Chinese Science Bulletin

ARTICLES

Reservoir-forming age and its exploration significance to stratigraphic reservoirs in southern Songliao Basin

ZOU CaiNeng†, TAO ShiZhen & ZHANG YouYu

PetroChina Research Institute of Petroleum Exploration & Development, Beijing 100083, China

Despite many studies concerning the forming age, evolution characteristics and the age of petroleum charging in the Fuxin upheaval of southern Songliao Basin, no consensus has been reached so far. This paper presents the first K-Ar dating of autogenetic illite from stratigraphic petroleum reservoirs in the Fuyu oil layer of the Fuxin upheaval belt. Isotopic test and age calculation were carried out based on the separation and purification of illite mineral, X-diffraction analysis and the detection of scanning electron microscopy. The evolution characteristics of structure, sedimentation, reservoir-forming about the Fuxin upheaval belt were interpreted in terms of the synthetical analysis of "six-type geological history" evolution in southern Songliao Basin. The geologic background of petroleum evolution and reservoir formation are similar in the entire central depression region of southern Songliao Basin. The Changling sag and the Fuxin upheaval belt brought about obvious upheaval-sag separation after the hydrocarbon-generation peak of K_2qn^1 and the main reservoir-forming period of the Fuyu oil layer, namely reservoir-forming happened before the Fuxin upheaval belt extensively raised. The reservoirs have three characteristics: the hydrocarbon source rock above the reservoir, the oil source in the locality, and the vertical migration. The geological cognition is corrected, that is, oil source came from the Changling sag and migrated from the side direction. The bulk process of petroleum charging in the stratigraphic hydrocarbon reservoirs in the Fuxin upheaval belt of southern Songliao Basin is determined according to the isotopic age of autogenetic illite in combination with the method of fluid inclusions. The cognition is helpful to exactly evaluate the resource potential and exploration direction in the Fuxin upheaval belt, Changling sag and their peripheral areas. The present results indicate that the combination of the two methods (the K-Ar dating of autogenetic illite and fluid inclusions) is an effective way to lay bare petroleum charging history and ascertain reservoir age.

illite, K-Ar dating, fluid inclusion, reservoir age, stratigraphic reservoir, Songliao Basin

GEOLOGY

Reservoir age is one of the key data in examining the origin of a reservoir. Except for buried hills, the Fuyang oil layer is one of the few oil layers that have upper sources and lower reservoirs onshore China, but the opinions on its age are diverse [1,2]. The main reason for this is that different researchers have taken different methods, samples and testing objectives in their studies. The evolution history, hydrocarbon migration and accumulation mechanism, and reservoir age of the oil layer are still in suspension. At present, the accumulation mechanisms are relatively clear in inner source reservoirs (Sa'ertu, Putaogpu and Gaotaizi oil layers) and in above source reservoirs (Heidimiao oil layer), whereas those in below source reservoirs (Fuyu and Yangdachengzi oil layers) are complicated and remain unclear. Most opinions hold that the Fuxin upheaval uplifted before the oil and gas charge, and that oils from the Qing 1 Member source rock of the Changling sag migrated vertically into the carrier bed of Quan 4 sandbody and then into the Fuxin upheaval laterally[3−5]. According to the K-Ar isotopic age of autogenetic illite, together with

Received May 29, 2007; accepted July 26, 2007
doi: 10.1007/s11434-007-0424-5
†Corresponding author (email: zcn@petrochina.com.cn)

fluid inclusions, the present paper examines the reservoir age of the Fuyu oil layer in the southern Songliao Basin and analyzes the oil source and the mechanisms of migration and accumulation.

Autogenetic illite K-Ar dating is a new technique developed in the mid and late 1980's. Hamilton et al.[6] have systematically described it. Zhang et al.[7−9] have studied it systematically and established a set of self-contained methods. Lee et al.[10] studied the autogenetic illite in the Groningen gas field, North Sea and Permian Rotliegendes sandstone reservoir in the Broad Fourteens Basin, using potassium-argon age dating and the history of gas-charging. Thereafter, especially in recent years, the technique has become one of the most intensively studied issues in the field of oil and gas exploration abroad[11−13]. Since 1995, the technique has drawn wide attention from Chinese experts and begun to be applied to the study of oil and gas accumulation[14,15]. In recent years, autogenetic illite K-Ar dating has been widely used in China[16−25]. Overseas, the technique is becoming more mature and being applied to wider fields, such as reservoir diagenesis and evolutionary age dating[26], metamorphic temperature and age dating[27], timing of hydrocarbon fluid migration[28,29], age dating of multi-stage charging of ancient fluids in fractures of different periods, etc.[30]

1 Geological setting

The Songliao Basin is a superimposition continental petroliferous basin of Middle-Late Jurassic-Early Cretaceous rift and Middle-Late Cretaceous depression, which is developed on the Hercynian folding basement. Since the discovery of the Fuyu oil field in 1965, a large number of below-source oil and gas fields, including structural, fault, stratigraphic, lithologic, combination hydrocarbon reservoirs, etc., have been successively found in the Lower Cretaceous Quan 3 and 4 Members of the Fuxin upheaval belt south of the Songliao Basin. Currently, the discovered oil fields include Fuyu, Xinmin, Xinli, Mutou, Xinbei, Liangjing, etc., of which the proved reserves of the Fuyu oil layer in the Quan 4 Member accounts for more than 50% in the southern Songliao Basin[1].

The Fuyang oil layer is a below-source layer in the southern Songliao Basin and is a typical one of the few reservoirs that have Upper Cretaceous Quan 3 and 4 Member sandstone deposited in river and delta environments. Oil and gas are mainly from the first member source rock of the overlying Qingshankou Formation, which also works as cap rock, and the source reservoir seal assemblage is upper source and lower reservoir. According to the analysis of the type, accumulation condition and distribution of the oil and gas reservoirs discovered in the south of the basin, the oil and gas accumulation and distribution of the Fuyang oil layer are controlled by delta front sandbody, effective source rock, source fault, favorable regional cap rock abnormal pressure, etc.[31−34].

The Upper Cretaceous Quantou Formation south of the basin, which is fine sandstone deposited in delta front submerged distributary channels and widely distributed in the Fuxin upheaval, is the principal producing formation of Mesozoic oil. Clastic constituents are mainly feldspar, quartz, and to a lesser extent debris, and some contain slight bioclasts (mostly Ostracoda, with few complete individuals). The clastic constituents are dominantly in linear contact. Calcite and ferro-calcite fill in the inter-granular pores and substitute for feldspar and other grains, but are distributed unevenly. Some quartz and feldspar have enlarged peripheries. Clasts are even in size and carbonate minerals experienced a strong substitution. Rock denudation is strong, the corrosion of feldspar and debris is obvious, and some grains are corroded with slight remnants left. The rock pore is predominantly feldspar, debris intra-granular corrosion pores and granular corrosion pores, and secondarily inter-granular corrosion pores. The inter-granular pores are distributed unevenly and pores are poorly developed in the area of high shale content.

In this study, the illites detected by SEM are dominantly filamentary autogenetic illites. The frequently observed are granular surface and inter-granular filamentary illites, filamentary illites in granular surface corrosion pits, authigenic quartz crystals and filamentary illites in intergranular pores, as well as slight laminated illites in secondary pores and in granular surface dissolution pores (Figure 1). The universal existence of autogenetic minerals provides the material base and preconditions for the isotopic age dating.

