Marine and Petroleum Geology 59 (2015) 245–267

Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

Research paper

Geothermal regime and source rock thermal evolution in the Chagan sag, Inner Mongolia, northern China

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A R T I C L E I N F O

Article history:
Received 8 January 2014
Received in revised form
29 May 2014
Accepted 2 September 2014
Available online 10 September 2014

Keywords:
Thermal history
Chagan sag
Apatite fission track
Vitrinite reflectance
Rock thermal conductivity
Heat production rate

A B S T R A C T

The Chagan sag has the greatest oil and gas exploration potential among other sags in the Yingen Ejinaqi Basin, Inner Mongolia. The average geothermal gradient in the Chagan sag is 33.6 °C/km, whereas the heat flow ranges from 65.9 mW/m^2 to approximately 85.5 mW/m^2, with an average value of 74.5 mW/m^2. Thermal history reveals that the Chagan sag experienced the following 4 stages of thermal evolutions: (1) a rapidly increasing geothermal gradient stage from the Early Cretaceous Bayingebi Formation depositional period to the Early Cretaceous Suhongtu Formation depositional period; (2) a geothermal gradient peak stage during the Early Cretaceous Yingen Formation depositional period; (3) a high geothermal gradient continuation stage during the Late Cretaceous Wulansuhai Formation depositional period; and (4) a thermal subsidence stage during the Cenozoic. Tectonic subsidence analysis reveals that the area experienced an initial synrift subsidence during the Early Cretaceous followed by a subsequent long-term thermal subsidence since Late Cretaceous. Thermal and tectonic subsidence histories of this area are of great significance to petroleum exploration and hydrocarbon resource assessment because they bear directly on issues of source rock maturation. The maturation histories of the 3 sets of source rocks in the sag were modeled on the basis of the present geothermal field, thermal history and tectonic subsidence history. The results reveal that the hydrocarbon generation of the Chagan sag was controlled by the Early Cretaceous geothermal fields, and the source rock maturity reached the maximum at the end of the Yingen Formation depositional period. Moreover, the maturation evolution degree shows a difference for the 3 sets of source rocks. The source rocks of the Bayingebi 1 and 2 Formations reached the middle mature and dry-gas stage. In contrast, the source rocks of the Suhongtu 1 Formation only reached the early mature and middle mature stage. This work may provide new insights for the understanding of the oil and gas exploration potential of the Chagan sag.

1. Introduction

Geothermal regime of the sedimentary basin mainly includes present geothermal field and thermal history. A study of geothermal regime of an oilfield area has the significance of hydrocarbon resource assessment because it bears directly on issues of source rock maturation. The generation and accumulation of oil and gas is at certain temperature and depth conditions, and is the result during the long geological periods. During this long geological history, source rocks may suffer complex thermal history in response to regional geothermal regime, the spatial variance of source rocks and other changed conditions. This will result in source rocks undergoing complex hydrocarbon generation process, and it thus affected the hydrocarbon expulsion and migration, hydrocarbon accumulation period and spatial distribution of reservoirs. Therefore, the geothermal regime of a sedimentary basin is critical for petroleum exploration (Hu et al., 2001; He and Wang, 2004; McCormack et al., 2007; Belaid et al., 2010; Qiu et al., 2010, 2012; Zuo et al., 2010, 2011, 2013; Pang et al., 2012; Carminati et al., 2010; Hudson and Hanson, 2010; Sahu et al., 2013).

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http://dx.doi.org/10.1016/j.marpetgeo.2014.09.001
0264-8172/

China is one of the biggest petroleum consumption countries, and more than half of the crude oil [>2 × 10^8 t (14 × 10^8 bbl)] depends on import by 2012. The production of the Chinese traditional large oilfields, including Daqing Oilfield, Shengli Oilfield, Zhongyuan Oilfield, is beginning to decrease, which seriously restricts the economic development in China. To address this issue, China has enhanced resource surveys in the Mesozoic rift basins on land, such as the Yingen–Ejinaqi Basin [Mesozoic effective sedimentary strata covering an area of 10.4 × 10^4 km^2 (4.0 × 10^4 mi^2)], Erlian Basin [about 10.0 × 10^4 km^2 (3.9 × 10^4 mi^2)], Hailaer Basin [about 7.1 × 10^4 km^2 (2.7 × 10^4 mi^2)] in the Inner Mongolia (Fig. 1), which show a great promise for petroleum resources. Exploration has validated certain petroleum resources in these Mesozoic rift basins. The petroleum reserves are proved to exceed 10 × 10^8 tons (70 × 10^8 bbl) in the Hailaer Basin so far and the Erlian and Hailaer Basins have reached millions of tons of annual production. Moreover, a large number of petroleum resources were discovered in the Chagan sag of the Yingen–Ejinaqi Basin. More than 0.5 × 10^8 tons (3.5 × 10^8 bbl) of petroleum reserves and two new oilfields (i.e., Jixiang and Ruyi oilfields) have been discovered in the Chagan sag so far. Especially, the highest yield of well Y9 reached 7.9 tons (55.3 bbl) per day in the central structural zone; the highest yield of the wells X6 and X6-1 reached 8.4, 21.9 tons (58.8, 153.3 bbl) per day (flowing) in the Wuliji structural zone since October 2012. These discoveries indicate that the Chagan sag is a promising exploration area. The exploration breakthrough of the Chagan sag will guide oil and gas exploration of other structural units in the Yingen–Ejinaqi Basin. However, there are still some problems restricting oil and gas exploration in the Chagan sag. For instance, the study of geothermal regime is rather poor, which severely restricts the understanding of maturation history, hydrocarbon generation and expulsion histories, accumulation period and resource potential. In recent years, with oil and gas exploration rapidly developing and the number of boreholes increasing, and a large number of rock thermal conductivity, heat generation rate, AFT and R_o data were measured. These provided the basis data for the study of geothermal regime in the region. It is thus possible to study the geothermal regime and model source rock maturation history, discuss the relations between the source rock thermal evolution history and oil and gas distribution, and point out the favorable directions of oil and gas exploration. This work may provide the geothermal regime, source rock maturation evolution information for further exploration of the Chagan sag and other structural units in the Yingen–Ejinaqi Basin.

