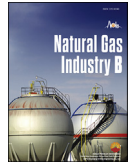



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Research Article

# Practices and prospect of petroleum engineering technologies in ultra-deep sour gas reservoirs, Yuanba Gasfield, Sichuan Basin<sup>☆</sup>

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## Abstract

Located in the Sichuan Basin, the Yuanba Gasfield is the deepest marine sour gas field among those developed in China so far. Its biohermal gas reservoir of the Upper Permian Changxing Fm is characterized by ultra depth, high content of hydrogen sulfide, medium–low porosity and permeability, and small reservoir thickness. Economic evaluation on it shows that horizontal well drilling is the only way to develop this gas reservoir efficiently and to reduce the total development investment. At present, the petroleum engineering technology for this type of ultra-deep sour gas reservoir is less applied in the world, so an ultra-deep horizontal well is subject to a series of petroleum engineering technology difficulties, such as safe and fast well drilling and completion, mud logging, well logging, downhole operation, safety and environmental protection. Based on the successful development experience of the Puguang Gasfield, therefore, Sinopec Southwest Petroleum Engineering Co., Ltd. took the advantage of integrated engineering geology method to carry out specific technical research and perform practice diligently for 7 years. As a result, 18 key items of technologies for ultra-deep sour gas reservoirs were developed, including horizontal-well drilling speed increasing technology, horizontal-well mud logging and well logging technology, downhole operation technology, and safety and environmental protection technology. These technologies were applied in 40 wells during the first and second phases of productivity construction of the Yuanba Gasfield. All the 40 wells have been built into commercial gas wells, and the productivity construction goal of 3.4 billion m<sup>3</sup> purified gas has also been achieved. These petroleum engineering technologies for ultra-deep sour gas fields play a reference role in exploring and developing similar gas reservoirs at home and abroad.

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**Keywords:** Sichuan Basin; Yuanba Gasfield; Late Permian; Bioherm; Sour gas reservoir; Ultra-deep horizontal well; Petroleum engineering; Safety; Environmental protection

## 1. Introduction

The Yuanba Gasfield is located in Cangxi County and Langzhong City of Sichuan Province. Structurally, this gas-field resides in the northern edge of the Central Sichuan low

and gentle structural belt in the Sichuan Basin, on the transition zone from Tongnanba structural belt and Jiulongshan anticline belt to the Central Sichuan low and gentle structural belt. It records as a major breakthrough in natural gas exploration after the Puguang Gasfield in the Kaijiang–Wangcang continental shelf Changxing–Early Feixianguan platform margin phase belt (Fig. 1) [1]. In November 2007, Sinopec Exploration Company performed acidization testing of reservoir intervals dominated by dolomite in Upper Permian Changxing Fm through Well Yuanba-1–Ce-1, an oil and gas exploration well. Under a tubing pressure of 18.9 MPa, natural gas productivity was determined to be  $50.3019 \times 10^4$  m<sup>3</sup>/d. With the discovery of ultra-deep high-sulfur bioherm gas

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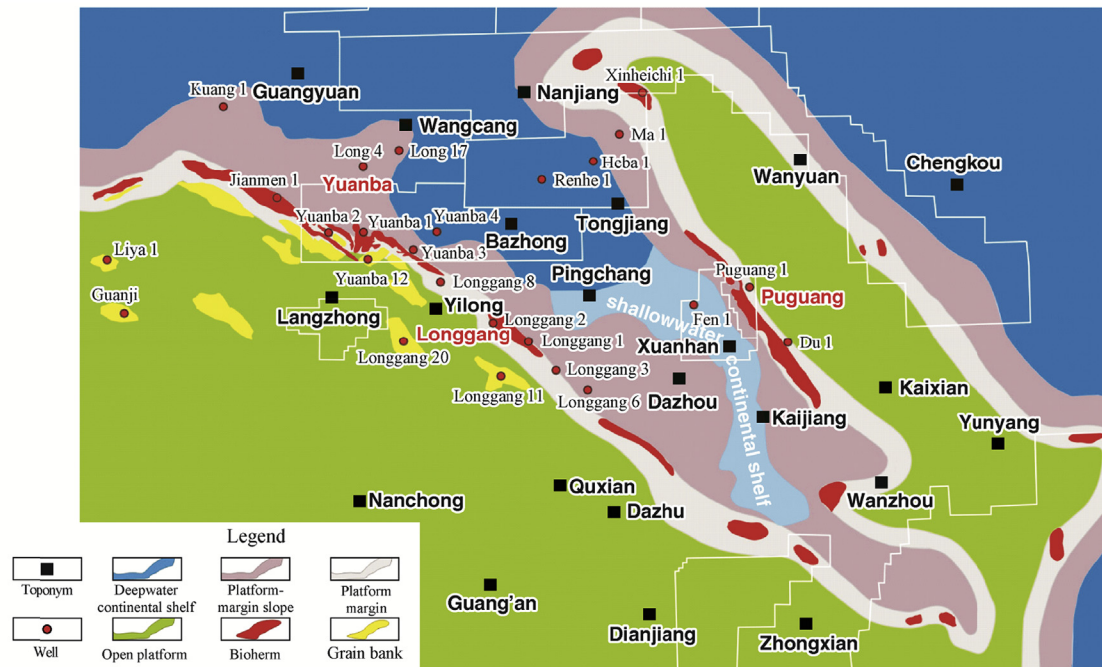


