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Characteristics of Fluid Inclusions and Hydrocarbon Accumulation Stages of Yingcheng Formation in Dehui Fault Depression

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Abstract: *In this paper, the characteristics of fluid inclusions in the reservoir of Yingcheng formation in Dehui Fault Depression of Songliao Basin are studied in depth by means of single polarized light, fluorescence microscope, laser Raman spectrum analysis and micro-cold and hot table temperature measurement observation, and the main stages and formation and evolution processes of oil and gas accumulation in the region are revealed. The results show that the reservoir inclusions in the Yingcheng formation of the Dehui Fault are mainly distributed in the quartz particle microfissures and pore-filling calcite minerals, and the gas composition is mainly alkane gas. In addition, there are many fluid inclusions in the reservoir. The hydrocarbon accumulation time of Yingcheng formation in Deshen 63 Well in Baojia Depression is early, and the first stage is early Quantou formation (100 ~ 94Ma). The second stage is late Nenjiang Formation (80 ~ 72Ma); The hydrocarbon accumulation time of Yingcheng formation in Deshen 36 Well in Nong'annan Sag is late, and the first stage is late Qingshankou formation-early Nenjiang Formation (92~82Ma); the second stage is the late Nenjiang formation (76 ~ 72Ma); the overall presents the "north early south late" reservoir formation characteristics, further confirmed that the region has a multi-period oil and gas accumulation evolution history. This study is of great theoretical and practical significance for in-depth understanding of the mechanism of oil and gas accumulation in this area and optimizing the exploration and development plan.*

Keywords: *Dehui fault depression; Yingcheng formation; Fluid inclusions; Laser Raman; Accumulation period*

1. Introduction

In recent years, in the field of petroleum geology, the application and research of fluid inclusions have made significant progress, which has become an effective way and key technical method for geologists to study the time of oil and gas accumulation and accumulation period [1-3]. By measuring the homogenization temperature of brine inclusions associated with hydrocarbon inclusions to analyze the formation temperature when the inclusions are captured, and combining with the analysis of reservoir burial-thermal evolution history, the oil and gas charging time and charging period can be determined, and then the oil and gas accumulation period can be comprehensively determined [4-6].

The Songliao Basin is one of the important oil and gas exploration fields in China. As one of the important tectonic units of the basin, the Dehui fault depression has always attracted the attention of petroleum geologists. For the process of hydrocarbon accumulation in Songliao Basin, previous people have also done relevant research. For example, Zhang Xuejun and others used micro-infrared spectroscopy technology, inclusions identification and homogenization temperature measurement to study and analyze the shallow and deep inclusions in Songliao Basin. At the same time, relevant parameters of infrared spectroscopy were used to divide the hydrocarbon accumulation stages of inclusions and determine the maturity of hydrocarbon inclusions [7]; Chang Ting et al. comprehensively applied fluid inclusion testing technology when studying the fluid encapsulation characteristics and accumulation stages of the 2 and 3 section of Qingshankou Formation in Taikang Uplift Belt, Songliao Basin, and restored the burial history, thermal history and hydrocarbon generation history of a single well through PetroMod-1D software, and comprehensively analyzed the accumulation period characteristics of the reservoir in Qingshankou section of 2 and 3. in Taikang Uplift Belt, Songliao Basin [8]. In Dehui fault depression, Yingcheng formation is an important reservoir unit, and its rich oil and gas resource potential attracts the attention of geologists and engineers. Oil and gas accumulation is the migration and

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accumulation process of hydrocarbon fluid from source rock to trap, and reservoir fluid inclusion is one of the indispensable key elements in the study of oil and gas accumulation process. Through the study of reservoir fluid inclusions, we can obtain the relevant geological history information about the formation, evolution and reservoir of oil and gas, such as reservoir temperature, pressure, genetic type, etc., which has important guiding significance for the exploration and development of oil and gas reservoirs. In view of this, the study selects 11 pieces of fluid inclusions in the Middle Jurassic of 4 wells in Dehui Fault Depression for systematic microscopic observation, and uses fluid inclusion testing technology to further clarify the time and period of oil and gas accumulation in the study area, so as to provide a basis for understanding the mechanism of gas accumulation and provide a basis for the study and exploration deployment of deep oil and gas accumulation in Dehui Fault Depression.

