Gas generation evaluation of Pingliang shale in Weibei Uplift, Ordos Basin using PetroMod

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Abstract. Ordos Basin is an important large petroliferous basin in China. In order to recover gas generation history and evaluate gas resources of Pingliang shale in Weibei Uplift, Ordos Basin, we took the Pingliang shale of Well XT-1 as the research target. We reconstructed burial and thermal histories of Pingliang shale based on PetroMod software. Besides, we also recovered gas generation history and its resources potential. The modeling results show that Well XT-1 had experienced five major tectonic stages. The burial depth of the bottom of Pingliang shale reached the maximum with the value of approximately 4500 m at the late Cretaceous and the current burial depth is 3068 m. The results of thermal history show that Pingliang shale had experienced oil-generation and gas-generation stages and current Ro is 2.52\%. Based on the calculation results about gas generation history, generation masses of methane, wet gas, and total gas are 1.24 $\times$ 10\textsuperscript{8} kg/km\textsuperscript{2}, 0.88 $\times$ 10\textsuperscript{8} kg/km\textsuperscript{2}, 2.12 $\times$ 10\textsuperscript{8} kg/km\textsuperscript{2}, respectively, which shows great gas resource potential of Pingliang shale in Weibei uplift, Ordos Basin.

1. Introduction
Ordos Basin, an important petroliferous basin, is located in the western part of North China Block [1]. The middle Ordovician Pingliang shale is widely distributed in the western and southern part of the Ordos Basin due to the influence of central paleo-uplift [1-3]. The mean thickness of Pingliang shale is about 250 m with a mean TOC value greater than 0.5\%, which is considered as Paleozoic excellent marine source rock in the Ordos Basin [2]. The Pingliang shale in Weibei Uplift has reached extremely-high thermal maturity with Ro ranging from 1.8 to 2.6\% [2]. Cao et al had established a relatively accurate model and recovered burial and thermal histories of Pingliang shale in Weibei Uplift [4]. Jia et al calculated hydrocarbon generation kinetics of methane and total gas for Pingliang shale based on a closed gold-tube system. In this paper, we also reconstructed burial and thermal histories of Pingliang shale from Well XT-1, Weibei uplift, Ordos Basin based on PetroMod software. Furthermore, we chose Jia’s kinetics [5] to recover gas generation history and evaluate the gas resources of Pingliang shale.

2. Geological background
Ordos Basin, with an area of 320,000 km\textsuperscript{2}, is a typical craton basin (Figure. 1) [6]. During middle Ordovician, the major part of Ordos Basin was uplifted due to the influence of Caledonian movement. Meanwhile, the southern part was settled and the deep slope and carbonate platform facies were well
developed in the southern part of the Ordos Basin [8]. The middle Ordovician Pingliang shale is L-shape distribution along the western and southern margin of the Ordos Basin and the lithologies are mainly composed of mudstone, marlstone and muddy limestone with a little graptolite [1-4]. The vitrinite reflectance and total organic carbon increase toward north and east [2]. Weibei Uplift is located in the southern part of the Ordos Basin. The thickness of Pingliang shale varies from 100 m to 800 m and the vitrinite reflectance ranges from 2.04% to 3.16% [1, 4]. Well XT-1 is located in the northern part of the Weibei Uplift (Figure 1). The thickness of Pingliang shale is 378 m and the current burial depth is 3068 m.

![The geological map of Ordos Basin (modified from [7]).](image1)

**Figure 1.** The geological map of Ordos Basin (modified from [7]).

![Burial and thermal histories of Well XT-1 in Weibei Uplift, Ordos Basin; (b) thermal calibration in well profile, the red spots are the measured values and the black line represents the modeled results.](image2)

**Figure 2.** (a) Burial and thermal histories of Well XT-1 in Weibei Uplift, Ordos Basin; (b) thermal calibration in well profile, the red spots are the measured values and the black line represents the modeled results.
3. Method and workflow
We use PetroMod software to model burial and thermal histories of Pingliang shale from well XT-1, Weibei Uplift, Ordos Basin. The basic input data include lithology, thickness, the age of depositional and erosional events, and boundary conditions (including heat flow, paleo water depth and sediment-water interface temperature). Besides, the modeling results of vitrinite reflectance are calibrated by some measured data (Figure 2b). We set the thickness of high-quality Pingliang shale as 50 m, and the initial hydrogen index and TOC are 600 mg/g•TOC, 1.00%, respectively. Moreover, gas generation kinetics for methane and total gas of Jia’s model [5] was used to recover gas generation history and calculate gas resources.