2. Geologic setting

The Chagan sag has the greatest oil and gas exploration potential among other sags in the Yingen–Ejinaqi Basin (Zuo et al., 2013). The Yingen–Ejinaqi Basin is a Mesozoic rift basin, developing on the Precambrian crystalline block and the Paleozoic fold basement (Wei et al., 2006). It is surrounded by the Lang Hill to the east, the North Hill to the west, the North Great Hill and the Yabrai Hill to the south, the China-Mongolian border, the Honggeerji Hill and the Mongan Wula Hill to the North. The Yingen–Ejinaqi basin, about 600 km (1968, 504 ft) long in its east-west direction, 75–255 km (246,063–836,614 ft) wide in its south-north direction, an area of 12.3 × 10^4 km^2 (4.7 × 10^4 mi^2), is located from 39°N to the Mongolian border, from 99°E to 108°E. The effective Mesozoic sedimentary strata cover an area of 10.4 × 10^4 km^2 (4.0 × 10^4 mi^2). The Yingen–Ejinaqi Basin consists of 8 depressions and 5 uplifts and has experienced four tectonic episodes since the Triassic, among which, the tectonic movements at the end of the Late Jurassic and the Early Cretaceous had a significant impact on the formation and evolution of the basin (Wei et al., 2006; Liu et al., 2006; Chen et al., 2006). The tectonic episodes included: (1) a initial rifting phase from the Late Triassic to the Jurassic, including post-orogenic relaxation stage in the Late Triassic; uplift and erosion stage at the end of the Late Triassic due to the late Indosinian tectonic movement; initial rifting stage due to subduction effects of the East Pacific Plate and southward effect of the Siberia Plate in the Early Jurassic; rifting enhancement stage due to the 2nd episode of Yanshan intense movement at the end of the Middle Jurassic and renewed uplift and erosion stage due to the 3rd episode of Yanshan

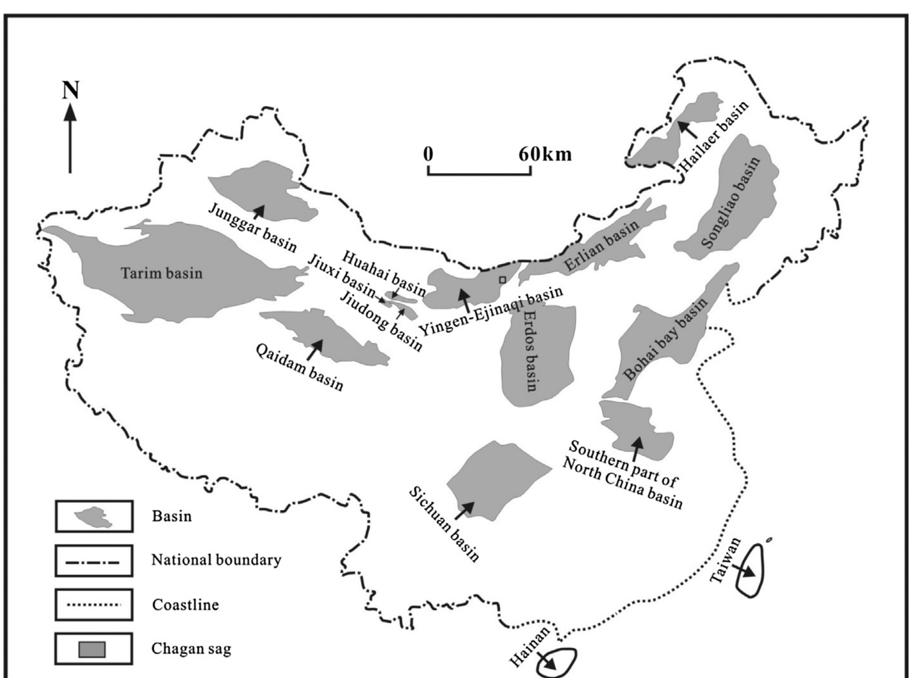

Figure 1. Major oil and gas basins on land in China.