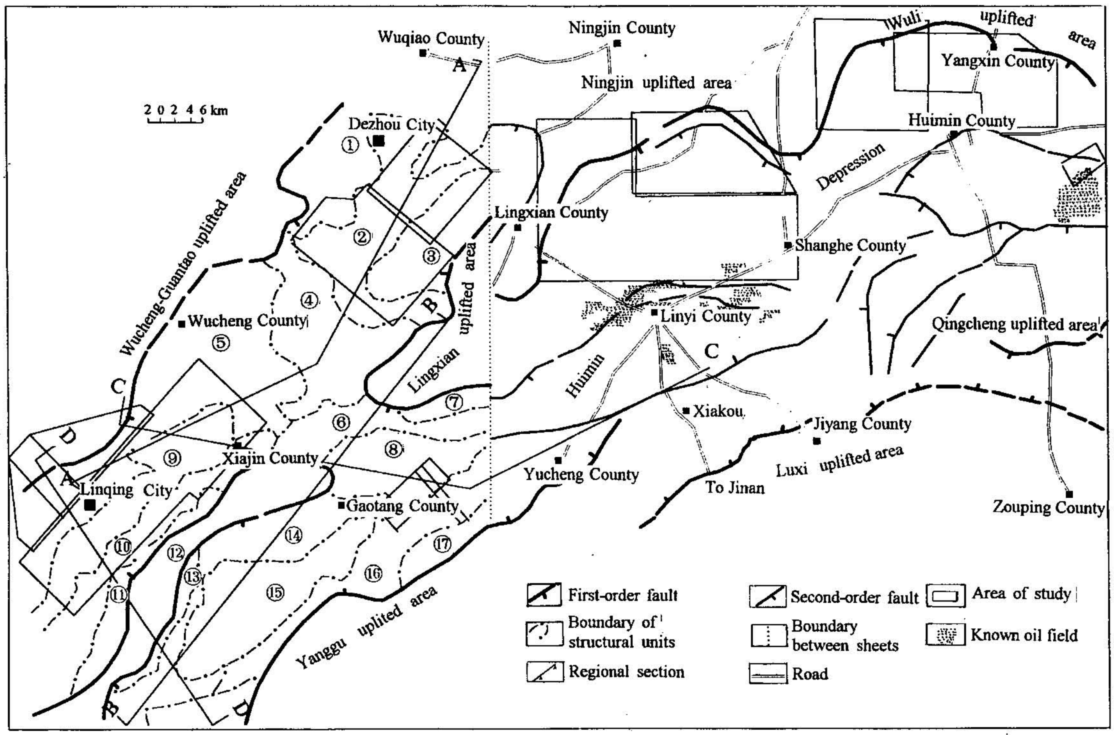

Fig. 1. Structural sketch map of the Linqing-Yangxin area of Shandong province in China.
① Bixuedian structural zone; ② Denan-Kongzhuang hollow zone; ③ Huanglukou structural zone; ④ Encheng structural zone; ⑤ Wunan-Linqing hollow zone; ⑥ Yaozhan-Suji hollow zone; ⑦ Xiaozhuang structural zone; ⑧ Dachengzhuang structural zone; ⑨ Xujiayingzi structural zone; ⑩ Xiajin-Guanxian hollow zone; ⑪ Guanxian structural zone; ⑫ Gaotang-Tangyi buried hill zone; ⑬ Tangyi structural zone; ⑭ Shenzhuang-Liangshuizhen hollow zone, ⑮ Jiangdian structural zone; ⑯ Yucheng-Yangguantun hollow zone; ⑰ Anren structural zone.

units of the Linqing depression, the Wunan-Linqing and Xiajin-Guanxian hollow zones have higher scores; the next is the Yucheng-Yangguantun hollow zone. (2) In the Xiakou area which has known oil and gas fields, all indicators of hydrocarbons or non-hydrocarbons have higher scores, but the indicators of hydrocarbons have higher scores and those of non-hydrocarbons have lower scores in the area of oil reservoirs of the Wells De-1 and Jia-2. This means that the score of hydrocarbons indicator should be taken as the main factor in evaluating the favourable structural zones in that region. (3) Among the structural zones, those with higher scores of hydrocarbons indicators are: the Gaotang-Tangyi buried-hill zone, the East Guanxian fault structural zone, and the Encheng, Xujiayingzi and Bixuedian structural zones. But spatially, the better hollow zones and structural zones that are bordering on each other and can constitute a favourable source-reservoir caprock association are the Wunan-Linqing hollow zone and Xujiayingzi structural zone. Therefore, this district is believed to be the best area for oil and gas accumulation in the Linqing depression. Petroleum geologists were greatly interested and carried out, regional geochemical reconnaissance in that district during 1994 to 1995. Consequently, three large prospects were delineated, which are located in the Baimahu area in the northwest part of the Xujiayingzi structural zone and around Linqing City in the central-west part. In recent years, the exploration department was arranging detailed three-dimensional seismic prospecting in these prospect areas, and there is the hope to make great a breakthrough for oil and gas exploration in the Linqing depression.