2. Regional geological background

The Dehui fault depression is located in the southeastern uplift area of the Songliao Basin, which was formed in the early Early Cretaceous and is a Mesozoic sedimentary depression developed on the late Paleozoic shallow metamorphic rock basement [9-10]. The structural evolution characteristics of the Dehui fault depression are similar to the overall evolution characteristics of the basin area. Together with the Songliao Basin, the fault depression has mainly undergone three stages of structural evolution: initial tension rift, fault development and depression [11-12]. The Dehui Fault Depression is connected with the Nong'an West Uplift in the west and adjacent to the Jiutai Terrace in the east. It is a typical "double-fault" fault depression and contains 7 secondary structural units. The main oil and gas-bearing volcanic formations are the Lower Cretaceous Huoshiling Formation, Shahezi Formation and Yingcheng Formation (Figure 1).

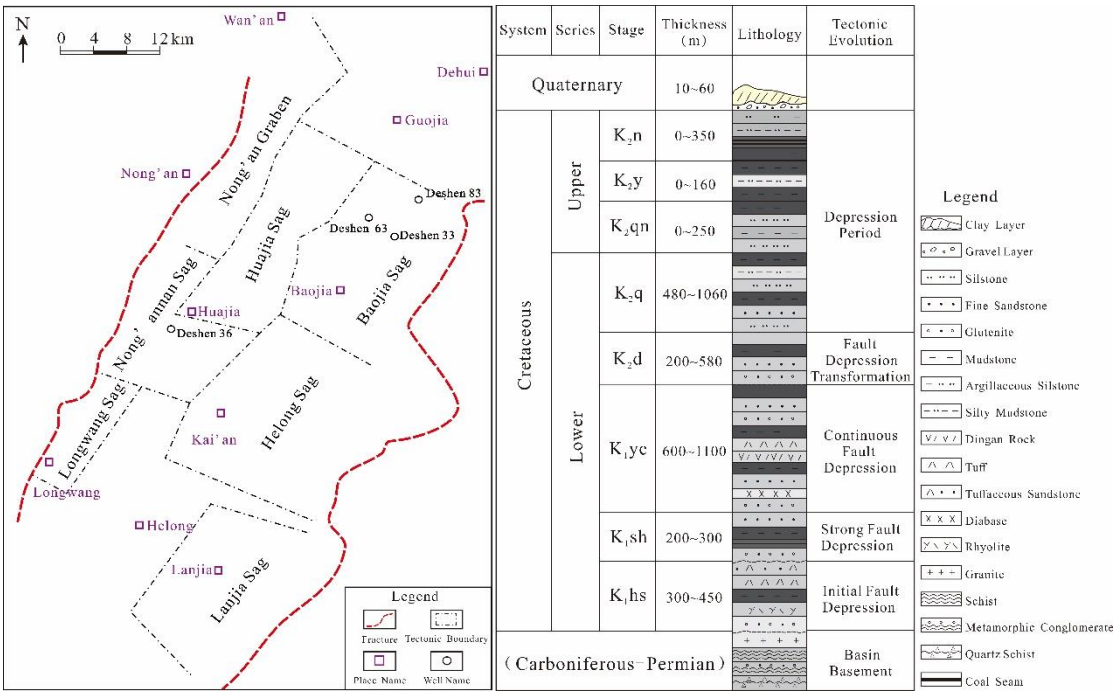


Figure 1: Structural unit division and stratigraphic column chart of Dehui fault depression

After more than 50 years of exploration, Dehui Fault Depression has deployed nearly 100 drilling wells so far, with natural gas resources far exceeding 3600×10^8 m^3, becoming the fourth planning area with natural gas exceeding $1000 \times 10^8 m^3$ in Jilin Oilfield [13-14]. There are many sags in Dehui Fault Depression, among which the largest one is Baojia Depression [15]. Through drilling and other data, it is revealed that the overlying strata on the base of Dehui fault depression are respectively Huoshiling formation, Shahezi formation, Yingcheng formation and Denglouku formation from bottom to top, and the study destination layer is Cretaceous Yingcheng formation. The deposition period of Yingcheng Formation is the late development period of the basin fault depression. Affected by the third act of Yanshan movement, the whole area suffered from weathering and denudation, especially in the southeast uplift area of the fault depression, which suffered from more intense weathering and denudation, and only the Yingcheng Formation remains at the fault depression edge [11].

