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Burial and thermal history of the Mesozoic marine sequences in the Qiangtang basin, northern Tibetan plateau: implication for the hydrocarbon preservation

Zhu Zhengping[1], Wang Licheng[2,*], Pan Renfang[1], Cui Yi[3], Gou Mingfu[4]
[1]Geosciences Academy of Yangtze University, Wuhan Hubei 430100, (CHINA)
[2]MLR Key Laboratory of Metallogeny and Mineral Assessment, Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing 100037, (CHINA)
[3]Coal Project Management Department, China Huaneng Group, Beijing 100031, (CHINA)
[4]CCDE Geophysical Prospecting Company, Chengdu 610213, (CHINA)

ABSTRACT

The Late Triassic to the early Cretaceous marine sequences of the Qiangtang Basin in the northern part of the Tibet Plateau has the best exploration prospect. The prototype basin has undergone multi-stage and complicated tectonic events and significant impact on petroleum preservation. Basin modeling was used to reconstruct the burial and thermal histories. The results showed that there was a rapid uplift and falling of palaeotemperature during the mid-Cretaceous which led no sedimentation of the Late Cretaceous in northern Qiangtang. While in southern Qiangtang, temperature falling was fairly gentle and the sedimentation and burial of the Late Cretaceous made the temperature rising up again. The event could damage the previously formed hydrocarbon traps especially in northern Qiangtang for the dramatically denudation.

KEYWORDS

Qiangtang basin; Cretaceous; Tectonic event; Hydrocarbon preservation.

INTRODUCTION

Tethyan domain is characterized by the high hydrocarbon production and the abundant reserves and known for its world famous petroleum production in the Middle East[16]. The Tibetan Plateau is located on the eastern Tethyan domain and long-term hydrocarbon prospects in Tibet have attracted the attention of some petroleum geologists, e.g., Taner and Meyerhoff[26,27], who acknowledged that the Tibet Plateau is poorly studied due to a harsh natural environment at very high altitude (avg. 4500-4700 m above sea level).

Basins with potential for commercial hydrocarbon accumulations in the Tibet Plateau can be divided into marine and continental sedimentary basins[28] (Figure 1A). The Mesozoic marine sequences of the Qiangtang Basin have the best exploration prospect in the Tibetan Plateau[28]. Comprehensive study since 1995 further confirmed that this basin has enormous potential hydrocarbon reserves and identified that the Mesozoic marine sequences are the target for hydrocarbon exploration[29,34,38]. The basin has undergone multi-stage and complicated tectonic events since the Cretaceous and became a typical superimposed basin[11,19]. These tectonic events significantly influenced the hydrocarbon accumulation in the Qiangtang Basin, especially mid-Cretaceous tectonic event[11,19,35]. However, little information between hydrocarbon accumulation and the mid-Cretaceous tectonic event was published. In this paper, we used an integrated approach of field survey, and basin modeling to reconstruct the burial and thermal history. Combined with previous data of apatite fission tract, the resulting data are used to constrain the influence of the tectonic event on the hydrocarbon preservation of the Mesozoic marine sequences in the Qiangtang Basin.

GEOLOGICAL SETTINGS

The Qiangtang Basin covers an area about 18.5×10^4 km^2, located on the central Tibetan Plateau, and is bounded by the Jinshajiang suture to the north and by the Bangong-Nujiang suture to the south (Figure 1A). Two sutures represented the remnants of Palaeo-Tethyan Ocean and Mid-Tethyan Ocean, respectively. The Qiangtang Basin had previous been divided into three parts: northern Qiangtang, central uplift, and southern Qiangtang[29,34] (Figure 1B). Tectonic features about ophiolites and high-pressure metamorphic rocks of the central uplift have been a subject of debate and controversy [12,13,17,22,29,34,37,38,40]. Recently advances in ophiolitic mélange indicated that the central uplift is a remnant of the Palaeo-Tethyan Ocean crust, named as Longmu TSo-Shuanghu suture[21,37] which represents the main Palaeo-Tethyan Ocean and be the westwards extension of the Changning-Menglian suture[21]. The basement of the Qiangtang block was poorly constrained. Wang and Wang[34] interpreted the Meso-Neo-Proterozoic Gemuri Group as the metamorphic basement, but the only dated basement rocks was discovered in Dugure Shan[22]. Guynn et al.[8,9] reported U-Pb zircon ages for the orthogneisses of the Ando basement and suggested the basement of the Qiangtang and Lhasa blocks is Neoproterozoic to early Paleozoic in age. However, it remains unknown whether or not a crystalline basement in the eastern part of Qiangtang exists[42].