3 Evaluation of Oil Traps and Determination of Prospective Oil and Gas Areas

This work has been conducted extensively both at home and abroad. But because of the differences in the indicators, the way of work, the anomaly patterns

Table 1 Comprehensive evaluation results of different hollow zones of the Linqing depression

Name of hollow zones	Geochemical indicator			Geologic indicator		Synthetic score
	H	NH	H+NH	Basic value	Score	
Wunan-Linqing	60.00	27.0	87.00	0.714	81.04	84.2
Xiajin-Guanxian	54.99	31.99	86.38	0.083	9.42	47.9
Denan-Kongzhuang	41.54	19.03	60.57	0.329	37.34	48.96
Shenzhuang-Liangshuizhen	34.87	19.33	54.20	0.589	66.86	60.53
Yaozhan-Suji	41.34	22	63.34	0.263	29.85	46.60
Yucheng-Yangguantun	38.74	33.03	71.77	0.881	100	85.89

Notes: H–hydrocarbons score, NH–non-hydrocarbons score.

Table 2 Comprehensive evaluation results of second-order structural units of the Linqing depression

Name of second-order structural units	H	NH	H+NH
Xujiayingzi	43.74	25.94	69.68
Encheng	46.43	26.52	72.95
Bixuedian	42.05	29.42	71.47
East GuanXian fault	47.81	26.48	74.29
Zhangluji	38.07	38.30	76.37
Jiangdian	39.61	20.42	60.03
Dachengzhuang	30.81	24.64	55.45
Gaotang-Tangyi buried hill	49.15	23.97	73.12
Guantao rise	31.36	40.00	71.36
Yanggu rise	29.02	22.82	51.84
Lingxian rise	38.23	32.18	67.41
Xiakou	46.86	37.85	84.71
Oil pool of Well De-1	43.75	21.42	65.17
Oil pool of Well Jia-2	45.44	18.73	64.17

Notes: H–hydrocarbons score, NH–non-hydrocarbons score.

and evaluation procedures used by different countries or research teams, and their different understanding to the genesis of the anomalies and the relationship between different indicators, the evaluation effects are varied.

After many years of practice, we believe that the oil-gas-bearing structures, traps and prospective areas can be determined on the basis of synthetic anomaly patterns of different types of oil and gas pools and by analyzing the anomalous characteristics of different indicators, the linear correlation among hydrocarbon components, the upward and downward relationship between hydrocarbons and ΔC (derived carbonate) and by comparing the anomaly patterns.

For instance, in the Baimamiao region of Sichuan basin, some good geochemical anomalies of oil and gas have been discovered by geochemical exploration. After evaluation of these anomalies by using the above-mentioned method, we believed these anomalies were caused by underground oil-gas accumulation and defined the prospective areas of oil and gas. Since 1995, the exploration department has drilled a number of wells to testify those geochemical prospective areas, and a large gas-field has been discovered in Baimamiao, which has natural gas reserves of $338\times10^9 m^3$ in deep level and $245.01\times10^9 m^3$ in shallow layers in an area of 80 km^2.

4 Predication of Deep-seated Oil-bearing Horizons

Researches in this field are few. After studies of many years, we have found that it is possible to prognosticate deep-seated oil-bearing horizons based on analyzing the characteristics of different components or indicators (including concentrations and various ratios) of vertical sections of drill holes and comparing the anomaly patterns.

For example, we consider that there are gas-bearing formations both in the Penglaizhen Formation in the upper part of the hole and in the Shaximiao Formation in the lower part after making analysis of the variation of different indicators of Well Song-1 of the Sichuan basin. The result of drilling verified our conclusions.

In the Penglaizhen Group (at depths of 800–1034 m) a commercial gas flow of 2.4×10^4 m^3 per day was obtained and in the Shaximiao Group (at depths of 2200–2400 m) good commercial gas flow was found.

5 Evaluation of Oil-Gas Geochemical Anomaly Genesis and Definition of Oil-Gas Pool Types

This work is a key step for oil and gas geochemical exploration. Its goal is to sift out the anomaly information concerned with oil-gas pools, distinguish and reject useless interfering anomalies, and make clear the distribution of oil and gas and to provide reliable geochemical base for oil and gas exploration.