The reservoir-forming characteristics and timing of the Fuyang oil layer have drawn wide attention from petroleum geologists. Although some research has been done on the accumulation timing, no unanimous result

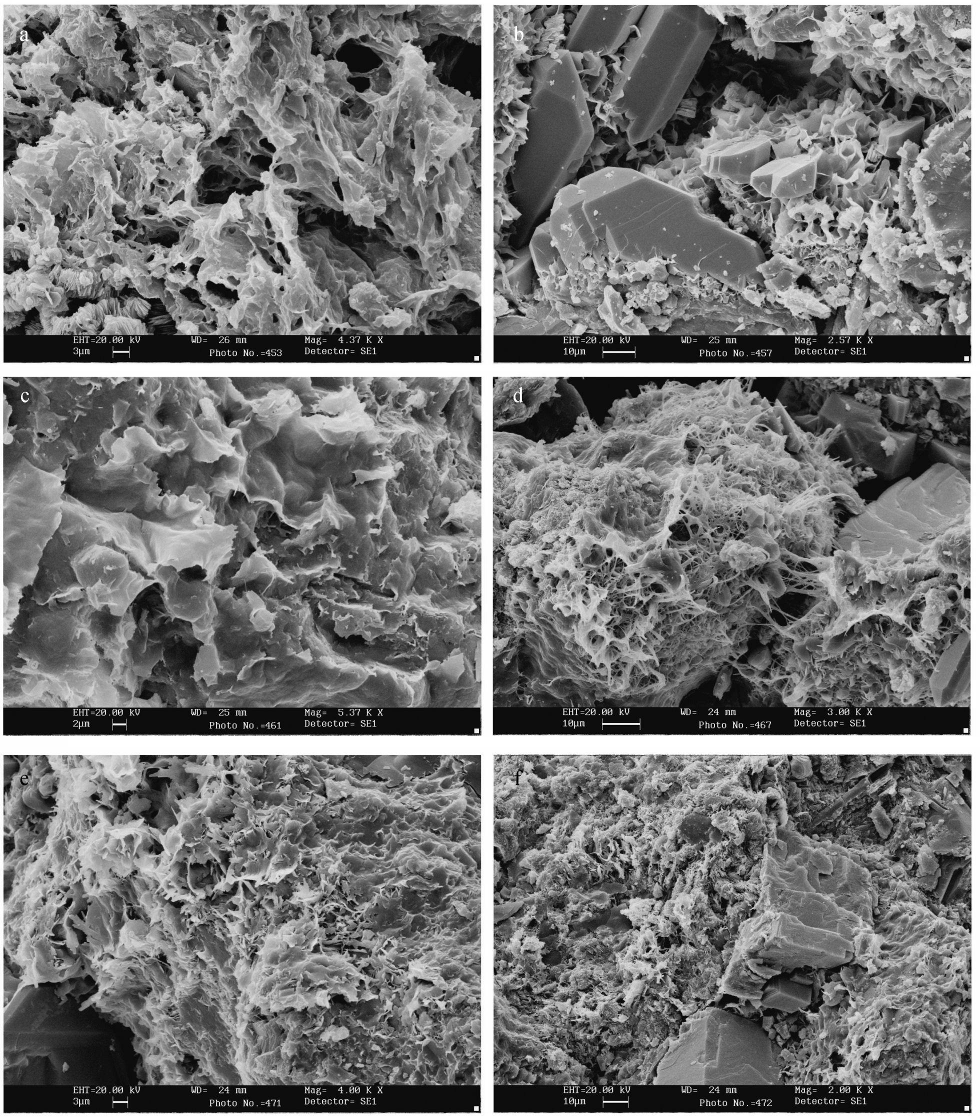

Figure 1 SEM characteristics of Quan 4 Member illite, Fuxin upheaval, south of Songliao Basin. a. Platy-flocculent mixed I/S and filamentous illites in intergranular pores, b. quartz overgrowth (3rd grade), authigenic quartz crystals and illites in intergranular pore, c. platy mixed I/S and filamentous illites on the surface of grains, d. platy mixed I/S and filamentous illites on the surface of grains, e. filamentous illites on the surface of grains, f. filamentous illites and ankerites in solution voids on the surface of grains.

is achieved. So, to study the accumulation timing and its spatial and temporal association with other accumulation conditions is the important base of establishing the oil and gas accumulation model. The study in this aspect can enable the understanding of the forming history of hydrocarbon reservoirs in the petroliferous basin, and reveal the forming conditions and distribution of the reservoirs in combination with structural, reservoir, migration, accumulation and other conditions, therefore predicting favorable exploration prospects in the basin. According to illite age dating and inclusion parameters, the present paper collates and stipulates the periods and timing of shallow and middle-depth hydrocarbon reservoirs south of the Songliao Basin, analyzes the oil and gas distribution in combination with the association of hydrocarbon generation and expulsion, and puts forward the potential areas to explore.

2 Experiments and results

2.1 Methodology

Autogenetic illite is a cementing mineral formed before oil and gas charging. The oil and gas replace formation water and lead to the stopping of silicate diagenesis, so the K-Ar age of late autogenetic illite records approximately the earliest occurrence time of the oil and gas charging event[6,12]. Oil and gas charging replaces formation water, thus causing the stop of illite diagenesis. This is the theoretical basis of using autogenetic illite K-Ar age dating to investigate oil and gas charging events. The diagenetic development of illite and its causal and effective relationship to the oil and gas charging are the theoretical precondition of successful dating[6,12]. The research extracts illites with smaller grain sizes (0.3—0.15 μm and <0.15 μm) particularly in order to get late formed autogenetic illites and abandon early formed ones. The main reasons are: (1) Early formed illites are big in size and later formed ones are smaller; (2) late formed ones are largely distributed on grain edges and liable to fall off; and (3) in terms of quantity, late formed ones are dominant and earlier formed ones are less[6,12]. In addition, due to the stop of the autogenetic illite growth at the time of charging, the late fine-grained autogenetic illites usually do not contain (or extremely less amount of) hydrocarbon inclusions, thus avoiding the influence of organic fragment peak that can cause the K-Ar age to become younger.

With the going on of exploration, the difficulties of exploration are progressively getting bigger. The study of hydrocarbon accumulation age is of great significance to revealing the regularity of accumulation and guiding oil and gas exploration. The Research Institute of Petroleum Exploration and Development, PetroChina has carried out a series of work relating to autogenetic illite isotopic age dating, such as clay mineral separation, X-ray, SEM analysis and K-Ar isotopic testing[7]. Yang et al.[35] studied illite alkyl amine cations in sedimentary rocks and K-Ar dating, and the results show that the K-Ar age of the part with small grain size is young and that with bigger grain size older. Wang[36,37] experimentally studied autogenetic illite $^{40}Ar/^{39}Ar$ dating of the gas reservoirs of the Sulige gas field, north of the Ordos Basin. Qiu et al.[38−41] studied in detail the theory, experiment and application of Ar-Ar age dating, pointing out that making extraction and purification systems small and automatizing experimental procedures are the inevitable developing trend of Ar-Ar labs, and also presented, with the Ar-Ar dating of the Lingling biotite granites west of the Yunnan Province as an example, the high-quality experimental data produced from a modern Ar-Ar lab. Other scholars studied the separation and purification procedures and other techniques of autogenetic illite K-Ar age dating from different aspects[42,43].

Autogenetic illite K-Ar age dating of reservoirs is actually the specific application of the K-Ar dating to determining the illite age. In theory, their methodologies are the same, however, due to the testing subjects and problems to solve being different, the autogenetic illite K-Ar dating has its own characteristics. Hamilton et al.[12] stated that due to the stop of silicate diagenesis caused by the substitution of hydrocarbon for formation water, the authigenic illite K-Ar age records the occurrence time of hydrocarbon charging events and represents the oldest forming age of traps, and illite clay minerals are often the latest (or one of the latest) cementing minerals formed before the hydrocarbon charging. From this, two preconditions have to be available if we want to determine the hydrocarbon charging time by autogenetic illite K-Ar age dating, one is that well-developed illite diagensis exists in studied sandstone reservoirs, i.e. it is necessary for sandstone samples to contain enough amount of illites and/or ordered illite/smectite inter-stratification and it must be the diagenetic autogenetic illite and/or diagenetic I/S inter-stratification; the second is that there should be a genetic relationship between the illite diagenesis and the hydrocarbon charging events in the studied sandstone reservoirs. These are the preconditions and guarantee of the successful dating by the method[9].