4. Results and discussions
4.1. Burial and thermal histories
The results of burial and thermal histories of Well XT-1 are shown in Figure. 2a. It could be divided into five stages based on the characteristics of tectonic evolution of Well XT-1.
(1) Early Paleozoic subsidence stage. The Pingliang shale was deposited since the middle Ordovician and the burial depth reached approximately 1300 m at the late Ordovician. The results of thermal history showed the Pingliang shale was in immature stage with Ro lower than 0.55% (Figure. 2a and 3).
(2) Early Silurian–Carboniferous uplifting and erosion stage. Since the early Silurian, Ordos Basin was uplifted and even Weibei Uplift was eroded by the influence of Caledonian movement. The time of this erosion event lasted approximately 105 Ma and the erosion thickness was about 200 m. Meanwhile, the Pingliang shale was still in immature stage (Ro < 0.55%).
(3) Permian–the middle Jurassic continuous subsidence stage. The Pingliang shale entered into rapid burial stage during the period from the early Permian to the middle Jurassic. Besides, there was also a small-scale erosion event caused by Indosinian movement during the late Triassic. Thermal history showed that Pingliang shale entered into rapid evolution stage and thermal maturity continuously increased with burial depth. The Pingliang shale entered into the main oil stage (Ro=0.70%-1.00%) and wet gas stage (Ro=1.30%-2.00%) at the middle Triassic (approximately 240 Ma) and the late Triassic (approximately 200 Ma), respectively.
(4) Yanshanian abnormal heat and erosion stage. The period from the middle Jurassic to the early Cretaceous was the most important tectonic stage in Weibei Uplift [9]. Since the middle Jurassic, Weibei Uplift was uplifted due to Yanshanian movement. It caused that there was an obvious unconformity interface between the upper Jurassic and the lower Cretaceous formations and the erosion thickness was approximately 400 m during this stage (Figure 2a). Besides, there was an abnormal tectonic thermal event during the early Cretaceous. This thermal event was related to the thinning of lithosphere, magma invasion and intensive tectonic activity of Qinling orogenic belt [9-11]. The Pingliang shale entered into the dry gas stage (Figure 2a and 3; Ro > 2.00%) at the early Cretaceous (approximately 105 Ma). The burial depth of Pingliang shale reached the maximum at the late Cretaceous and the maximum burial depth was approximately 4500 m (Figure 2a).
(5) Himalayan rapid uplifting stage. Well XT-1 was rapidly uplifted during the Himalayan period. The erosion thickness was approximately 1200 m [4] and the current burial depth of the bottom of Pingliang shale is 3068 m. The thermal maturity of Pingliang shale was stopped when the burial depth reached the maximum and the current thermal maturity is 2.52% based on the modelling results (Figure 2a and 3).
4.2. Gas generation history and its resources

The burial and thermal histories both control hydrocarbon generation process. In this section, we used Jia’s model (Figure 4) [5] to recover gas generation history and calculated gas resources of Pingliang shale (Figure 5). When the Ro reached 0.6% (the early Triassic, approximately 245 Ma) the Pingliang shale started to generated massive gases. The period from the early Triassic to the middle Jurassic was the main gas generation stage (Figure 5). The gas generation was stopped during Yanshanian erosional stage (Figure 3 and 5). Then generation mass of methane and total gas was continuously increased with the increasing of thermal maturity. When the burial depth reached the maximum and thermal maturity nearly reached current value (Ro = 2.52%), the hydrocarbon generation was stopped both for methane and total gas. Based on calculated results, the generation masses of methane, wet gases and total gases are $1.24 \times 10^8$ kg/km$^2$, $0.88 \times 10^8$ kg/km$^2$, $2.12 \times 10^8$ kg/km$^2$, respectively. The gas generation mass shows great gas resource potential of Pingliang shale in Weibei uplift, Ordos Basin.
5. Conclusions
In this paper, we reconstructed burial and thermal histories and calculated the gas potential of Pingliang shale from Well XT-1, Weibei Uplift, Ordos basin. Based on the modeling results, the following conclusions can be drawn.

(1) The burial history shows that the Pingliang shale of Well XT-1 suffered 5 major tectonic stages: the early Paleozoic subsidence stage, the early Silurian-Carboniferous uplifting and erosion stage, Permian-middle Jurassic continuous subsidence stage, Yanshanian abnormal heat and erosion stage and Himalayan rapid uplifting stage. The maximum burial depth of the bottom of Pingliang shale reached approximately 4500 m at the late Cretaceous and the current burial depth is 3068 m.

(2) The thermal history shows that the Pingliang shale of Well XT-1 entered into main oil stage (Ro= 0.70%-1.00%) , wet gas stage (Ro= 1.00%-1.30%) and dry gas stage (Ro > 2.00%) at middle Triassic, the late Triassic and at Cretaceous, respectively. The current thermal maturity is 2.52%.

(3) The gas generation history shows that the Pingliang shale started to generate massive gases when the Ro reached 0.60%. Based on the calculated results, the generation mass of methane, wet gases and total gas are 1.24×10^8 kg/km^2, 0.88×10^8 kg/km^2, 2.12×10^8 kg/km^2, respectively, which shows great gas resource potential in Weibei Uplift, Ordos Basin.

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References
[1] Liu QY, Jin ZJ, Wang Y, Han PL, Tao Y, Wang QC, Ren ZL and L WH. 2012 Acta. Pet. Sinica 28 847.
[2] Sun YP, Wang CG, Wang Y, Yang WL, Xu HZ, Liu WB and Wu TH. 2008. Pet. Geol. Exp. 30 162.
[3] Liu BX, Yan XX, Bai HF and Li Y. 2008. Nat. Gas. Ind. 19 657.
[4] Cao ZP, Ren ZL, Xiong P, Qi K and Chen ZJ. 2016. Acta. Geo. Sinica. 90 513.
[5] Jia WL, Wang QL, Liu JZ, Peng PA, Li BH and Lu JL. 2014. Org. Geochem. 71 17.
[6] Yang YT, Li W and Ma L. 2005. AAPG. Bull. 89 255.
[7] Wang Y, Zhu YM, Wang HY and Feng GJ. 2015 Mar.Pet. Geol. 24 521.
[8] Yang H, Fu JH and Bao HP, 2010 Mar. Origin. Pet. Geol. 15 1.
[9] Ren ZL, Cui JP, Guo K,Tian T, Li H, Wang W, Yang P and Cao ZP. 2015 Chin. Sci. Bull. 60 1298.
[10] Ren ZL, Qi K, Liu RC, Cui JP, Chen ZP, Zhang YY, Yang GL and Ma Q. 2020. Acta. Geo.
[11] Ren ZL, Zhang S, Gao SL, Cui JP and Liu XS. 2006. Acta. Geo. Sinica. 80 674.