Burial and thermal histories of the Yingshan Formation in Well GC-6, Gucheng Low Uplift

Rui Deng¹,², Chengsheng Chen¹,², Shuyong Shi¹,², and Yunpeng Wang*¹
¹ State Key Laboratory of Organic Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640, China
² University of Chinese Academy of Sciences, Beijing 100049, China

Corresponding author e-mail: wangyp@gig.ac.cn

Abstract. The burial and thermal histories of the Yingshan Formation in Well GC-6, Gucheng Low Uplift, were constructed in detail by using the PetroMod software. The results show that the Gucheng Low Uplift has experienced multiple stages of tectonic movement and the Hercynian movement had the most important impacts on the study area. The burial depth of the Yingshan Formation reached its maximum (>6300 m) in the Middle Devonian. The deep burial of strata and the high heat flow in the early times made the maturity of Yingshan Formation reached its maximum value of nearly 2.5%Ro in the Late Devonian and did not change anymore. The favorable paleo-structural background, good source-reservoir-seal assemblage and developments of deep strike-slip fractures made a high yield gas reservoir formed in the Yingshan Formation, Well GC-6.

1. Introduction
The Tarim Basin is one of the richest oil and gas bearing basins in China, which has undergone complex tectonic movements [1]. The burial and thermal histories of the basin, closely related to its tectonic evolution, play important roles in controlling the formation, migration, and accumulation of hydrocarbons. The Yingshan Formation in Well Gucheng-6 (GC-6) has achieved a major breakthrough with daily gas production of 267,000 m^3 in 2012, which made the Gucheng Low Uplift become an important exploration target in the Tarim Basin [2]. However, in previous work [3], the simulation of its burial and thermal histories is not precise and the process is missing. Therefore, in this paper, burial and thermal histories of the Yingshan Formation, Well GC-6 were constructed in detail by using the PetroMod software, aiming to reveal the tectonic evolution characteristics and maturity evolution process in the study area, which can also provide data for the next step of oil and gas exploration in the adjacent areas.

2. Geological Setting
The Tarim Basin is the largest superimposed basin in the northwestern China, containing four uplifts (the Tabei Uplift, the Bachu Uplift, the Tazhong Uplift and the Tadong Uplift) and five depressions (the Kuqa Depression, the Northern Depression, the Tanggu Depression, the Southwestern Depression and the Southeastern Depression) [4]. The Gucheng Low Uplift is a Lower Paleozoic large-scale nose-shaped structure plunging to the northwest, which is located in the south-central of the Northern Depression, the triangle area of the Tazhong No.1 fault belt and Che’erchen fault belt (Figure 1). It is surrounded by the Manjiaer Depression to the north, the Tazhong Uplift to the southwest, and the...
Tadong Uplift to the east [5]. Well GC-6 is in the No. 6 lithologic trap of the Gucheng Low Uplift, with a borehole of 6169 m. It encountered strata from the Quaternary to the Lower Ordovician from top to bottom with the absence of Silurian, Devonian, Permian and Jurassic strata. The high yield gas reservoir was discovered in the Yingshan Formation (O$_3$, 6144-6169 m).

![Figure 1. Map showing the location of Well GC-6 and the geological structures of the Gucheng Low Uplift (modified from Reference (no 4)).](image)

3. Methods and Data

3.1. One-dimensional (1D) basin modeling method
The burial and thermal histories of the Yingshan Formation (O$_3$), Well GC-6, were modeled using the PetroMod 2016 (1D) software developed by Schlumberger Limited. The primary input parameters contain stratigraphy (age, thickness, and lithology), tectonic events (unconformities, erosion time, and erosion thickness), and boundary conditions (heat flow, paleowater depth, and sediment-water interface temperature) [6]. During the simulation process, the measured values of maturity and porosity were used to validate modeling results. The burial and thermal histories were finalized once the modeled and measured maturity and porosity were consistent. The maturity was calculated by the EASY%Ro model in the software [7].