2.2 Analysis procedures and results

The main purpose of separation and purification is to the largest extent to enrich late autogenetic illites and to get rid of clastic potassic fielspars, clastic illites and other potassium-bearing minerals. The theoretical basis is that autogenetic illite crystals are smaller in sandstone reservoirs and clastic potassic feldspars and clatic illites (including clastic micagroup mineral) are larger. Hanmiton et al.[12] believed that only illites with the smallest grain size are most possibly the late developed autogenetic illites, and their age can most possibly represent the ending age of the autogenetic illite growth.

(i) Current situation of technological development at home and abroad. The separation and purification of autogenetic illite clay constituents of less than 2 μm grain size are usually carried out using the highspeed or ultrahigh speed centifugalization technique at home and abroad. Hamilton et al.[12] for example, first separated constituents of less than 2 μm by using settling method and then further separated grain constituents of 2—1 μm, 1—0.5 μm, 0.5—0.1 μm and <0.1 μm by ultra-high speed method. The former Geological Analysis and Testing Research Center of Beijing Geological Research Institute, Nuclear Industry Ministry of China, also acquired good results of separation and purification by the vacuum swabbing and filtering technique.

(ii) Technical procedures. The separation, purification, and K-Ar age dating of autogenetic illites are analysis techniques that contain many contents. The systematic analysis procedures designed in the present study are shown in Figure 2. The designed process consists of 6 parts including oil removing, identifying illite origin type and its development degree through studying the characteristics of sample clay mineral by SEM and SRD (X-ray diffraction), autogenetic illite separation and purification, K content testing, isotopic ratio analysis and purity degree of XRD, and finally calculating the K-Ar age. Each and every step is extremely important, and any improper treatment may lead to errors of the final testing results of autogenetic illite ages. The procedure is shown in Figure 2, and the results are listed in Table 1.

Based on the relevant literatures, the autogenetic illite separation and purification technique in the present study took the vacuum pumping and filtering as the main method, together with the settling separation method and the centrifugalization method. The technique can extract grain constituents of 2—1 μm, 1—0.45 μm, 0.45—0.3 μm, 0.3—0.15 μm and less than 0.15 μm. In practice, the flow can be adjusted according to constituent grain sizes that need to be extracted, laboratorial equipment condition, and specific samples. The present study mainly extracted constituents of 0.3—0.15 μm and less than 0.15 μm grain size.

The autogenetic illite separation and purification vacuum pumping and filtering system designed and assembled by ourselves in the study is composed of 6 parts: vacuum pump; buffer bottle; electromagnetic valve; double-hole filling vacuum bottle; pumping and filtering filler; mixed cellulose ester Millipore filter (φ= 150 mm, pore diameter = 0.45 μm, 0.3 μm, 0.15 μm). The system can selectively extract autogenetic illites of different grain sizes.

(iii) XRD purity degree testing. The quality of the separation and purification of autogenetic illite clay samples determines whether its K-Ar dating is accurate. The ideal samples are composed largely of the latest autogenetic illite, with extremely less clastic potassic feldspar and clastic illite. The XRD testing results of illite in modern sediment and metamorphic rock show that clastic illite has obvious X-ray diffraction characteristics: one is that peak position is 10.05×10^{-1} nm and almost doesn't change; the other is that the half height width is less than 0.42°(2θ), and the peak-separated technique can be used to analyze the two quantitatively.

XRD shows that as grain sizes decrease, the contents of all impurities decrease, and quartz, potassic feldspar, albite, calcite, dolomite and other impurities can not be detected when grain sizes are less than 0.2 μm. Taking account of both grain size and the purity of autogenetic illite, the products of 0.1—0.2 μm grain size are generally applicable to Ar-Ar age dating and K-Ar age dating. However, in actual analysis of age, the XRD and TEM (transmission electron microscope) analyses should be done ahead of time. Ar-Ar and K-Ar age dating cannot be used until the diagenetic mixed I/S content is about 100% (at lest above 95%) and the S content is less than 25%[42]. The XRD purity testing of the studied samples shows that they can hardly contain any clastic potassic feldspar and clastic illite, whose contents are within reasonable ranges and negligible (Figure 1).

(iv) Result analysis. The experiment is carried out strictly according to the industrial standard. The performance and state of equipment are tested according to the standard before the experiment. The experimental pollution has been deducted from the Ar isotopic measurements. The measured data of the studied area by autogenetic illite K-Ar age dating are shown in Table 1.

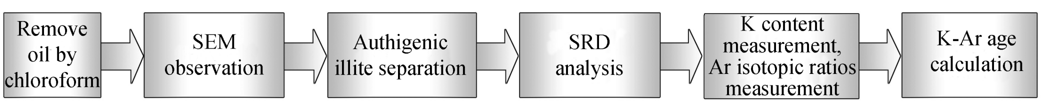

Figure 2 Flow diagram of autogenetic illite K-Ar age anaylysis.

Table 1 Results of illite K-Ar dating south of Songliao Basin

Setting	Sample	Lithology	Depth (m)	Size fraction (μm)	Potassium (%)	Clay mineral composition (%)						I/S (%)	C/S (%)	K-feldspar (XRD)	($^{40}Ar_R$/g) (mol/g)	^{40}K (^{40}K/g) (mol/g)	$^{40}Ar_R$/$^{40}Ar_T$(%)	$^{40}Ar_R$/^{40}K	Age (Ma, 1σ)
						Smectite (%)	I/S (%)	Illte (%)	Kaolinite (%)	Chlorite (%)	C/S (%)								
Changling sag	Qian 193	Oil-bearing sandstone	2145	0.3—0.15	4.72		84	2		14		25		trace	5.363E-10	1.409E-07	89.69	0.0038068	64.4±1.6
	Qian 193	Oil-bearing sandstone	2145	<0.15	4.72		83	2		15		25		trace	5.677E-10	1.409E-07	93.79	0.0040301	68.1±0.6
	Cha 25-3	Oil-bearing sandstone	2385	0.3—0.15	5.94		100					10		–	7.185E-10	1.773E-07	85.30	0.0040527	68.4±0.7
	Cha 25-3	Oil-bearing sandstone	2385	<0.15	6.13		100					10		–	7.408E-10	1.830E-07	93.08	0.0040491	68.4±0.5
	Jian 23-2	Oil-bearing sandstone	506	0.3—0.15	3.90		88	2	4	6		25		trace	5.553E-10	1.164E-07	87.20	0.0047706	80.3±1.1
	JIan 23-2	Oil-bearing sandstone	506	<0.15	3.78		89	2	3	6		25		trace	5.191E-10	1.128E-07	65.50	0.0046009	77.5±0.8
	Jian 23-3	Oil-bearing sandstone	310.1	0.3—0.15	4.66		88	5	7			25		trace	7.375E-10	1.391E-07	93.11	0.0053022	89.0±0.7
	Jian 23-3	Oil-bearing sandstone	310.1	<0.15	4.58		88	4	8			25		trace	7.402E-10	1.367E-07	91.92	0.0054147	90.9±0.7
Fuxin Upheaval	Xin 211-1	Oil-bearing sandstone	1147	0.3—0.15	4.68		90	5	5			25		trace	6.864E-10	1.397E-07	85.60	0.0049139	82.7±2.0
	Xin 211-1	Oil-bearing sandstone	1147	<0.15	4.70		89	5	6			25		trace	6.617E-10	1.403E-07	83.34	0.0047172	79.4±2.4
	Rang 46-2	Oil-bearing sandstone	1514.1	0.3—0.15	4.31		68	3		29		20		–	5.585E-10	1.286E-07	90.32	0.0043420	73.2±0.6
	Rang 46-2	Oil-bearing sandstone	1514.1	<0.15	4.32		66	3		31		20		–	5.720E-10	1.289E-07	83.45	0.0044365	74.8±0.6
	Mu125-3-5-B	Oil-bearing sandstone	531.2	0.3—0.15	3.84		75	4	21			20		–	5.539E-10	1.146E-07	86.00	0.0048330	81.3±0.7
	Mu 125-3-5-B	Oil-bearing sandstone	531.2	<0.15	3.85		75	5	20			20		–	5.697E-10	1.149E-07	80.66	0.0049577	83.4±0.6
	Qian 48A-44	Oil-bearing sandstone	1138.7	0.3—0.15	3.94		66	4		30		20		–	6.075E-10	1.176E-07	91.57	0.0051663	86.8±0.8
	Qian 48A-44	Oil-bearing sandstone	1138.7	<0.15	4.18		66	4		30		20		–	6.878E-10	1.248E-07	97.58	0.0055134	92.5±1.1

