Journal of Petroleum Science and Engineering 139 (2016) 171–184

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

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

Mesozoic and Cenozoic thermal history and source rock thermal evolution of the Baiyinchagan sag, Erlian Basin, Northern China

Yinhui Zuo [a,b], Changcheng Wang [a,b,*], Shilin Tang [a,b], Qingqing Hao [c]

[a] State Key Laboratory of Oil and Gas Geology and Exploitation, Chengdu University of Technology, Chengdu 610059, China
[b] College of Energy Resources, Chengdu University of Technology, Chengdu 610059, China
[c] Institute of Mineral Resource Research, China Metallurgical Geology Bureau, Beijing 100025, China

ARTICLE INFO

Article history:
Received 25 January 2015
Received in revised form
23 December 2015
Accepted 24 December 2015
Available online 25 December 2015

Keywords:
Baiyinchagan sag
Thermal history
Mesozoic and Cenozoic
Mature
Basin modeling

ABSTRACT

The hydrocarbon-bearing Baiyinchagan sag is located in the west of the Erlian Basin in the Inner Mongolia, Northern China. Its potential source rocks include the Lower Cretaceous Aershan, Tenggeer and Duhongmu 1 Formations. The former two formations are major source rocks. They are dominated by dark mudstone with the largest thickness of 560-600 m, and mainly distributed in the western sub-sag.

In this study, temperature data from three wells used to calculate the present-day geothermal gradient in the sag, and used 144 vitrinite reflectance measurements from 35 wells together with seven apatite fission track data from seven wells to reconstruct the Mesozoic and Cenozoic thermal history. The results show that the present-day geothermal gradient is 35.1 °C/km. In the Early Cretaceous, the geothermal gradient was 40.0–42.1 °C/km during the early deposition of the Aershan Formation (135–110 Ma), and then increased to 49.9–56.4 °C/km at the end deposition of the Saihantala Formation (100–95 Ma). The geothermal gradient decreased to a present-day value of 32.0–35.4 °C/km.

Using this model of thermal history, combined with the source rock geochemistry, the maturation histories of three source rock intervals, including the Aershan, Tenggeer and Duhongmu 1 Formations, were modeled. The modeled results suggest that source rock maturation was controlled by palaeo geothermal gradient, and that source rocks in the eastern sub-sag have not reached hydrocarbon generation threshold (0.5% R_o). In the western sub-sag, Aershan Formation source rocks reached a high mature ($1.0\% < R_o < 1.3\%$) with greater hydrocarbon generation potential, and the Tenggeer Formation is mid-mature ($0.7\% < R_o < 1.0\%$). The Duhongmu 1 Formati$_o$n possesses the least hydrocarbon generati$_o$n potential ($0.5\% < R_o < 0.7\%$) at the present day.

1. Introduction

The thermal history of a sedimentary basin controls source rock maturation evolution (Qiu et al., 2010a, b, 2012a; Sahu et al., 2013; Zuo et al., 2010, 2011, 2015) and hydrocarbon generQiuation and expulsion history (Pang et al., 2004, 2012; Kosakowski, et al., 2013; Zuo et al., 2010, 2011), and therefore petroleum resource assessment (Zuo et al., 2010). It also provides information for basin formation mechanism and tectono-thermal evolution (Rudnick et al., 1998; Hu et al., 2001; Marechal and Jaupart, 2004; Qiu et al., 2012b; Zuo et al., 2013a; Qiu et al., 2014).

China is one of the biggest petroleum consumption countries, and more than half of the crude oil (more than 14×10^8 bbl) depends on import by 2014. 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 Erlian Basin (about 10.0×10^4 km^2), Yingen-Ejinaqi Basin (about 10.4×10^4 km^2), Hailaer Basin (about 7.1×10^4 km^2) in the Inner Mongolia (Fig. 1a), 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 70×10^8 bbl in the Hailaer Basin so far, and the Erlian and Hailaer Basins have reached millions of tons of annual production.