The Qiangtang Basin is dominated by Upper Triassic-Early Cretaceous marine sequences with a thickness of more than 5000 m[11,19,29,34]. These marine deposits are unconformably overlain by the Late Cretaceous Abushan Formation[11,14,19] and underlain by the Lower Triassic sequence. The Jurassic sequences, which are the main targets for petroleum exploration, are composed of the Early Jurassic Quse Formation, the Middle Jurassic Quemo Co, Buqu, and Xiali Formations, the Upper Jurassic-Early Cretaceous Suowa and the Xueshan formations[29,34,35,38,40]. The source rocks are composed of Late Triassic Xiaochaka Formation, Buqu Formation and Xiali Formation, as well as the Suowa Formation[23,29,34, 38].

Mesozoic Qiangtang basin had previously been interpreted as foreland basin (Wang et al., 2001) or passive continental margin basin and back-arc basin[6,10]. Recently,[10] suggested a rift basin based on the volcanic rocks of the Late Triassic Nadigangri Formation. However, Zhai and Li[36] argued that these volcanic rocks were the result of a northward subduction of the Longmu Tso-Shuanghu suture in the Late Triassic. The Late Triassic granite formed in the post-collisional tectonic setting[11] and bimodal volcanism caused by post-orogenic collapse due to break-off of the subducting Western Qiangtang[37,41] support the view of foreland basin.

MATERIALS AND METHODS

No good-quality seismic data is yet available, and only few shallow drilling holes have been drilled for the severe natural conditions in the Qiangtang Basin. Consequently, hydrocarbon exploration is in the early evaluation stage. About four drilling holes are performed to basin modeling. These drilling holes named as QZ-2, QZ-3, QD-1, and QD-2. Drilling holes of QZ-2, QD-1, and QD-2 are located in southern Qiangtang while QZ-3 is located in northern Qiangtang (Figure 1B). The final depth of drilling hole QZ-3 is about 887 m and only the Suowa Formation was encountered in drilling. The final depth of drilling hole QZ-2, QD-1, and QD-2 is about 812 m, 712 m, and 847 m, respectively. The Buqu and Quse formations were encountered in QZ-2. The Xiali Formation was encountered in QD-1. The Buqu Formation was encountered in QD-2. Ninety core samples are collected for kerogen analysis and vitrinite reflectance (Ro) measurement. Ro measurements were performed under a Leica MPV Compact Ⅱ reflected light microscope fitted with an oil-immersion photomicrometer.

The burial and thermal histories are reconstruction based on Ro data using BasinMod software in order to characterize influence of the tectonic event. Backstripping analysis is employed to reconstruct the burial history. Processes of backstripping analysis are read in many papers (see details in Allen and Allen, 1990; Wang and Li, 2003; Shi, 2004, and references therein).

Geothermometer analysis is widely used for thermal history reconstruction[2,7]. Common geothermometers include vitrinite reflectance, Apatite fission tract (AFT), fluid inclusion, and newly U-Th-He method[30]. Wang and Wei[35] reconstructed the thermal history using AFT method. In this paper, we apply mainly Ro method to thermal history reconstruction.

BASIN MODELING

Burial history

When we reconstruct burial history of the Mesozoic Qiangtang Basin, the paleogeothermal gradient is calculated using Ro data. We used the Ro data of all four drilling holes to calculate the thickness, respectively. There is a positive correlation between depth and Ro data of QZ-3 (Figure 2A). Therefore, according to Barker et al. (1986) ($lnRo=0.0096T_{max}-1.4$)(1), the highest paleotemperature (T_{max}) was calculated and regression equation between T_{max} and depth (H) was generated (Figure 2B). The result is $T_{max}=0.073H+140.86$ (2). The equation (2) indicated that paleogeothermal gradient of the QZ-3 is 7.3℃/100 m.

Similarly, the regression equation between T_{max} and depth (H) in QZ-2 is Tmax=0.0564H+146.66 (3). The equation (3) indicated that paleogeothermal gradient of the QZ-3 is 5.64℃/100 m (Figure 3A). The regression equation between T_{max} and depth (H) in QD-1 is Tmax=0.0305H+166.9 (4). The equation (4) indicated that palaeogeothermal gradient of the QD-1 is 3.05℃/100 m (Figure 3B). There is no obviously positive correlation between depth and Ro data of QD-2. It might be caused by analytic error of Ro data. Therefore, the palaeogeothermal gradient cannot be calculated in QD-2.

Based on the thickness of denudation calculated by the palaeogeothermal gradient, BasinMod software was used in the burial modeling. The results indicate that there was two times of uplift-denudation in northern Qiangtang (Figure 4). The rapid uplift and denudation was occurred at the end of the Early Cretaceous to the early Late Cretaceous. It is indicated that the mid-Cretaceous tectonic event has significant influence on the Jurassic prototype basin. However, three times of uplift-denudation were indicated in southern Qiangtang (Figure 5, 6). Therefore, burial history indicated a different sedimentation-burial-uplift process in southern and northern Qiangtang. Namely, rapid uplift in northern Qiangtang led no sedimentation of the Late Cretaceous. The modeling results are similar to those of Liu et al.[20].