3 Analysis and discussion

3.1 Hydrocarbon charging periods and time

As shown in Table 1, the age data of the autogenetic illites range from 64.4 to 92.5 Ma, and the corresponding geological ages are from the late period of the Qingshankou Formation to that of the Mingshui Formation in Late Cretaceous. According to the hydrocarbon charging ages in different positions, the data change from the Changling sag to the Fuxin upheaval does not show a regular pattern, the mean age and the distributions are similar, and the age change from the sag to the upheaval is not from old to young. So, it can be inferred that the oil of the Changling sag and Fuxin upheaval was migrated vertically and charged from the *in-situ* overlying Qing 1 Member source rock. Although the Changling sag is deeply buried currently, the oil charging didn't take place very early. The Fuxin upheaval burial depth is shallow now, but its oil charging was not later than that of the Changling sag. In the tested samples, for example, two obviously older samples are not confined to the Changling sag. The Jian 23-3 (Changling) sample and the Qian 48A-44 sample are older (86—92 Ma) and it may be caused by the samples themselves, or it may be the case that some well areas were charged earlier. Likewise, two clearly younger samples are not confined to the Fuxin upheaval. The reservoir-forming ages of Wells Qian 193 and Cha 25(64—68 Ma), which are adjacent to the Changling sag, are young suggesting a later charging. The Charging time of other wells is similar. According to the study results of autogenetic illite dating, thermal history and hydrocarbon-generating history (Figure 3), the Upper Cretaceous Qingshankou 1 source rock entered into the hydrocarbon generating threshold at 85 Ma (R_o = 0.7%, the corresponding formation temperature 90℃).

Therefore, ages older than 85 Ma are possibly caused by illite samples themselves. It is, of course, possible that slight amount of crude oil or low-mature oil generated by the source rock at early maturity charges at these ages, but the amount of the generated crude oil and its charging range are limited (only the ages of two samples, Qian48A-44 and Jian 23-3, are older than 85 Ma in the table). In the area, the source rock maturity and its oil-generating peak (paleo-temperatures range from 90° to 140°, R_o = 0.7%—1.4%) corresponded to the geological time of 85—65 Ma (Figure 3), i.e. Late Cretaceous Nenjiang age to Mingshui age, and most age data

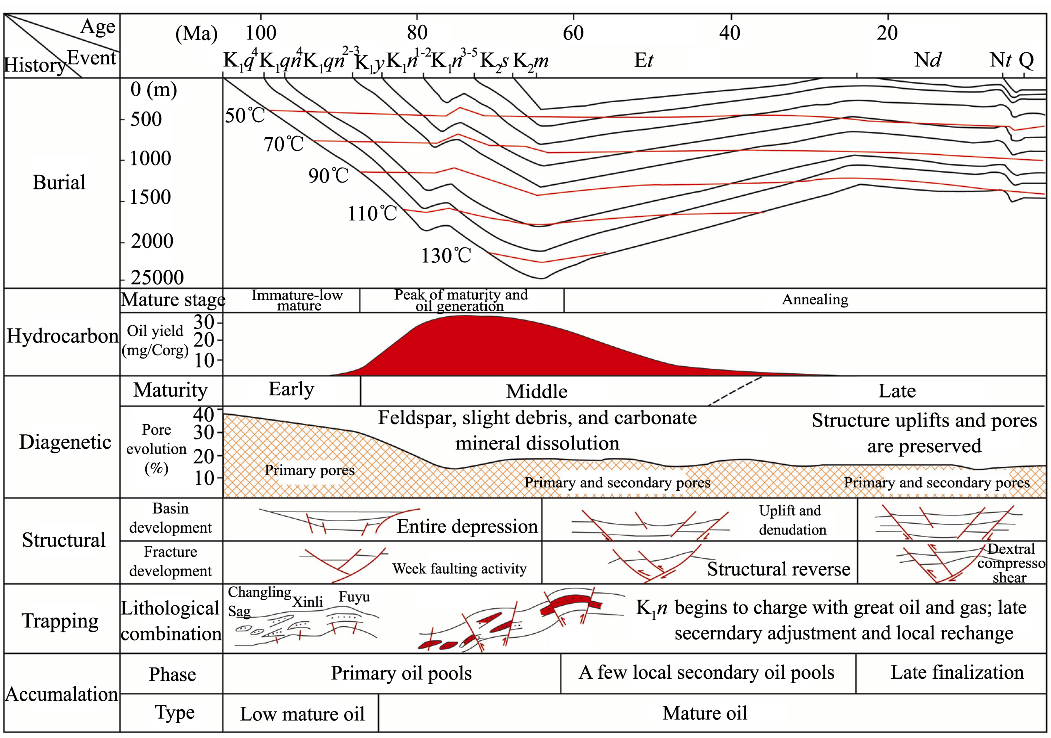

Figure 3 "Six history" comprehensive evolution of Fuxin upheaval south of Songliao Basin.

in the table are within this range, reflecting the ages of source rock maturity and oil charging in its peak generation period. The majority of the samples in the table range from 15 to 85 Ma in age and they should be treated as oil and gas charged in the same period. The gap of 20 Ma doesn't mean that charging time must be different in different well areas. There are two possibilities here, one is the identical charging time and it was the samples in different well areas that caused the gap between the autogenetic illite ages, the other could be that the hydrocarbon generation time was the same but the expulsion time was different, that is, there was a natural difference in the crude oil charging time, which is reasonable because the hydrocarbon generation, expulsion, migration and charging of source rocks are a process like the growth of minerals, and trap sandstones that were in different wells areas or vertically different positions had different opportunities to entrap oil and gas. In addition, the different charging time was possibly caused by the change of charging conditions, that is, the charging conditions such as smooth transport system and effective reservoirs were not available in some well areas until in a late period.

The autogenetic illite K-Ar dating data can be used to rectify the initial charging time of oil and gas, but can not be used to deal with the later continuous charging, the charging of the secondary hydrocarbon generation, or the secondary finalization of original reservoirs after adjustment. Fluid inclusions which record the various stages of geological history, however, can be used to restore the subsequent charging history and multi-stages of accumulation[44].