ISSN 2616-5872 Vol.6, Issue 1: 75-83, DOI: 10.25236/AJEE.2024.060111

In summary, the Songliao Basin is one of the important oil and gas exploration and development zones in China, and the Dehui fault depression, as one of the important tectonic units, is rich in oil and gas resources, but the fault depression is greatly affected by tectonic activities and the process of oil and gas accumulation is complex. Therefore, Yingcheng Formation is one of the main reservoirs in Dehui Fault Depression, and the study of reservoir fluid inclusion characteristics and hydrocarbon accumulation stages has important guiding significance for the exploration and development of oil and gas resources in this area.

3. Sample Collection and Experimental Methods

The samples for fluid inclusion analysis are derived from the Deshen 33, Deshen 63, Deshen 83 wells in the Baojia Sag and the Deshen 36 well Yingcheng Formation reservoir in the Nong'annan Sag (Table 1), involving 4 wells and a total of 11 samples.

The research experiments were completefd in the Shaanxi Key Laboratory of Petroleum Accumulation Geology of Xi'an Shiyou University. The experimental procedures and technical requirements strictly abide by the the People's Republic of China nuclear industry standard SY/T 6010-2011 "Microscopic Thermometry Method for Fluid Inclusions in Sedimentary Basins" to carry out test experimental analysis. The experimental instrument for observing the phase state, distribution characteristics and genetic type of fluid inclusions is Leica4M experimental microscope. The composition test of fluid inclusions was identified on a RenshawinVia laser Raman instrument, and the sample was tested with 532 μm laser at room temperature and normal pressure. LinKam THMS600G microscopic cold and hot table was used for the determination of homogenization temperature and freezing point, and the measurement error was 0.1 ℃. The temperature measurement experiment was carried out at room temperature of 20 ℃ and humidity of 30 %. Experimental process: 1) Select rock samples, make inclusions thin slices, carry out petrographic analysis on the thin slices under the microscope, observe and identify the inclusions under the microscope, and determine the distribution characteristics, size, shape and gas-liquid ratio of oil and gas inclusions in different stages; 2) According to the distribution characteristics of fluid inclusions observed under the microscope, the secondary fluid inclusions in the secondary enlarged edge of the quartz particle formation period are mainly selected for analysis and study, 3) the composition of the inclusion body is identified and analyzed by laser Raman instrument, and the uniform temperature measurement experiment of the inclusion body is carried out by using the hot and cold table, and the uniform temperature and freezing point temperature are recorded.

Table 1: Testing inventory of inclusion samples in the study area

Well number	Depth/m	Structural unit	Lithology
Deshen 33	3940.1~3944.1	Baojia Sag	Tuffaceous coarse-grained fellitic lithic sandstone
Deshen 36	1833.7~1844.5	Nong'annan Sag	Coarse-medium-grained lithic feldspar sandstone
Deshen 63	2291.7~2302.5	Baojia Sag	Tuff
Deshen 83	4103	Baojia Sag	Tuff