Thermal history

Based on the burial history of single hole and confined by evolution of palaeotemperature gradient, four drilling holes were modeled using EASY%Ro method[5,25], respectively. The calculated values of Ro can be correlative to measured Ro values indicating that the modeled results are reliable (Shi, 2004) (Figure 7,8).

The results showed that the Suowa Formation in QZ-3 reached the maximum palaeotemperature 180℃ at 100 Ma (Figure 4). Then the strata began to uplift and fall of palaeotemperature. During the end of the Paleogene, the temperature was fallen to 20℃. However, modeling results of holes in southern Qiangtang showed two obvious periods of high palaeotemperature. The Xiali Formation in QD-1 reached the highest palaeotemperature 160℃ at 125 Ma, which is the same with the Buqu Formation in QD-2 (Figure5, 6). Then the Xiali and Buqu formations began to uplift. At the late Paleogene, the formations reached the maximum palaeotemperature again. Thermal modeling indicated that there is a regional falling of palaeotemperature in the Qiangtang Basin. The results are similar to thermal modeling used apatite fission tract. Thermal modeling used AFT indicated that the Cretaceous tectonic event led to rapidly fall to surface palaeotemperature in northern Qiangtang, while temperature falling was fairly low in southern Qiangtang[35].

DISCUSSION AND CONCLUSIONS

The mid-Cretaceous tectonic event

The unconformable contact between the Abushan Formation and the underlying Jurassic sequences are widely distributed in the Qiangtang Basin (Figure 9A). The regional unconformity represented a tectonic event. Thus, the age of the tectonic event can be constrained by the age of overlying and underlying formations. Recently, Li et al.(2010) reported a zircon U-Pb age of 75.9 Ma at the bottom of the Abushan Formation. Combine previous ages of underlying sequences, the tectonic event might be took place during 125-75 Ma[11,19]. Moreover, the mid-Cretaceous tectonic event was also found in marine sequences of the Coqen Basin, approximately 200 km south of the Qiangtang Basin. There is a widely distributed unconformity between the Aptian-Albian Langshan Formation marine carbonate rocks and the overlying Late Cretaceous Jingzhushan Formation continental red beds[29,34,39] (Figure 9B). The unconformity shares the same time with those in the Qiangtang Basin and represent the same period of tectonic event. The mid-Cretaceous tectonic event led to termination of marine sedimentation in these basins and intensive shortening[11,19] and magmatic activities[15]. The event was believed to relate to closure of Bangong-Nujiang Mid-Tethyan Ocean caused by collision of Qiangtang and Lhasa blocks[14,15].

The mid-Cretaceous tectonic event can be inferred from basin modeling results. Basin modeling data based on Ro and AFT indicated that there was an extensive distributed uplift-denudation event during the end of the Early Cretaceous to the early Late Cretaceous. In northern Qiangtang, the event led to rapid falling to surface of palaeotemperature and substantially denudation. Geological map showed that the sediments of Late Cretaceous Abushan Formation barely in northern Qiangtang (BGMRT, 1993). While in southern Qiangtang, temperature falling was fairly gentle and the sedimentation and burial of the Late Cretaceous made the temperature rising up again.

The tectonic event and hydrocarbon preservation

The formation of possible traps in the Qiangtang Basin can only be speculated due to the lacking drilling and reliable seismic data. Our field observations suggested that structural traps such as folds and salt related traps, lithologic traps related to reefs and dolomite may occur within the Qiangtang Basin. The large-scale anticlines in the Jurassic strata began to develop during the late Jurassic-early Cretaceous[18]. These large-scale folds can be favorable traps such as the Long'eni palaeo-oil reservoir identified in the northern compound anticline belt in the Southern Depression[31]. The salt-related structure traps were interpreted to be developed in the late Jurassic or early Cretaceous[32]. Many platform margin reefs and platform reefs were found in the Buqu and Suowa formations in the Qiangtang Basin. Limited knowledge about the traps in the Qiangtang indicates that all traps were formed no later than the early Cretaceous. Therefore, the mid-Cretaceous tectonic event could damage the previously formed hydrocarbon traps especially in northern Qiangtang for the dramatically denudation. It can be evidenced by AFT data of the palaeo-reservoir. We reinterpreted the previous AFT data of the Long'eni palaeo-oil reservoir[29,34]. It is indicated that those AFT ages are in the interval 83-130 Ma and recorded the mid-Cretaceous tectonic event which made the destruction of the palaeo-oil reservoir. The denudation thickness using AFT data is about 1500 m in the Long'eni area[35]. Therefore, the Cretaceous tectonic event is unfavorable to hydrocarbon preservation in the Qiangtang Basin.

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