Based on the analysis of fluid inclusion features, host minerals and diagenetic sequences, this paper measures the homogenization temperature of the brine solution inclusions associated with hydrocarbon fluid inclusions. And the inclusion burial depth and the corresponding geological times were then determined in combination with paleo-geothermal gradient and sedimentary burial history. The brine solution inclusions of the reservoirs in the Fuyu oil layer are well developed, including gaseous liquid inclusion and pure fluid phase inclusion. The inclusions are mainly distributed in the enlarged edges of quartz, quartz cracks, calcite and other cementing minerals. The testing results show that the homogenization temperatures of the fluid inclusions of the Fuyu oil layer are mainly within 90—120℃. Some specific samples have inclusions of abnormally high homogenization temperatures owing to unusual factors, for example, the reservoir-experienced highest temperature restored according to thermal history and hydrocarbon generation history is lower than 140℃, but the homogenization temperature of specific inclusions is up to 160℃. This situation was frequently met in the testing of inclusions. There usually are two reasons for the abnormally high temperatures of inclusions: one is that the inclusions were captured in a non-homogeneous phase when they were formed, the other is that they were influenced by deep thermal fluid activity. The former is more resonable because the structure of the Songliao Basin was stable in the depression stage of late rifting.

As shown in Table 2, there is no regularity among the homogenization temperature changes of different well areas, that is, there is not the changing trend of high to low geotemperature from sag to upheaval. It indicates that the paleotemperature field and the entrapment depth were close when the inclusions were entrapped, thus indicating that the inclusions were captured before the uplifting of the Fuxin upheaval. Therefore, the oil of the Changling sag and the Fuxin upheaval was migrated downwards vertically and charged from the *in-situ* overlying Qing 1 Member source rock. Table 2 shows that the homogenization temperature and formation time of the brine solutions in different wells of Fuyu do not clearly correspond to the uplift and sag pattern of the present Changling sag and Fuxin upheaval, that is, the temperature and formation age of the inclusions in the Changling sag are not necessarily greater than those in the Fuxin upheaval. For example, the inclusion temperature and entrapment burial of the samples of wells Hong 75-1, Cha 25, Qian 193 near the Changling sag are smaller than those of the Fuxin upheaval, suggesting that the reservoirs were formed before the large-scale uplifting of the Fuxin upheaval. The buried history analysis shows that the hydrocarbon charging of the reservoirs in the Fuyu oil layer took place largely between the Cretaceous Nenjiang Age and the Cretaceous Mingshui Age.

The forming ages of the fluid inclusions (Table 2) are determined based on the homogenization temperature and the map of thermal history and hydrocarbon-generation (Figure 3). The area experienced a process from subsiding to uplifting in the geological evolution (Figure 3), i.e. the area experienced firstly subsidence, sedimentation and increasing temperature, and then uplifting,

Table 2 Inclusion testing results of central depression south of Songliao Basin

Setting	Sample	Type	Host-mineral	Homogeneous temperature (℃)	Generated time before the uplift (Ma)	Generated time after the uplift (Ma)
Changling sag	Hong75-1	brine	Quartz fracture and upgrading	92—134	84—66	62—25
	Hong 90	hydrocarbon	Quartz fracture and upgrading, calcite, gypsum	58—105	95—82	37—23
		brine	Quartz fracture and upgrading, calcite fracture	92—125	84—71	56—24
	Da50	hydrocarbon	Quartz fracture and upgrading, calcite, gypsum	80—98	88—83	33—23
		brine	Quartz fracture, calcite fracture	90—120	85—73	51—23
	Jian 23-0	brine	Quartz fracture and upgrading, calcite	95—128	83—70	59—26
	Jian 23B	hydrocarbon	Quartz fracture and upgrading, gypsum	65—142	92—65	65—23
		brine	Quartz fracture and upgrading	95—108	84—81	39—23
	Jian 23-2	hydrocarbon	Quartz fracture and upgrading	60—125	94—71	57—23
	Qian 193	hydrocarbon	Quartz fracture and upgrading	60—70	94—91	
	Qian 193	brine	Quartz fracture and upgrading	82—108	88—81	39—23
	Cha 25-2	hydrocarbon	Quartz fracture and upgrading, gypsum	70—85	91—87	
		brine	Quartz fracture and upgrading	84—98	87—83	33—23
Funxin Upheaval	Xin 211-2	hydrocarbon	Quartz fracture and upgrading, calcite, gypsum	74—145	89—65	65—23
		brine	Quartz fracture and upgrading, calcite fracture	105—118	82—74	50—37
	Xin 211-2	hydrocarbon	Quartz fracture and upgrading, gypsum	54—116	96—75	48—23
		brine	Quartz fracture and upgrading, gypsum	92—162	85—65	65—23
	Rang 46-2	hydrocarbon	Quartz fracture and upgrading	50—90	96—85	
		brine	Quartz fracture	85—105	87—82	37—23
	Qian 48A-44	hydrocarbon	Quartz fracture and upgrading	65—95	92—84	29—23
		brine	Quartz fracture and upgrading	105—138	82—66	64—37
	Min 62	brine	Calcite fracture and upgrading	92—115	84—76	47—24

erosion and decreasing temperature. So the forming ages derived from the homogenization temperature can be explained in two ways, that is, the same geo-temperature may appear in the period of subsidence and sedimentation or appear in the period of uplifting and erosion. The hydrocarbon inclusions in the former period stand for those charged in the peak of hydrocarbon generation and the formed reservoirs are primary reservoirs, while those in the latter period stand for the inclusions charged in later structural adjustment period and the formed reservoirs are secondary reservoirs (or local adjustment of reservoirs). In view of the above, the fluid inclusions and their corresponding oil charging can be classified into two periods. In the first period, inclusions were formed in the phase of forming primary reservoirs when source rocks generated and expelled hydrocarbons in a great amount, and the corresponding geological time is within 65—85 Ma, which is in line with most of the autogenetic illite dating data. The geological ages of the inclusions formed even earlier (more than 85 Ma) were restored mainly according to the homogenization temperature of the hydrocarbon inclusions. The inclusions are usually 10—20℃ lower than their associated brine solution inclusions, and the older ages are caused by the different types of inclusions. As shown in the table, the forming ages of brine solution inclusions are mostly within 85—65 Ma. In the second period, inclusions were formed when the hydrocarbon generation was nearly over, the primary reservoirs were finalized and small primary reservoirs in local areas were adjusted owing to the structure adjustment. The inclusion amount in the second period is of course less than that in the first period because the formation of the primary reservoirs inhibited to a great extent the formation of diagenetic autogenetic minerals and inclusions in this period. The corresponding geological ages of the inclusions in this period range from 50 to 25 Ma. The calculation of this period is the advantage of the inclusion dating method.

The isotopic ages of autogenetic illite reflect the initial charging ages of oil and gas, i.e. 65—85 Ma, while the ages of oil and gas charged in the later structural adjustment period (formation uplifting and erosion) are determined by inclusion data (50—25 Ma). Autogenetic illite isotope dating and inclusion dating can complement each other, the former dates the charging time in hydrocarbon generation peak of source rocks, and the latter can be used to determine the local hydrocarbon charging time in the later uplifting and adjustment period. Thus, the whole process of hydrocarbon charging and accumulation can be determined.

3.2 Hydrocarbon evolution and accumulation features

The "Six history" comprehensive evolution map is established based on the structure-sedimentation-accumulation study of the Fuxin upheaval, illite age dating and inclusion age dating (Figure 3). The analysis shows that the Fuxin upheaval didn't uplift on a large scale until Paleogene and this is also proved by the sedimentary evolution and corrosion features revealed by practical drilling data (Figure 4). The geochemical study of the source rock indicates that the source rock in the uplifting part is mature[31]. The Qing 1 Member source rock in Well Xin 333, for example, has a vitrinite reflectance of 0.94 and can provide hydrocarbon downwards effectively. The study of biomarkers and isotopic compositions shows no change in the upper Fuxin oil layer in the whole Fuxin upheaval and no lateral migration, suggesting that the oil and gas of the Fuxin upheaval were mainly from the *in-situ* overlying source rock, and not migrated laterally from the Changling sag (Figure 5).

