Characteristics of paleogeothermal field and its influence on hydrocarbon accumulation in Qingyang area

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Abstract. Geothermal field has an important influence on hydrocarbon accumulation. The geotemperature field in Qingyang area is studied by vitrinite reflectance and homogenization temperature of inclusions. The results show that the average geothermal gradient in Qingyang area is about 2.8 °C / 100M, which is close to the median value of global average heat flow. It belongs to the medium temperature type geothermal field. In Qingyang area, the geothermal gradient is low from Paleozoic to early Cenozoic, ranging from 2.2 °C to 3.0 °C / 100M, rising to 3.3-4.3 °C / 100m in the late Mesozoic, and gradually decreasing to 2.8 °C / 100M since Cenozoic. Generally speaking, high temperature field is favorable to the formation of petroleum system, and vice versa.

1. Introduction
The formation, evolution and scale of oil and gas are largely controlled by the geothermal field of the basin [1]. Due to the influence of tectonic thermal events, the geothermal gradient of Ordos Basin is low from Paleozoic to Mesozoic (2.2 ~ 3.0 °C / 100m), and the geothermal gradient increased to 3.3 ~ 4.3°C / 100m in the late Mesozoic, and gradually decreased to 2.8 °C / 100m since Cenozoic. High temperature field is favorable to the formation of petroleum system, and the low temperature field is unfavorable to the formation of petroleum system [2, 3]. In this paper, vitrinite reflectance and homogenization temperature of inclusions are used to study the geothermal field in Qingyang area, and the relationship between the geothermal field and hydrocarbon accumulation is revealed.

2. Geological background
According to the present structural form, Ordos basin can be divided into six tectonic units, i.e., Yimeng uplift, Jinxi flexure fold belt, Weibei uplift, Northern Shaanxi Slope, western margin thrust belt and Tianhuan depression. Qingyang area in the study area is located in the southwest of Ordos Basin, mainly across the Tianhuan depression and Yishan slope two first-order structural units (Fig. 1). The structural oil and gas reservoirs in Ordos Basin are rarely developed, and most of them are lithologic, stratigraphic and lithologic stratigraphic composite reservoirs. Generally speaking, Ordos Basin is a relatively stable large cratonic petroliferous basin [4].
Figure 1. The study area in Ordos Basin

3. Characteristics of paleogeothermal field
The paleogeothermal study of sedimentary basins has always been a very active field in Geoscience. Since the 1980s, the research methods of basin geothermal evolution history have been emerging and improved [5]. From the perspective of development trend, there are two obvious directions: one is the establishment and improvement of thermal evolution history model, from qualitative to quantitative development; the other is comprehensive comparative study of various paleogeothermal methods. More attention should be paid to the detailed geological research work in the paleogeothermal restoration, which is the precondition of paleogeothermal restoration.

3.1. Restoration of paleogeothermal by Ro
Vitrinite reflectance, as an organic matter maturity index, is widely used in basin analysis and petroleum geology research. Vitrinite refers to the gel formed by the biodegradation of lignin in higher plants. Vitrinite reflectance is the ratio of reflected light to incident light on the surface of vitrinite. It is usually expressed by the reflectance measured under an oil immersion objective, expressed by Ro. Vitrinite reflectance is one of the widely used and reliable methods in maturity measurement. When vitrinite undergoes thermal metamorphism, its reflectance increases irreversibly. Therefore, the reflectance of vitrinite retains the information of the maximum paleogeothermal temperature that has been reached during the evolution of the basin.

Since there is a corresponding relationship between vitrinite reflectance and paleogeothermal, the temperature at the maximum buried depth can be calculated by using the formula in \( (R_m) = 0.0096\text{Tmax} - 1.4 \) (\( R_m \) is the average vitrinite reflectance, \( \text{Tmax} \) is the maximum temperature corresponding to \( R_m \)), so the paleogeothermal gradient can be calculated according to the relationship established by Barker and pawlewicz[6,7]. A large number of temperature measurement data show that the current average geothermal gradient in Qingyang area is about 2.8 °C / 100m, which is close to the median value of global average heat flow, and belongs to medium temperature geothermal field. Based on a large number of vitrinite reflectance data collected in Ordos Basin, the paleogeothermal gradient of Late Mesozoic in Ordos Basin was restored according to various paleogeothermal restoration methods. The results show
that the paleogeothermal gradient in the late Mesozoic of Ordos Basin is mainly between 3.3 °C and 4.8 °C / 100m. Generally speaking, the geothermal gradient is higher in the late Mesozoic about 130 ~ 100ma, and the paleogeothermal gradient in the south of the basin is higher than that in the north of the basin. The geothermal gradient of well Qing 36 in the south of the basin is as high as 4.4 °C / 100 m at 130 ~ 100 Ma in the late Mesozoic (Fig. 2,3). This simulated value is close to the paleogeothermal gradient calculated by paleogeothermal scale.