4. Characteristics of fluid inclusions

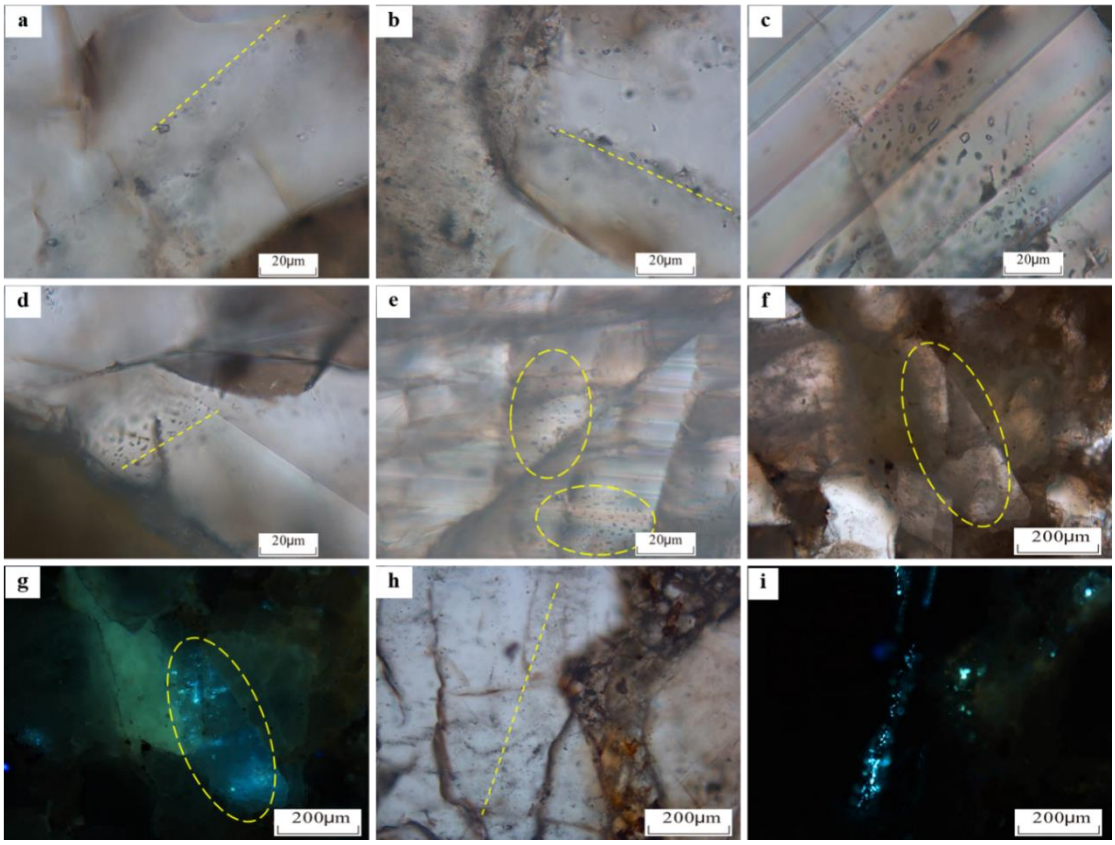
4.1. Petrographic characteristics

The petrographic characteristics of fluid inclusions in the study area are analyzed by combining single polarization and fluorescence microscopy. The type and occurrence of host minerals of fluid inclusions are observed and analyzed under a microscope, and the evolution and formation stages of oil and gas are analyzed. Observation and analysis of fluorescence identification photos of inclusions are the basis for studying the stage division of fluid inclusions and the degree of thermal evolution of organic matter.

The microscopic and fluorescence characteristics of reservoir fluid inclusions in the Yingcheng Formation of Dehui Fault Depression are shown in Figure 2. Through the observation and research on the core slice samples of the Yingcheng Formation of Dehui Fault Depression, it is found that the reservoir inclusions are mostly produced in the micro-cracks along the secondary enlarged edge of quartz particles after diagenetic period (Figure 2(a-b, d, h)), and a small part of them are produced in the calcite minerals filled with holes (Figure 2(c, e)), occasional feldspar corrosion particles (Figure 2(f)). Through the observation and study of the fluorescence photos of the core samples of the Yingcheng Formation in

ISSN 2616-5872 Vol.6, Issue 1: 75-83, DOI: 10.25236/AJEE.2024.060111

the Dehui Fault Depression, it is found that only the reservoir samples of the Yingcheng Formation in the Deshen 36 well in the Nong'annan Sag develop blue and white fluorescent gas-liquid hydrocarbons and liquid hydrocarbon inclusions, and the remaining sample inclusions show no fluorescence, indicating that the thermal evolution of organic matter in the southern part of the Dehui Fault Depression is relatively high.



(a) Well Deshen 33, 3940.1m, tuffaceous coarse-grained feldspar lithic sandstone, inclusions distributed along quartz particle micro-fracture zonation, with single polarization; (B) Well Deshen 33, 3944.1m, tuffaceous coarse-grained feldspar lithic sandstone, inclusions distributed along quartz particle micro-fracture zonation, with single polarization;(c) Well Deshen 63, 2291.7m, tuff, inclusions are distributed in calcite minerals filled with holes, with single polarization. (d) Well Deshen 63, 2302.5m, tuff, inclusions are microfissures along quartz particles after diagenetic period, with single polarization;(e) Well Deshen 83, 4103.0m, tuff, inclusions are distributed in groups in calcite minerals, with single polarization;(f) Well Deshen 36, 1834.3m, coarse-medium-grained lithic feldspar sandstone, with dissolution genesis and inclusions distributed in groups in feldspar particles, single polarization;(g) Well Deshen 36, 1834.3m, coarse-medium-grained lithic feldspar sandstone, colorless, gas-liquid hydrocarbon and liquid hydrocarbon inclusions showing blue-white fluorescence, fluorescence;(h) Well Deshen 36, 1837.2m, coarse-grained feldspar sandstone, the inclusions are distributed along the micro-fissure formation zone after the quartz grain diagenesis period; (I) Well Deshen 36, 1837.2m, coarse-grained lithic feldspathic sandstone, colorless gas-liquid hydrocarbon and liquid hydrocarbon inclusions showing blue-white fluorescence, fluorescent

