The Burial and Thermal Histories of Wufeng-Longmaxi Shale of Well Anye-1, Zheng’an Area, North Guizhou

Shuyong Shi¹², Yunpeng Wang¹, Yu Sun¹², Min Liu¹²
¹ State Key Laboratory of Organic Geochemistry, Guangzhou Institute of Geochemistry, Guangzhou, 510640, China
² University of Chinese Academy of Sciences, Beijing, 100049, China
Corresponding author e-mail: wangyp@gig.ac.cn

Abstract. Great breakthrough had taken place in the field of shale gas exploration of Wufeng-Longmaxi shale in Zheng’an Area, North Guizhou. In this paper, we reconstruct the one-dimensional geological model of Well Anye-1 by using PetroMod software. The burial history shows that the Wufeng-Longmaxi shale of Well Anye-1 mainly experienced four erosion movements. It reached the maximum burial depth (5331 m) at the late Cretaceous and the current burial depth is 2331 m. The thermal history shows that the shale started to generated oil (Ro>0.55 %) at the middle Devonian, entered into the wet gas stage (Ro=1.30-2.00%) at middle Jurassic and the dry gas stage (Ro>2.00 %) at the end of early Cretaceous, and now the thermal maturity is around 2.07 %Ro.

1. Introduction
The Upper Ordovician Wufeng formation and the Lower Silurian Longmaxi formation are widely distributed in the Sichuan basin and its adjacent areas. Compared with Changning and Jiaoshiba areas, the thickness of high-quality shale of Wufeng-Longmaxi shale is about 30 m in North Guizhou [1]. Besides, the North Guizhou is located in the basin-orogen transitional belt and the geological preservations are extremely complicated [2]. The shale gas exploration is still in the primary stage and its prospect is also not clear [3]. In 2016, the Well Anye-1, which is located in Zheng’an Area, North Guizhou, was successfully drilled and acquired commercial shale gas flow in the Wufeng-Longmaxi formations [4]. In this study, we reconstruct the one-dimensional geological model of Well Anye-1 by using PetroMod software, and the purpose is to recover the burial and thermal histories of Wufeng-Longmaxi shale in Zheng’an Area, North Guizhou.

2. Geological Setting
North Guizhou is located in the basin-orogen transitional belt and it belongs to the part of upper Yangtze Block [2, 5] (Figure. 1). The Wufeng-Longmaxi shale is only distributed in North Guizhou due to the Qianzhong paleo-uplift to the south [6]. As shown in Figure 1, Well Anye-1 is located in the core part of Anchang syncline. The burial depth of Wufeng-Longmaxi shale is 2331 m and the thickness of high quality (TOC> 2.00 %) shale is 19.5 m [4]. The lithologies are organic-rich shale, carbonaceous shale, and siliceous shale with abundant graptolites.

3. Model construction and calibration
We establish one-dimensional geological model based on the measured drilling data of Well Anye-1 [4, 7]. The modeling procedures could be mainly divided into two parts: basic data inputting and calibration. The basic data includes the lithology, thickness and its depositional age, erosional thickness and age. Besides, the boundary conditions, such as paleo water depth, sediment-water interface temperature and heat flow, should also be considered into our model. Finally, we use some measured data to constrain our model. As shown in Fig. 2b, the measured Ro data show a good correlation with the calculated thermal maturity from Sweeney & Burnham model [8].

4. Model results

4.1. Burial history
As shown in Figure. 2c, Well Anye-1 experienced multiple-staged tectonic movements. The Wufeng-Longmaxi shale was deposited from Late Ordovician to Early Silurian and buried to 1500 m at the late Silurian. Then it experienced long-term erosion caused by Guangxi movement, which caused the lack of middle-upper Silurian, Devonian and Carboniferous strata in Well Anye-1 [9]. During the Permian period, Well Anye-1 experienced a rapid erosion in the short time due to Dongwu movement. There was a considerable unconformity interface between the lower Permian Maokou formation and the upper Permian Longtan formation, which is related to the regional uplifting caused by the Emeishan mantle-plume [10]. Since the Triassic, Well Anye-1 continued to be buried until it reached the maximum burial depth. However, there was also a small-scale erosion caused by the Indosinian movement during the late Triassic period, which represented North Guizhou entered into the terrestrial depositional stage [11]. The maximum burial depth of Wufeng-Longmaxi shale was 5331 m at the late Cretaceous. Then, Well Anye-1 was uplifted rapidly and eroded by the influence of the Himalayan movement [11]. The erosion thickness was about 3000 m in this stage, and now the burial depth of Wufeng-Longmaxi shale is 2331 m.

4.2. Thermal history
Thermal maturity evolution is mainly controlled by temperature and time. We use Easy%Ro model to calculate the thermal maturity of Wufeng-Longmaxi shale [8].

Since the Wufeng-Longmaxi shale was deposited, the thermal maturity was increased with the burial depth. The Wufeng-Longmaxi shale started to generate oil (Ro> 0.55 %) at the late Silurian, then the
thermal maturity was stopped or increased slowly due to long-term erosion caused by the Guangxi movement (Figure 2d). There was an abnormal heat-flow, which is related to the eruption of Emeishan basalts, during the Permian period, and the heat flow could reach 80 mW/m² in North Guizhou (Figure. 2d) [12]. The thermal maturity was also increased and it entered into the main oil stage (Ro= 0.55-0.70 %) at middle Permian. Then, Well Anye-1 entered into the rapid burial stage, and the thermal maturity was increased rapidly with the burial depth (Figure. 3c and d). The Wufeng-Longmaxi shale entered into the wet gas stage (Ro=1.30-2.00%) at milled Jurassic and the dry gas stage (Ro>2.00%) at the late of early Cretaceous. After the late Cretaceous, the thermal maturity of Wufeng-Longmaxi shale was stopped due to the long-term uplifting and erosion movement and now the thermal maturity is 2.07 %, which shows the good correlation with the measured Ro data.

Figure 2. (a)The heat flow of Well Anye-1; (b) thermal calibration in well profile, the red spots are the measured values and the yellow represents the calculated results; (c) the burial and thermal histories of Well Anye-1; (d) the thermal maturity evolution of Wufeng-Longmaxi shale of Well Anye-1

5. Conclusions
In this paper, we recovered the burial and thermal histories of Well Anye-1 of Anchang syncline, Zheng’an Area, North Guizhou. Based on PetroMod modeling results, the following conclusions can be drawn.
(1) The burial history shows that the Wufeng-Longmaxi shale of Well Anye-1 had four major uplifting and erosion events, such as Guangxi movement, Dongwu movement, Indosinian movement and Himalayan movement. The burial depth reached the maximum at late Cretaceous, and the maximum burial depth was 5331 m. Then, Well Anye-1 was eroded about 3000 m by Himalayan movement, and now burial depth of Wufeng-Longmaxi shale is 2331 m.

(2) The thermal history shows that the Wufeng-Longmaxi shale of Well Anye-1 started to generate oil at the late Silurian and entered into the main oil stage at middle Permian. Then the thermal maturity was increased rapidly with the burial depth, and it entered into the wet gas stage at middle Jurassic and the dry gas stage at the late of early Cretaceous. The thermal maturity evolution was stopped due to the Himalayan movement, and now the thermal maturity is 2.07 %. Besides, there was an abnormal heat flow event, which was related to the eruption of Emeishan basalts.

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