The calculation of oil-forming temperatures by light hydrocarbon gas chromatogram showss that the temperatures of oil are different and increase from SE to NW, but the difference is not great suggesting that the hydrocarbon kitchens are close and the maturity difference is not great. It further proves that the maturity degrees of source rock and oil were identical when oil and gas were formed in the Fuxin upheaval and the Changling sag. It also shows that the thermal burial settings were identical or similar, and that oil and gas had been formed and charged before the Fuxin upheaval uplifted on a large scale.

Carbon isotopic data and biomarkers of oil also indicate that the oil of the Fuyu oil layer in the Fuxin upheaval was from the *in-situ* overlying Qiang 1 Member source rock[31]. The oil carbon isotopic compositions in the sag slope and upheaval areas are very close (−30.3‰−−31.6‰), suggesting that there was no isotopic fractionation of lateral migration and the oil was generated above and stored below by vertical migration. The comparison of oil and source rock terpanes between Fuxin and Changling shows that the terpane characteristics of their oil and rock are all clearly different. The

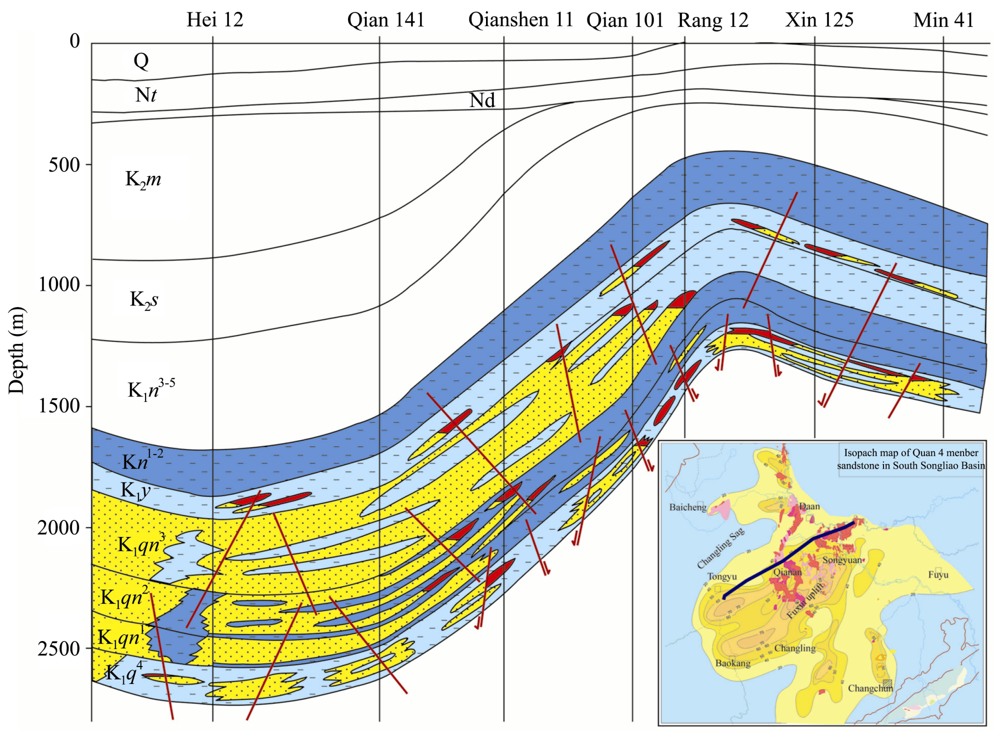

Figure 4 NE-SW trending well-tie geological section, Changling sag-Fuxin upheaval.

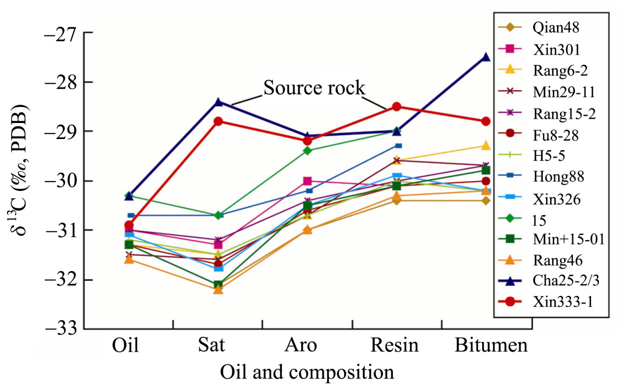

Figure 5 Carbon isotopic correlation of oil and components in central sag of southern Songliao Basin.

Fuxin oil is well correlated to the local source rock and badly to the Changling source rock. The Changling oil is well correlated to its local source rock. These further prove that the Fuyu oil is from the overlying Qing 1 Member rock by vertical migration. Besides, the oil and gas charging in the area took place before the uplifting of the Fuxin upheaval, the relief is gentle, and the sedimentary sandbody is a channel sandbody with poor horizontal connection. These facts rule out the possibility of predominantly lateral migration.

3.3 Exploration significance

The result of the illite age dating shows that the oil and gas charging time in the whole Fuxin upheaval and the central depression area is 85—65 Ma, i.e. from Nenjiang age to Mingshui age in Upper Cretaceous. The fluid inclusions record two periods of oil and gas events. The first period is in the forming stage of primary oil reservoirs in the peak generation and expulsion period of the source rock, and the corresponding geological age ranges mainly from 65 to 85 Ma, being in line with most autogenetic illite dating data. The second period is the later adjustment stage of the hydrocarbon reservoirs during formation uplifting. The corresponding geologic age is 50—25 Ma. The amount of inclusions generated in the second period is much less than that in the first period.

As mentioned above, the results from both autogenetic illite K-Ar age dating and fluid inclusion age dating indicate that the charging time in the Fuxin upheaval and that in the Changling sag are approximately the same, revealing the relationship between the time of oil and gas accumulation and that of the "uplift-sag" differentiation. The oil and gas had been formed before Fuxin uplifted on a large scale. The relationship of the two reflects different accumulation mechanisms and driving powers. That the oil and gas formation is earlier than the formation of the Fuxin upheaval shows that when the source rock was mature and even when the oil and gas were charged and accumulated, Changling and Fuxin were in approximately the same altitude, there was no differentiation of uplift and sag, and the landform of the whole central depression area was nearly flat. In this situation, it is not possible that the oil and gas migrated laterally on a large scale. The oil of the Fuyang layer was from the overlying source rock which migrated downwards vertically into the layer. The driving power of the oil was abnormally high pressure difference between the source rock and the reservoirs. The migration path was faults and fractures and the main controlling factor of the oil and gas accumulation was the good association of "fault-sandstone-abnormal pressure". If the oil and gas accumulation had taken place after the "uplift-sag" differentiation of the Changling sag and the Fuxin upheaval, i.e. the Fuxin upheaval uplifted on a large scale, the situation would have been greatly different. Due to the difference of potentials, the oil and gas of the Changling sag would have been migrated laterally, expelled into the higher position of the Fuxin upheaval, and then, under different pressures, charged into the underlying Fuyang oil layer. The accumulation dynamics and mechanisms are different in the two situations and the oil and gas potential distribution and exploration are also different.