Figure 2: Microscopic characteristics of fluid inclusions in Yingcheng Formation of Dehui Fault

4.2. Laser Raman Characteristics of Fluid Inclusions

Different substances have different Raman shift characteristic peaks, and the Raman shift peak of the same substance is basically stable within the corresponding range. Therefore, the type of substance can be determined according to the characteristic Raman spectrum shift peak of the substance [16]. Using laser Raman technology to analyze and identify inclusions developed in oil and gas bearing basins can realize qualitative analysis of single inclusions without damage and repeatability. In inclusions developed in petroliferous basins, the Raman shift characteristic peaks of common gas components are as follows [17-18]:① CH_4 characteristic peak (v_1) is 2917cm^{-1};② C_2H_6 characteristic peak (v_1) is 2954cm^{-1};③ C_3H_8

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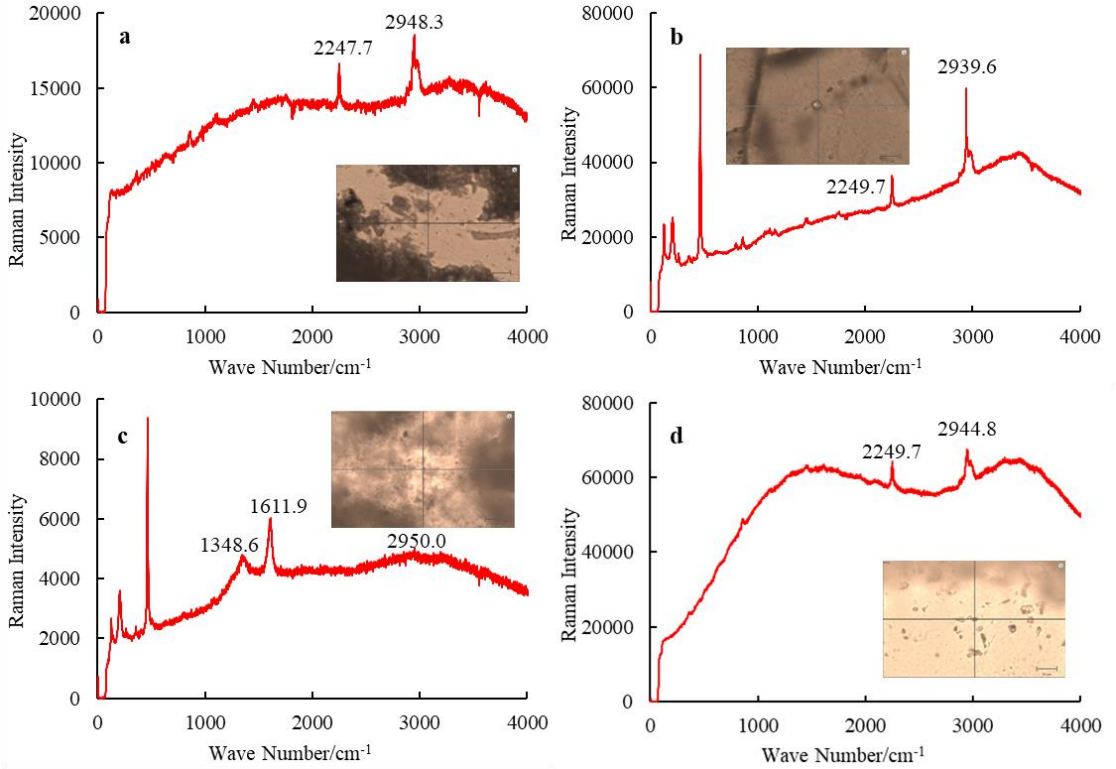
characteristic peak (v_1) is 2890cm^{-1};④ N_2 characteristic peak (v_1) is 2331cm^{-1};⑤ CO_2 has double characteristic peak resonance, the low frequency peak (v_1) is 1285cm^{-1} and the high frequency peak (v_2) is 1388cm^{-1}. It should be clear that the Raman shift peak of the same material is not exactly the same, and the Raman shift peak will vary in a small range due to the temperature, pressure, density and other conditions when the inclusion is captured, and the Raman shift peak of most gas molecules will decrease with the increase of pressure and density [19].