The Baiyinchagan sag, located in the western margin of the Chuanjing depression, has one of the greatest oil and gas exploration potential in the Erlian Basin. Moreover, the oil and gas has been found only in the Baiyinchagan sag for the Chuanjing depression (Chen et al., 2014). Oil and gas shows were discovered in the Baiyinchagan sag in the early 1980 s; commercial oil and gas flow was found in 1994. More than 150 wells have so far been

* Corresponding author at: State Key Laboratory of Oil and Gas Geology and Exploitation, Chengdu University of Technology, Chengdu 610059, China.
E-mail address: wcc-126@163.com (C. Wang).

http://dx.doi.org/10.1016/j.petrol.2015.12.025
0920-4105/

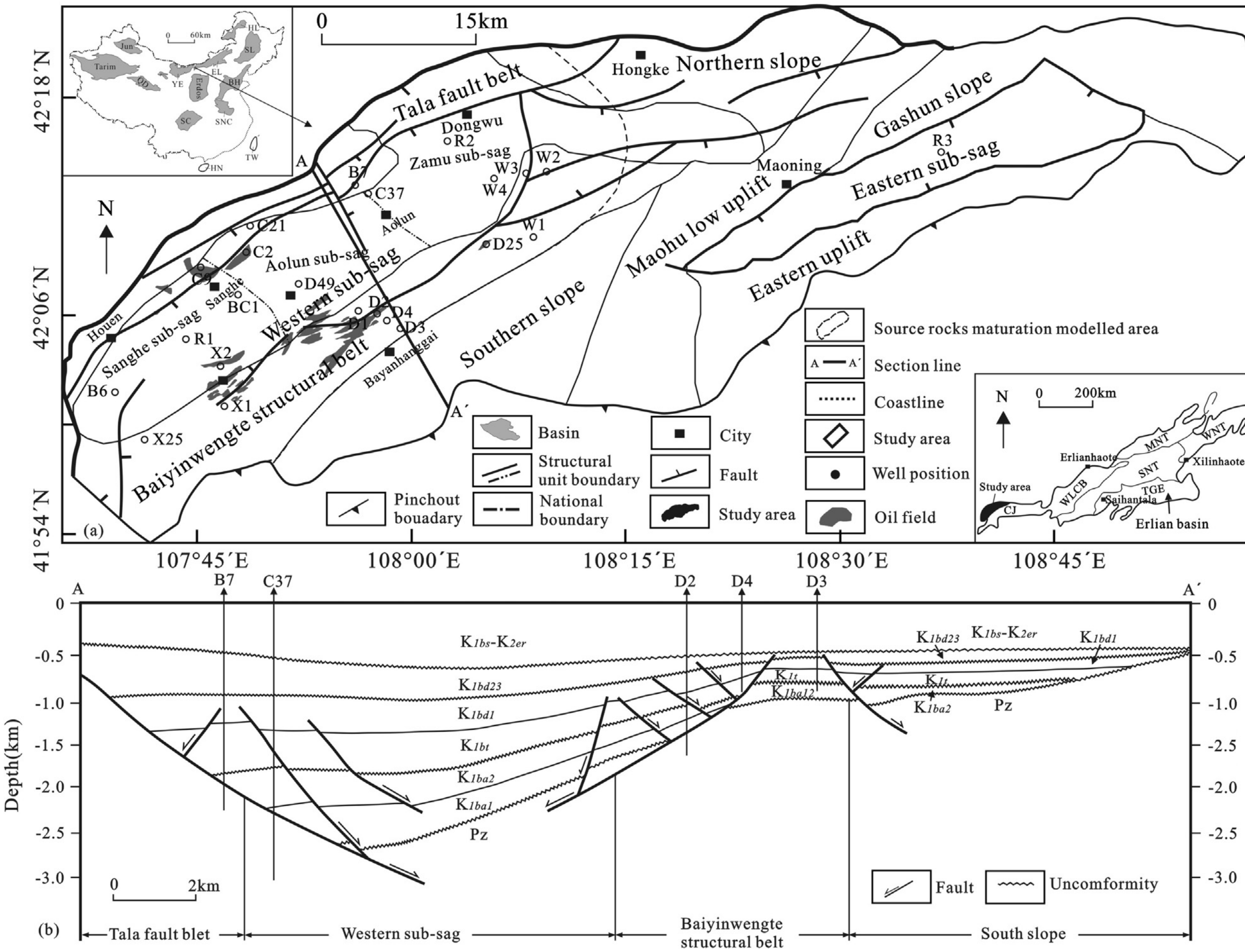

Fig. 1. (a) Structural unit division of the Baiyinchagan sag (modified from Deng, 2013); (b) Structural profile map (modified from Wang, 2006). Jun=Junnggar; QD=Qaidam; YE=Yingen-Ejinaqi; EL=Erlian; HL=Hailaer; SL=Songliao; BH=Bohai Bay; SNC=Southern part of North China; SC=Sichuan; HN=Hainan; TW=Taiwan; CJ=Chuanjing depression; WLCB=Wulanchabu Depression; WNT=Wunite depression; TGE=Tenggeer depression; MNT=Manite depression; SNT=Sunite uplift.

drilled. Oil and gas shows and commercial discoveries have been made in the West Daerqi, Daerqi, Sanghe, Wengte, Xilinhaolai and Guer areas, and the Daerqi, Sanghe and Xilinhaolai oilfields with reserves of more than 35×10^6 bbl. More than 560×10^6 bbl of oil reserves has so far been found in the Baiyinchagan sag and exploration is continuing.

However, there are still some problems restricting oil and gas exploration in the Baiyinchagan sag. Petroleum resources appear to be clustered in the Sanghe and Aolun in the western sub-sag. While there have been no commercial oil and gas discoveries in the eastern and Zhamu sub-sags whose exploration potential is uncertain. The thermal history of the Baiyinchagan sag has been little documented which restricts understanding of the source rock maturation history, hydrocarbon generation, expulsion and timing, and the resource potential. Moreover, source rock maturation has not been systematically studied.