The following techniques have been used:

(1) Linear correlation analysis of hydrocarbon constituents

As a direct index to indicate oil-gas pools—the constituents of hydrocarbon compounds have the closest relationship with oil-gas pools. The constituents of hydrocarbon compounds which came from oil-gas pools, although quite different in content, have undergone the same process of geology and evolution when they accumulated to form an oil-gas pool, migrated to the surface and dispersed to the wall rocks. Therefore, there is a particular proportional relationship among these constituents an obvious linear correlation. If there are some gases from other sources (such as from coal, biological degradation and artificial pollution) to enter, the original relationship would be broken, the linear correlation would be weakened, or even lost. Therefore, the genesis of oil-gas geochemical anomalies can be determined by using this technique.

(2) Isotope analysis of methane

Because of the isotopic fractionation of carbon, the $\delta^{13}C$ values are varied for the oil and gas of different genetic types and different development periods. Thus the isotope analysis of methane has been widely used to determine the genesis of hydrocarbons.

It needs to point out that the conditions of source-reservoir-caprocks association and the surface geochemical background of different basins are varied, and so are the isotopic composition and isotopic exchange reactions of carbon. Therefore, when determining the genesis of hydrocarbons, it is necessary to compare with the classic $\delta^{13}C$ values of hydrocarbons of different geneses, but it is more important to compare with the $\delta^{13}C$ values of known oil fields in the same basin or similar regions.

(3) Three-dimensional fluorescence spectrum analysis

The three-dimensional fluorescence spectrum analysis is a new technique developed in the 1980s, which is used to detect aromatic hydrocarbons. The aromatic hydrocarbons are one of the main constituents of oil. Their contents in oil-gas pools are the second highest, only next to those of paraffin alkane and nepthene. Aromatic hydrocarbons and their derivations have a large π link, and the three-dimensional fluorescence spectrum can detect it easily. The constituents of tested samples can be shown by an isogram consisting of Ex (excitation wavelength), Em (emission wavelength) and fluorescence intensity, or described digitally in a qualitative and quantitative way. The finger-print-like maps of three-dimensional fluorescence are varied because of the difference in genesis and genetic type of aromatic hydrocarbons of different samples. This technique can be used to compare oil and oil, oil and source rock, oil and coal, oil and pollution, and to determine the genesis of geochemical anomalies. According to the research of Yong Kelan (1992), the following conclusions may be drawn: a) The main peaks of Ex and Em of crude oil vary around 228 nm and 340 nm respectively. The main peaks of Ex and Em of the surface samples (soil or rock) which are distributed in the range affected by underground oil reservoirs are slightly smaller than that of crude oil. The disparity is commonly <10 nm. The finger-print-like maps are mainly of the Q type, sometimes the O type. b) For the surface samples which are affected by the activity of oil-gas migration, the main peaks of Ex and Em are also relatively small, but their finger-print-like maps usually show the B type. c) The finger-print-like maps of coal and its connected samples are of the P type. d) To some individual polluted districts or samples, the main peaks usually show great deviation, or even scatter everywhere without any fixed finger-print-like maps.

(4) Analysis of anomaly patterns

Because of the differences in the textures of hydrocarbons and their associated elements, the characteristics of reservoirs and caprocks and the migration and diffusion styles of different elements in different types of oil-gas pools, the corresponding anomaly patterns are various. After studies of many years, it is discovered that: a) The geochemical patterns for oil-gas pools where oil is dominant are characterized by the following zonation: the Hg anomaly shows a massive shape at the top position (inner zone); anomalies of hydrocarbons ΔC, Ks and Fe^{2+} are distributed at the periphery in bay-shaped or ring-like forms. b) Over the lithologic oil-gas pools or those dominated by gas, the anomalies of all indicators (including Hg) are ring-shaped and distributed at the periphery. c) Over the gas accumulations, the anomalies of different indicators often show an "apical ring" pattern, i.e., these anomalies are distributed at the periphery to form a ring-shaped zone and also occur in the apical position.

(5) Prediction of burial depths of oil and gas pools

This work is very difficult, and there are few reports about it at home and abroad. After tests for years, it is discovered that the special element technique is one of the good methods to solve this technical problem.

The basic procedure is as follows: First, make a multi–component analysis of the various strata in the study area. Second, select the constituents or elements which can migrate to the surface, and become special for a reservoir, or are obviously higher in content at one stratum against other strata. Third, use a suitable method and technique to detect the content of these special elements in the surface soil. Fourth, forecast the burial depth of oil-gas pools by analyzing and comparing the characteristics of those special elements. For instance, in the Baimamiao region of the Sichuan basin, H_2 in heat release is the special element of the deep-seated Xujiahe Formation, whereas O_2 and N_2 in heat release are the special elements of the Shaximiao Formation at a medium-deep level.

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