The experimental analysis of the samples in the study area shows that 27 effective gas hydrocarbon inclusion measuring points are obtained. The laser Raman spectrum analysis results of typical samples show that (Figure 3), the Raman characteristic peak of CH_4/C_2H_6 appears in the laser Raman spectrum of all measuring points, indicating that the gas composition of the inclusions in the Yingcheng Formation of Dehui Fault is mainly alkane gas. The laser Raman spectrum does not show the CO_2 gas composition, but the actual production contains CO_2 gas, indicating that the latter is filled in the late stage of the main diagenesis and does not form inclusions. The peak distribution range of Raman shift characteristics of inclusions in different well positions and depths of Yingcheng Formation in Dehui Fault Depression is relatively large (2939.6~2950.0 cm^{-1}), which indicates that the capture conditions of inclusions developed in the reservoirs of Yingcheng Formation in Dehui Fault Depression are quite different, and multi-stage oil and gas charging and accumulation processes may develop.



(a) Well Deshen 63, 2302.5m, single-phase hydrocarbon-containing inclusions; (B) Well Deshen 33, 3944.1m, single-phase hydrocarbon-containing inclusions;(c) Well Deshen 33, 3944.1m, asphaltene-containing hydrocarbon inclusions in quartz;(d) Well Deshen 83, 4103m, tuff, gas-liquid two-phase hydrocarbon-containing inclusions

Figure 3: Characteristics of laser Raman spectra of typical gas hydrocarbon inclusions in Yingcheng Formation of Dehui fault depression

4.3. Temperature characteristics of fluid inclusions

Microscopic thermometry of fluid inclusions is an important method used in the field of petroleum geology and mineralogy to study the temperature and geological processes in the geological history of the deep earth. Fluid inclusions are inclusions containing tiny liquids or gases in minerals, which record the conditions of temperature and pressure in the geological history of mineral formation. By analyzing the nature and characteristics of these fluid inclusions, we can understand the temperature change, the formation history of rocks and the process of fluid activity in the geological history of strata. There are obvious differences in the homogenization temperature distribution frequency of inclusions in different

ISSN 2616-5872 Vol.6, Issue 1: 75-83, DOI: 10.25236/AJEE.2024.060111

periods; therefore, the homogenization temperature of inclusions can be used as an effective parameter to judge the formation period of fluid inclusions.

According to the distribution characteristics of homogenization temperature of brine inclusions associated with hydrocarbon inclusions in the reservoir of Yingcheng Formation in the study area (Figure 4(a, B)), the homogenization temperature of inclusions in the reservoir of Yingcheng Formation ranges from 70 to 150 ℃, with a wide distribution range, but the overall difference of freezing point temperature is small, and the corresponding salinity is generally low, indicating that multi-stage inclusions are developed in the reservoir. According to the distribution characteristics of homogenization temperature of reservoir inclusions in wells Yingcheng Group of Deshen 33, Deshen 63 and Deshen 83 in Baojia Sag (Figure 4(c)), the homogenization temperature of inclusions in Baojia Sag is 80~150 ℃, and the main peak temperature is 110~140 ℃. According to the distribution characteristics of homogenization temperature of reservoir inclusions in Yingcheng Group of Well 36 in Nong'annan Sag (Figure 4(d)), the homogenization temperature of the inclusions is 70~140 ℃, and the main peak temperature is 70~100 ℃.