The charge and accumulation of oil and gas took place before the uplifting of the Fuxin upheaval, so their distribution wasn't strictly controlled by the source rock in the Changling sag. If mature effective source rock existed in the Qing 1 Member and the transport channels and sandbody association was available, the abnormal pressure produced by hydrocarbon generation would expel the oil and gas downwards into the Fuyang layer. So, the "sweet spots" controlled by "source rock /overpressure+fault+sandbody" should be the targets for plays. Statistics shows that the currently discovered stratigraphic reservoirs are largely distributed horizontally in the Qing 1 Member and Quan 4 Member with the pressure difference of source and reservoir ranging from 8 to 12 MPa (Figure 6). According to the formulae of pressure sealing oil column, in theory, oil and gas can be expelled downwards 270—340 m under the pressure of 8—12 MPa. Therefore, in the central depression, the effective migration and accumulation area of oil and gas is a 3-dimentional space of 8—12 MPa source reservoir pressure difference horizontally and 270—340 m below the corresponding Qing 1 Member vertically. This area lies in the transfer zone of uplift and sag in the central depression, in which faults and fractures are developed and source rocks are widely developed. The areas having abnormal high pressure difference of source and reservoir, well developed sandbody and good trap conditions are potential play targets of the Fuyang oil layer.

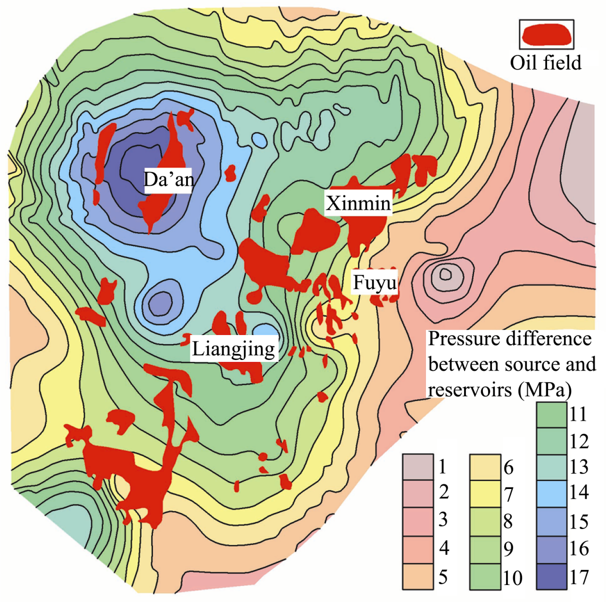

Figure 6 Source reservoir pressure difference of K_1qn^1-K_1q^4 and distribution of below source oil pools of Fuxin upheaveal.

4 Conclusions

According to the interpretation of the autogenetic illite K-Ar ages and fluid inclusions, together with the comprehensive geological consideration of the target area, the conclusions are drawn as follows:

(1) The result of the illite K-Ar dating shows that the oil and gas charging time in the whole Fuxin upheaval and the central depression area is 85—65 Ma, i.e. from Nenjiang age to Mingshui age in Upper Cretaceous. The fluid inclusions record two periods of oil and gas events. The first period is in the forming stage of primary oil reservoirs in the peak generation and expulsion period of the source rock, and the corresponding geological age ranges mainly from 65 to 85 Ma, which is in line with most autogenetic illite dating data. The second period is the later adjustment stage of the hydrocarbon reservoirs during formation uplifting. The corresponding geologic age is 50—25 Ma. The amount of inclusions generated in the second period is much less than that in the first period.

(2) Based on the comprehensive study of the "Six history" evolution of the southern Songliao Basin, this paper analyzes the characteristics of the structure, depression and accumulation of the Fuxin upheaval. It is considered that the geological settings of the hydrocarbon reservoir formation are simlar in the whole central depression in the southern Songliao Basin, and the "uplift-sag" differentiation of the Changling sag and Fuxin upheaval takes place after the hydrocarbon generation peak of the Qing 1 Member and the main accumulation stage of the Fuyang oil layer. That is, the charge and accumulation happen before the large-scale uplifting of the Fuxin upheaval.

(3) The autogenetic illte K-Ar dating and fluid inclusion analysis reveal that the oil reservoirs are characterized by above source and below reservoirs, local source, and vertical migration. This corrects the past understanding that oil source was laterally migrated from the Changling sag.

(4)The study of reservoir-forming age is beneficial to accurate evaluation of the resource potential and exploration direction in the Fuxin upheaval, the Changling sag and their peripheral areas. The accumulation characteristics of the Fuyu oil layer display poor lateral connection of transport beds, well-developed lithological and combination traps, and great exploration potential. According to the dating and the analysis, there is a great potential of exploration from the peripheral areas of the Fuxin upheaval to the Fuyang oil layer that underlies the mature source rock of the Changling sag. From this, the suggestion for exploration is to find the "sweet-spots" associating K_1q^3 and K_1q^4 traps with faults in the K_1q^4-K_1qn^1 source fault-developed areas. The "sweet-spot"-distributed area controlled by "sourc rock/overpressure + fault + sandbody" in the 8—12 MPa area in the Fuyang oil layer, southern Songliao, is the important target for future reserve growth and production increase.

(5)The theoretical study and its practical application indicate that the combination of autogenetic illite K-Ar dating and fluid inclusion analysis is a feasible and effective method to evaluate the charge history, reservoir age, and accumulation characteristics.

The authors extend heartfelt thanks to Prof. Zhao Zhanyin, Wang Xing-

guan, Jiang Tao and Song Lizhong of Jinlin Petroleum Research Institute, PetroChina, as well as Prof. Yuan Xuanjun of RIPED, PetroChina, for their support and help in the research, and Gu Zhidong and Zhou Hui for their work in literature searching.

1 Wang Y C. Formation and Distribution of Lithological Reservoirs in Southern Songliao Basin (in Chinese). Beijing: Petroleum Industry Press, 2001. 116—125

2 Huang Z L, Gao G. Hydrocarbon accumulation in Haituozi region in Southern Songliao basin. J Univ Petrol, Chin (in Chinese), 2003, 27(1): 4—7

3 Liu B Z, Sun W J, Chen S J, et al. The history of hydrocarbon accumulation in the south of the Songliao basin. Geoscience (in Chinese), 2003, 17(1): 87—91

4 Zhang G, Lin J Y, Yang Q J, et al. Reservoir-froming conditions and exploration potential of Fuyang oil layer in the Western Songliao basin. PGODD (in Chinese), 2002, 21(5): 5—7

5 Yang X Z, Fu G. Main controlling factors of petroleum accumulation and distribution of Fuyang oil layer in Northern Songliao basin. Special Oil and Gas Reservoirs (in Chinese), 2002, 9(2): 8—11

6 Hamilton P J, Kell Y S, Faluck A E. K-Ar dating of illite in hydrocarbon reservoirs. Clay Minerals, 1989, 24: 215—231

7 Zhang Y Y, Dong A Z, Luo X Q. Separation of authigenic illite in hydrocarbon reservoirs and its K-Ar dating techniques. Geoscience (in Chinese), 2001, 15(3): 215—231

8 Zhang Y Y, Horst Z, Andrew T, et al. K-Ar dating of authigenic illite and its applications to study of oil-gas charging histories of typical sandstone reservoirs, Tarim basin, Northwest China. Earth Sci Front (in Chinese), 2004, 11(4): 637—648

9 Zhang Y Y, Luo X Q, Song J. Discussions on K-Ar isotopic geochronological studies of authigenic illites in hydrocarbon reservoirs. Geoscience (in Chinese), 2002, 16(4): 403—407

10 Lee M C, Aronson J L, Savi n S M. K-Ar dating of time of gas emplacement in Rotliegendes Sandsto, Netherlands. Am Assoc Petrol Geol Bull, 1985, 69(9): 1381—1385

11 Liewlg N, Clauer N, Sommer F. Rb-Sr and K-Ar dating of clay diagenesis in Jurassic sandstone oil reservior, North Sea. Am Assoc Petrol Geol Bull, 1987, 71: 1467—1474