3.2. Restoration of paleogeothermal by fluid inclusions

Fluid inclusions are part of the ore-forming fluid captured by the crystallization of diagenetic minerals. The composition, phase state, abundance, homogenization temperature and salinity index of fluid inclusions can reflect the geophysical and chemical conditions of different metallogenic stages. As a new method, fluid inclusions can be used to measure paleotemperature and restore basin geothermal history in petroleum geology, determine the degree and formation stage of oil and gas evolution, study the physical and chemical conditions of oil and gas formation, determine the migration time, direction
and channel of oil and gas, study the recovery of burial history and determine the formation period and sequence of structures.

After the formation stages of inclusions are determined, the homogenization temperature of inclusions in different stages is measured. After the homogenization temperature of inclusions is corrected to a certain extent, the paleogeothermal of mineral formation or oil-gas accumulation can be obtained, and the maximum paleotemperature of the rock stratum can be obtained. Furthermore, the paleotemperature gradient, buried depth and denudation thickness can be determined, and the geothermal evolution history of the basin can be restored.

The fluid inclusions in Ordos basin can be divided into multiple stages, among which the early primary inclusions are mostly distributed in quartz authigenic margin or early calcite cement. The number of such inclusions is small, and the measured temperature represents the formation temperature of the measured minerals. The late inclusions are mainly distributed in the micro fractures of clastic grains such as quartz or cements in the late diagenetic period. The homogenization temperature of these inclusions is obviously higher than that of the early ones. This kind of inclusions were formed when the strata in the late diagenetic stage approached or reached the maximum burial depth, which mainly reflected the paleogeothermal conditions and diagenesis of the late Mesozoic strata when they approached or reached the maximum burial depth Environmental Science.

The homogenization temperature of inclusions in Qingyang area is about 80 ~ 110 °C, and the formation temperature is 90 ~ 120 °C. The corresponding paleogeothermal gradient is 3.5 ~ 4.3 °C / 100m (Table 1).

| Well | Age | Depth (m) | Mineral composition | Homogenization temperature (°C) | Formation temperature (°C) | G (/100m) |
|------|-----|-----------|---------------------|---------------------------------|----------------------------|----------|
| Q-1  | T_y | 1262      | quartz              | 80~90                           | 90~100                     | 3.5      |
| Q-1  | T_y | 1262      | calcite             | 80~110                          | 90~120                     | 4.3      |

4. Influence of paleogeothermal on hydrocarbon accumulation
The maturity of source rocks is mainly controlled by the geothermal evolution and tectonic evolution of sedimentary basins. Generally, in the process of structural decline of sedimentary basins, the thermal generation of source rocks increases with the increase of burial depth as a result of normal sedimentary burial thermal processes. Hydrocarbon can only be generated when the source rocks are buried to a certain depth and reach a certain thermal degree. Under the normal reservoir management conditions of sedimentary basins, the thermogenic and thermal evolution history of hydrocarbon source rocks is controlled by the structural movement of sedimentary basins. The descending and uplifting processes of basins will lead to hydrocarbon generation or destruction and dissipation. During the subsidence period of basins, the source rocks generally generate progressive heat due to reservoir management Oil and gas are formed by evolution. In the process of basin uplift, the thermal evolution of source rocks will stop, and the maturity of organic matter will not increase, but it will not decrease due to basin uplift and cooling. Multiple tectonic subsidence and uplift in a basin can cause multiple hydrocarbon generation, accumulation and destruction of source rocks. The formation, migration and accumulation of oil and gas are related to the regional large-scale tectonic movement in the basin. Small scale short-term local tectonic movement is not enough to cause large-scale formation, large-scale migration and accumulation of oil and gas in the basin the formation, large-scale migration and main reservoir forming are inseparable from the major tectonic events in the key geological periods.

The Paleozoic Ordos Basin was a passive marginal basin with a geothermal gradient of 2.5 ~ 3.0 °C / 100m. From Late Paleozoic to early Mesozoic, the area belongs to coastal shallow sea basin in the early stage, and then transformed into inner craton basin in the later stage. The basin belongs to foreland basin with low geothermal gradient, ranging from 2.2 °C to 2.4 °C / 100m. In the late Mesozoic, strong Yanshanian movement occurred in the southern margin of the basin and its surrounding areas,
and the paleogeothermal gradient rose to 3.5 ~ 4.3 °C / 100m, which made the organic matter mature and entered the peak period of hydrocarbon generation.

5. Conclusion
The present geothermal field in Qingyang area is of medium temperature type, and its distribution is mainly in plane shape with multi-layer structure characteristics. The early Paleozoic geothermal gradient in Qingyang area is 2.5 ~ 3.0 °C / 100m. The geothermal gradient from Late Paleozoic to early Mesozoic is about 2.2 ~ 2.4 °C / 100m. In the late Mesozoic, the paleogeothermal gradient increased to 3.5 ~ 4.3 °C / 100m, which made the organic matter mature and entered the peak of hydrocarbon generation. Generally speaking, high temperature field is beneficial to the formation of petroleum system, and its scale is large, but high paleogeothermal will make source rock over mature and cause oil and gas to escape; low temperature field is relatively unfavorable to the formation of oil and gas system.

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