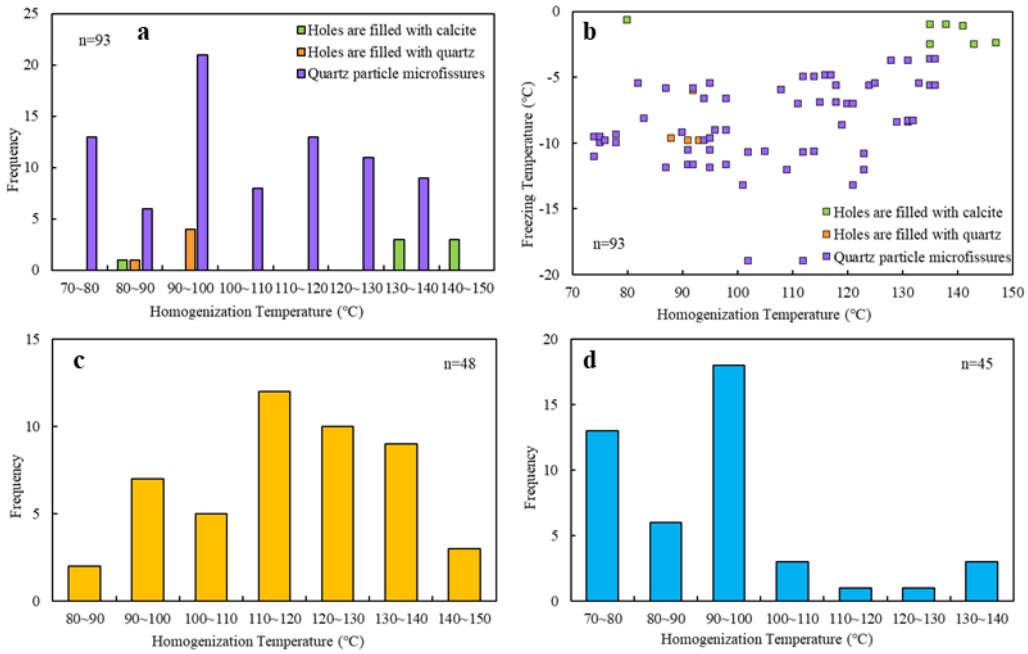


Figure 4: Temperature characteristics of fluid inclusions in Yingcheng Formation of Dehui Fault

4.4. Oil and gas accumulation period and time

In order to carry out the burial history-thermal history recovery, the single well burial history-thermal history of Deshen 63 and Deshen 36 wells was simulated. The faulted period of Dehui Fault Depression in Songliao Basin is a lacustrine sedimentary environment, and the sag period is a fluvial sedimentary environment. The paleogeothermal gradient in Songliao Basin is determined by using the vitrinite reflectance method to calculate the paleogeothermal flow data [20], and by using the data of inclusions temperature measurement and clay mineral transformation [21]. With the help of BasinMod-1D software for burial history-thermal history simulation, according to the results of single well burial history-thermal history simulation, combined with the oil and gas inclusions associated with the brine inclusions uniform temperature characteristics, the uniform temperature projection to the burial history-thermal history map to determine the oil and gas accumulation time, and then determine the oil and gas accumulation period.

Combined with the results of the simulation of the burial history-thermal history of the single well of the Deshen 63 well and the uniform temperature characteristics of the reservoir inclusions of the Yingcheng group of the well, the oil and gas charging period of the well was studied. According to the relationship between homogenization temperature of inclusions and thermal history, the oil and gas charging time of Yingcheng Formation of Well Deshen 63 is 100 ~ 94Ma and 80 ~ 72Ma, corresponding to the early sedimentary period of Quantou Formation and the late sedimentary period of Nenjiang Formation (Figure 5).

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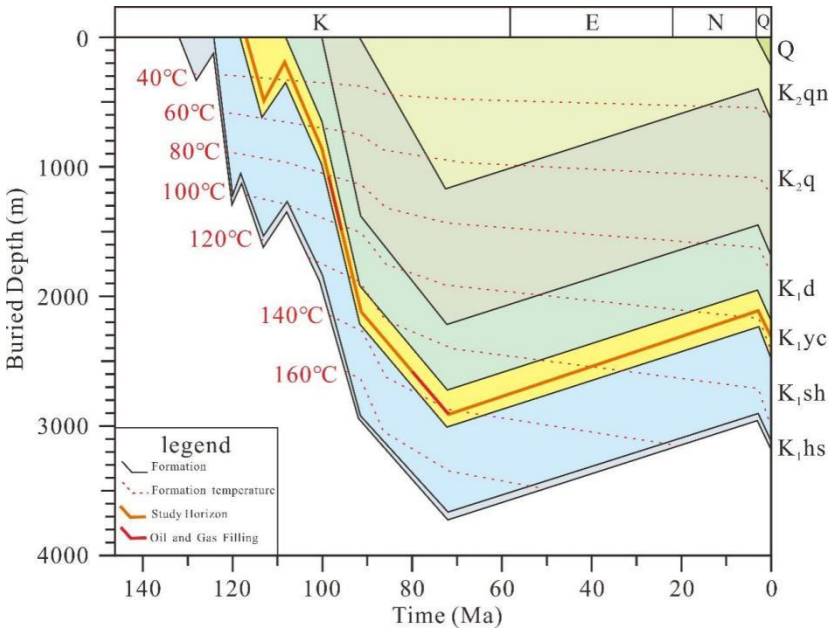