12 Hamilton P J, Giles M R, Ainswort H P. K-Ar dating of illite in Bent Group reservoirs: A regional perspective [A]. In: Morton A C, Haszeldine R S, Giles M R, et a1. Geology of the Brent Group. Geol Soc Spec Publ No. 61. London: The Geological Society Publishing House, 1992. 377—400

13 Hogg a J C, Hamilton P J, Macintyre R M. Mapping diagenetic fluid flow with a reservoir: K-Ar dating in the Alwyn area (UK North Sea). Mar Petrol Geol, 1993, 10: 279—294

14 Wang F Y, He P, Zhang S C, et al. The K-Ar isotopic dating of authigenic illites and timing of hydrocarbon fluid emplacement in sandstone reservoir. Geol Rev (in Chinese), 1997, 43(5): 540—546

15 Xin R C, Tian C Z, Dou T J. Study of oil-pool-forming chronology——a case study on Daqing oil field. Earth Sci Front (in Chinese), 2000, 7(3): 48—54

16 Zhang Y Y, Liu K Y, Luo X Q. K-Ar Dating of authigenic illites and its applications to the study of hydrocarbon charging histries of typical sandstones reservoirs in Tarim Basin, China. Petrol Sci, 2005, 2(2): 12—24, 81

17 Wang F Y, Hao S S, Lei J J. Dating of authigenic illites to determine the timing of hydrocarbon reservoirs in sandstone reservoir. Acta Petrol Sin (in Chinese), 1998, 19(2): 40—43

18 Bai G P. Advances on K-Ar dating of illites to determine the timing of hydrocarbon reservoirs. J Univ Petrol Chin (in Chinese), 2002, 24(4): 100—103

19 Zhang Z M, Zhou J, Wu X W. Oil and gas migration periods and accumulation process in central anticlinal zone in the Xihu sag, the east China sea basin. Petrol Geol Exp (in Chinese), 2006, 28(1): 30—37

20 Lin J Y, Yang Q J, Ying D Q, et al. Dating of authegenic mineral in quantitative analysis on reservoir formation time. PGODD, 2005, 24(6): 14—16

21 Mi J K, Zhang S C, Tu J Q, et al. Formation of Hadexun oilfield in Tarim Basin, NW China. Geochimica (in Chinese), 2006, 35(4): 405—412

22 Ren Z L, Xiao D M, Chi Y L. Research on generation of hydrocarbon source rock of Carboniferous-Permian system on the base of Songliao basin. Adv Nat Sci (in Chinese), 2006, 16(8): 974—979

23 Yu J C, Liang J P, Wang S H, et al. Study of oil-pool-forming chronology of Lamadian oil reservoirs and its significance. J Daqing Petrol Inst (in Chinese), 2006, 30(3): 5—7

24 Li Y L, Pu C P, Nan H L, et al. Application of authigenic illite K-Ar dating to hydrocarbon reservoiring study in Yanqi basin. Oil Gas Geol (in Chinese), 2003, 24(2): 181—183

25 Huang D J, Liu X S, Zhang Q, et al. Application of K-Ar dating technique to determination of timing of Oil/Gas entrapment in Ordos basin. Low Permeability Reservoirs (in Chinese), 2004, 9(4): 37—39

26 Andreia Dias Elias, Luiz Fernando De Ros, Ana Maria Mizusaki, et al. Isotopic evidence on the diagenetic evolution of coastal sabkha reservoirs from the Solimões Basin, northern Brazil. Gondwana Research, 2007, 11(4): 553—567

27 Crouzet C, Dunkl I, Paudel L, et al. Temperature and age constraints on the metamorphism of the Tethyan Himalaya in Central Nepal: A multidisciplinary approach. J Asian Earth Sci, 2007, 30(1): 113—130

28 Sant' Anna L G, Clauer N, Cordani U G, et al. Origin and migration timing of hydrothermal fluids in sedimentary rocks of the Paraná Basin, South America. Chem Geol, 2006, 23: 1—21

29 Ylagan R F, Kim C S, Pevear D R, et a1. Illite polytype quantification for accurate K-Ar age detemfination. Am Mineral, 2002, (8): 1536—1545

30 Michel C, Serge F, Norbert C, Stephane Buschaert, et al. Dating mul-

tistage paleofluid percolations: A K-Ar and $^{18}O/^{16}O$ study of fracture illites from altered Hercynian plutonites at the basement/cover interface (Poitou High, France). Geochim Cosmochim Acta, 2004, 68(11): 2529－2542
31 Zou C N, Jia C Z, Zhao W Z, et al. Accumulation dynamics and distribution of litho-stratigraphic reservoirs in South Songliao Basin. Petrol Exp Develop (in Chinese), 2005, 32(4): 125－130
32 Zhao W Z, Zou C N, Wang Z C, et al. The intension and signification of "Sag-wide Oil-Bearing Theory" in the Hydrocarbon-rich Depression with terrestrial origin. Petrol Exp Develop (in Chinese), 2004, 31(2): 5－12
33 Zou C N, Tao S Z, Xue S H. Connotation of "Facies Control Theory" and its significance for exploration. Petroleum Exploration and Development (in Chinese), 2005, 32(6): 7－12
34 Dai J X. Oil and gas reservoirs in syncline. Acta Petrol Sin (in Chinese), 1983, 4(4): 27－30
35 Yang Z F, Ji J F, Che C, et al. Alkylammonium cations treating and K/Ar dating of illite from mudstones. Chin Sci Bull, 2002, 47(19): 1669－1672
36 Wang L Z, Dai T M, Peng P A. Experiment research of K/Ar isotopic dating of authigenic illites in reservoir of gas pools. Chin Sci Bull (in Chinese), 2004, 49(spe.): 81－85
37 Wang L Z, Dai T M, Peng P A. $^{40}Ar/^{39}Ar$ dating of diagenetic illites and its application in timing gas emplacement in gas reservoirs. Earth Sci (in Chinese), 2005, 30(1): 78－82
38 Qiu H N, Wijbrans J R. Amphibolite-facies overprinting and a hydrothermal activity in southern Dabie terrane： insight from Ar-Ar dating of Zhujiachong eclogite and metamorphic amphibole vein. Geochimica (in Chinese), 2006, 35(5): 517－524
39 Qiu H N. Construction and development of new Ar-Ar laboratories in China, Insight from GV-5400 Ar-Ar laboratory in Guangzhou Institute of Geochemistry, Chinese Academy of Sciences. Geochimica (in Chinese), 2006, 35(2): 133－140
40 Qiu H N, Wijbrans J R. Caledonian Ar-Ar age messages of the Bixiling ultrahigh-pressure metamorphic eclogites in southern Dabieshan. Geochimica (in Chinese), 2005, 34(5): 417－427
41 Qiu H N, Dai T M, and Li C Y. ^{40}Ar-^{39}Ar chronometry of quartz fluid inclusion of Shangmanggang gold ore deposit in West Yunnan province. Chin Sci Bull (in Chinese), 1994, 39(3): 257－260
42 Zhang Y, Chen W, Yang H N. The Separation of authigenic illite from detrital illite in sedimentary rock for Ar isotope dating. Acta Geosci Sin (in Chinese), 2003, 24(6): 622－626
43 Zhang Y, Chen W, Yang H N. The separation of authigenic illite from detrital illite in sedimentary rock for Ar isotope dating. Acta Geosci Sin (in Chinese), 2003, 24(6): 622－626
44 Tao S Z, Zhang B M, Zhao C Y. Application of fluid inclusion in oil-gas source trace. Acta Petrol Sin (in Chinese). 2003, 19(2): 327－336