In this paper, the Mesozoic and Cenozoic thermal history of the Baiyinchagan sag was modeled based on the vitrinite reflectance (R_o) and apatite fissure track (AFT) data. Based on the thermal history, the source rock maturation history was then modeled, and the relationship between source rock maturation history and oil and gas distribution were discussed.

2. Geological setting

The Baiyinchagan sag (longitude 107 °30′ to 109 °10′; latitude 41 °50′ to 42 °30′) is a second-order structural unit in the Chuanjing depression, Erlian Basin (Fig. 1a). The Erlian Basin is a Mesozoic rift basin, developing on the Inner Mongolia-Daxinganling Hercynian fold basement (Yu, 1990; Ren et al., 2000; Cui et al., 2011; Li et al., 2012). It located in central-northern Inner Mongolia, China. It is surrounded by the Daxinganling to the east, the Wulatehouqi to the west, the Yin Mountains to the south, the China-Mongolian border to the north. The Erlian Basin, about 1000 km (east to west), 20–220 km (south to north), an area of 10×10^4 km^2, is one of the largest onshore sedimentary basins in China. The Erlian Basin consists of five depressions and an uplift, and forty-five sags and twenty-one uplifts.

The Erlian Basin has experienced five phase of tectonism since the Mesozoic (Yu, 1990; Cui et al., 2011; Li et al., 2012). These phases are (1) a crustal uplift stage during the Triassic, including regional crustal uplift, missing the Triassic sedimentary, and strong volcanic activity accompanied by acidic magma intrusion; (2) an initial rifting stage during the Jurassic, with a lot of heat dissipation within the crust, mantle uplift shrinkage and tensile rupture gradually expanded in the Early-middle Jurassic, forming NNE-NE trending tensional rifts with deposition of 300–1000 m mudstone, sandstone, conglomerate and coal; Late Jurassic, the Erlian Basin N–W trending extensional strengthened in respond to the Pacific plate subduction to the Asian continent, volcanism frequently along the NE-NNE trending faults, and developing a set of volcanic and volaniclastic rocks; (3) an intense rifting phase