Figure 5: Burial history-thermal history of Well Deshen 63

Combined with the results of the simulation of the burial history-thermal history of the single well in Deshen 36 and the uniform temperature characteristics of the reservoir inclusions of the well Yingcheng group, the oil and gas charging period of the well was studied. According to the relationship between homogenization temperature and thermal history of inclusions, the oil and gas charging time of Yingcheng Formation of Well Deshen 36 is 92 ~ 82Ma and 76 ~ 72Ma, corresponding to the late sedimentary period of Qingshankou Formation-early sedimentary period of Nenjiang Formation and late sedimentary period of Nenjiang Formation (Figure 6).

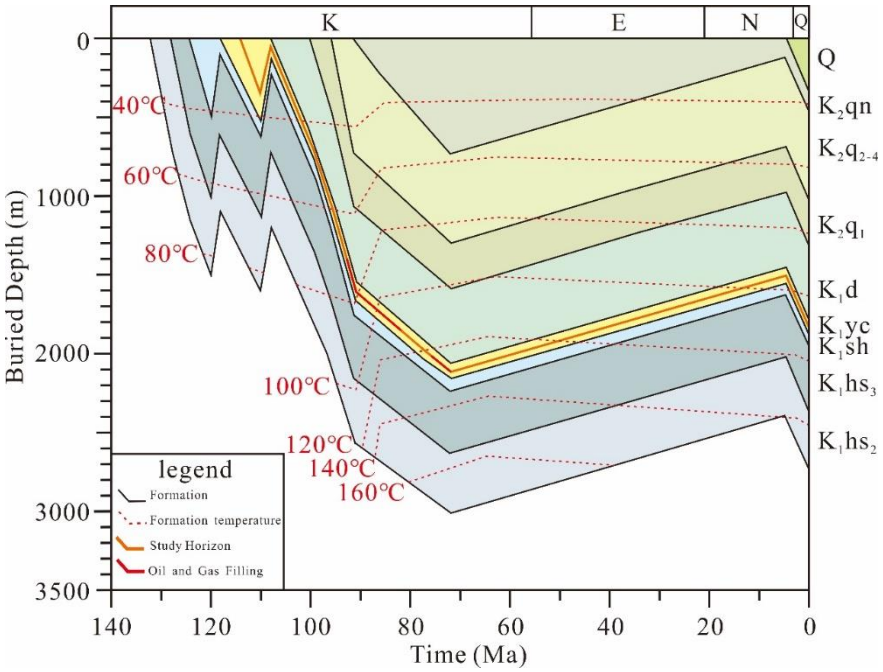

Figure 6: Burial history-thermal history of Well Deshen 36

5. Conclusions

(1) Reservoir inclusions in the Yingcheng Formation of the Dehui Fault are mainly distributed in quartz grain microfissures and pore-filled calcite minerals, and the gas composition is mainly alkane gas;

(2) Combined with the parameters of burial history-thermal history and inclusion homogenization

ISSN 2616-5872 Vol.6, Issue 1: 75-83, DOI: 10.25236/AJEE.2024.060111

temperature of wells Deshen 63 and Deshen 36 in Dehui Fault Depression, it can be determined that the Yingcheng Formation reservoir in Dehui Fault Depression has experienced two stages of accumulation. The alkane gas accumulation time of Yingcheng Formation in Deshen 63 Well in Baojia Depression is early, and the first stage is early Quangtou Formation (100 ~ 94Ma). The second stage is late Nenjiang Formation (80 ~ 72Ma; the oil and gas accumulation time of Yingcheng Formation of Deshen 36 well in Nong'annan Sag is late, the first stage is late Qingshankou Formation-early Nenjiang Formation (92 ~ 82Ma); the second stage is late Nenjiang Formation (76 ~ 72Ma); The overall reservoir formation characteristics are "early in the north and late in the south".

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