Fig. 1. Plane distribution of sedimentary facies of Changxing Period in NE Sichuan Basin.

reservoirs in the Changxing Fm of Yuanba Gasfield, a major breakthrough has been made in exploration.

By the end of 2013, the total original gas in place (OGIP) proved in Changxing Fm of the Yuanba Gasfield had been  $1834.2 \times 10^8 \text{ m}^3$ . With an average pay zone depth of 6673 m, the Yuanba Gasfield is the deepest large-scale marine gasfield ever discovered in China, and it is also the second largest sour gasfield discovered by China Petroleum & Chemical Corporation (Sinopec). Since the Changxing Fm is characterized by ultra-depth, high  $\text{H}_2\text{S}$ , medium to low porosity and low permeability in bioherm reservoirs, and thin effective thicknesses, overall efficiency of vertical well development is less satisfactory. In April 2011, in Well Yuanba 103H, the first experimental development well drilled in the gasfield, a horizontal section of 7047.0–7695.5 m in the Changxing Fm produced  $93.897 \times 10^4 \text{ m}^3/\text{d}$  natural gas under a tubing pressure of 41.5 MPa during the test. High productivity of the well shows that horizontal wells can be seen as effective ways for high-efficiency development of ultra-deep Changxing Fm since horizontal wells can significantly enhance productivity and dramatically increase reserves controlled by a well. Up to the first half of 2016, the  $34 \times 10^8 \text{ m}^3$  purified gas productivity construction project in the Yuanba Gasfield has entered its final stage, with 37 producers constructed in total. These producers include 18 existing exploration wells and 19 newly drilled development wells.

Through technical researches and applications in the past few years, the Yuanba Gasfield developed key techniques required for fast drilling of high-efficiency horizontal wells in the development of ultra-deep sour gas reservoirs, key technologies in mud logging and well logging of ultra-deep horizontal wells, core technologies in downhole operations and safety & environmental protection technologies in ultra-deep highly sour gas reservoirs in the field of petroleum engineering. In fact, these

technologies are the most advanced technologies in the development of ultra-deep sour gas reservoirs in China.

## 2. Engineering technical challenges

### 2.1. Geologic features

Yuanba Area has Upper Jurassic–Cretaceous formations exposed on ground surface. From top to bottom, well drilling penetrated Cretaceous Jianmenguan Fm, Jurassic Penglaizhen Fm, Suining Fm, Shaximiao Fm, Qianfoya Fm, and Ziliujing Fm, Triassic Xujiache Fm, Leikoupo Fm, Jialingjiang Fm, and Feixianguan Fm, Permian Changxing Fm, Wujiaping Fm, and Maokou Fm, and others [2] (Fig. 2). The Leikoupo Fm and the formations below are dominated by marine sediments, while the Xujiache Fm and formations above are dominated by continental sediments. During exploration, four gas-bearing formations, namely Changxing, Leikoupo, Xujiache and Ziliujing Fms were discovered. Among them, the Changxing Fm is predominantly a gentle monocline structure with faults poorly developed. There are some minor anticlines with low amplitudes developed regionally. These faults are characterized by smaller quantities, shorter extensions, minor fault throws and steep dip angles [3].

As far as engineering geologic features are concerned, gas reservoirs in the Changxing Fm are characterized by “one ultra-depth, three highs and five complexities”:

- ① Ultra-depth: Gas reservoirs have burial depths of 6200–7100 m with 6673 m on average;
- ② High pressure: Gas reservoirs have a pressure of 70 MPa with formation pressure of the overlying Feixianguan Fm at 147 MPa;

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