3.2. Input data for 1D basin modeling
The fundamental strata data (age, thickness, and lithology) were collected from the logging report of the Tarim Oil Company. Erosion events have vital impacts on burial and thermal histories. The specific erosion time and erosion thickness of Well GC-6 were obtained from [8]. For boundary conditions, the evolution of the heat flow is crucial to the thermal maturity history and its values were derived from [9]. The values of paleowater depth were estimated by the sedimentary environments and the sediment-water interface temperature was calculated automatically after inputting the latitude of the well to PetroMod. The calibration data were collected from [10] and the logging report.

4. Results and Discussion

4.1. Burial and thermal histories
As revealed in Figure 2, the modeled values of vitrinite reflectance (%Ro) and porosity have a good fit with the measured values, indicating the reliability of burial and thermal simulation results. The burial history overlaying with the thermal history of Well GC-6 is shown in Figure 3(a), which illustrates that the Gucheng Low Uplift, a long-term inherited paleo-uplift, has experienced multiple stages of tectonic movement. The study area was in the stable carbonate platform development stage during the Cambrian-Middle Ordovician and encountered a slight erosion in the Late Middle Ordovician. During
the Late Ordovician, it was characterized by the rapid subsidence and the mudstone with the great thickness (>2200 m) was deposited. Subsequently, the burial depth of the Yingshan Formation reached its maximum (>6300 m) in the Middle Devonian. Then during the Late Devonian, the greatest uplift and erosion happened and the Gucheng Low Uplift was formed. The tectonic movements followed showed little influences on the structure of Gucheng Low Uplift. Among all these movements, the Hercynian movement had the most important impacts on the study area.

**Figure 2.** A good fit between the measured porosity, maturities and the modeled results of Well GC-6.

**Figure 3.** The burial history overlaysing thermal maturity history (a) and heat flow evolution (b) of Well GC-6.
The evolution of heat flow in the Tarim basin is also shown in Figure 3(b), which reveals an overall decreasing trend except for the abnormal thermal event happened in the Permian. In general, the Tarim Basin belongs to the cold basin as a whole and the present heat flow is nearly 50 mW/m². The thermal history is closely related to the evolutions of heat flow and burial depth. As shown in Figure 3(a), the maturity of Yingshan Formation increased slowly at the beginning and reached the mature stage (>0.5%Ro) in the Early Silurian. Then the maturity showed a rapidly increasing trend with the deep burial of strata and got to the over-mature stage (>2.0%Ro) in the Middle Devonian. Finally, it reached its maximum value of nearly 2.5%Ro in the Late Devonian and did not change anymore.

4.2. Features and forming conditions of the gas reservoir in Well GC-6

The gas reservoir in Well GC-6 was originated from the Cambrian and Lower Ordovician source rocks in the Manjiaer depression and then accumulated in the carbonate reservoir of Yingshan Formation (Lower Ordovician). The overlying mudstone of the Que’erqueke Formation (Upper Ordovician) serves as regional caprocks with a thickness of more than 2000 m. The deep strike-slip fractures provided ways for hydrocarbons migration and reservoir reconstruction. The gas reservoir is mainly composed of methane (89.4-91.4%), and the content of nonhydrocarbon gas (CO₂ and N₂) varies from 8.4-9.9%, which reveals that the dry coefficient is very high (99.7%) and the gas is overmature. The carbon isotopic composition of the gas in Well GC-6 is in the order of δ¹³C₂<δ¹³C₃<δ¹³C₁, and the concrete values of δ¹³C₁, δ¹³C₂ and δ¹³C₃ are -33.6‰, -37.6‰ and -34.9‰, respectively, which illustrates that the gas belongs to oil cracking gas, originating from type II kerogen [11].

5. Conclusions

The modeled burial history shows that the Gucheng Low Uplift has experienced multiple stages of tectonic movement, causing the absence of Silurian, Devonian, Permian and Jurassic strata. Among all the movements, the Hercynian movement had the most important impacts on the study area. The burial depth of the Yingshan Formation reached its maximum (>6300 m) in the Middle Devonian. The evolution of heat flow shows an overall decreasing trend except for the abnormal thermal event happened in the Permian. The deep burial of strata and the high heat flow in the early times made the maturity of Yingshan Formation reached its maximum value of nearly 2.5%Ro in the Late Devonian and did not change anymore. The favorable paleo-structural background, good source-reservoir-seal assemblage and developments of deep strike-slip fractures made a high yield gas reservoir formed in the Yingshan Formation.

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