

Research article

# Comprehensive evaluation technology for shale gas sweet spots in the complex marine mountains, South China: A case study from Zhaotong national shale gas demonstration zone

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## Abstract

The exploration and development of marine shale gas reservoirs in South China is challenged by complex geological and geographical conditions, such as strong transformation, post maturity, complex mountains and humanity. In this paper, the evaluations on shale gas sweet spots conducted in Zhaotong demonstration zone in the past six years and the construction of 500 million m<sup>3</sup> shale gas productivity in Huangjinba region were discussed, and the results of shale gas reservoir evaluations in China and abroad were investigated. Accordingly, it is proposed that another two key indicators be taken into consideration in the evaluation on shale gas sweet spots in marine mountains in South China, i.e. shale gas preservation conditions and pore pressure, and the research on ground stress and natural microfracture systems should be strengthened. Then, systematic analysis was conducted by integrating shale gas multidisciplinary data and geological and engineering integration study was carried out. Finally, a 3D model, which was composed of “geophysics, reservoir geology, fracture system and rock geomechanics”, was established for shale gas reservoirs. Application practice shows that the geological engineering integration and the 3D reservoir modeling are effective methods for evaluating the shale gas sweet spots in complex marine mountains in South China. Besides, based on shale gas sweet spot evaluation, 3D spatial congruency and superposition effects of multiple attributes and multiple evaluation parameters are presented. Moreover, the short-plate principle is the factor controlling the distribution patterns and evaluation results of shale gas sweet spots. It is concluded that this comprehensive evaluation method is innovative and effective in avoiding complex geological and engineering risks, so it is of guiding significance in exploration and development of marine shale gas in South China.

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**Keywords:** South China; Marine shale gas; Reservoirs; Sweet spot; 3D reservoir model; Geological engineering integration; Comprehensive evaluation; Zhaotong (Yunnan) national shale gas demonstration zone

Shale gas, as a clean unconventional energy source, is the focus for exploration in recent years due to its abundant resources and the successful development in the United States [1]. Zhaotong exploration area in northern Yunnan–Guizhou

was granted with the first shale gas prospecting license in China in 2009 and was listed in the first national shale gas demonstration zones in South China established by PetroChina in 2012. Currently, in this demonstration zone, commercial breakthroughs have been obtained through shale gas wells in the marine Upper Ordovician Wufeng Fm and Lower Silurian Longmaxi Fm. In addition, four shale gas sweet spots have been selected and Huangjinba shale gas producing area with a productivity of 500 million m<sup>3</sup> has been basically established.

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The proven shale gas in place (GIP) has been booked to the government. Through studies and practices in the past years, a systematic exploration and development scheme suitable for marine shale gas reservoirs in the mountains of South China has been formed, which is “orderly play selection → stage evaluation → production capacity construction by play → beneficial development”. It opens an efficient and leading development mode for the geological engineering integration of marine shale gas [1–4] and lays a solid foundation for the exploration and development of shale gas in the complex marine mountains of South China.

**1. Evaluation and selection of shale gas sweet spots in mountains**

In Zhaotong demonstration zone, the high-quality Wufeng and Longmaxi shales, as the target formations, are developed at the bottom of the lower member of Longmaxi and Wufeng Fms [5]. It can be divided into five sub-layers (pay zones), i.e. I<sub>1</sub>, I<sub>2</sub>, I<sub>3</sub>, I<sub>4</sub> and I<sub>5</sub> (Fig. 1, Table 1). Under the control of the depositional environment and sedimentary facies belt of Guangxi Period and the Eastern Yunnan–Central Guizhou paleouplift, the high-quality shale gas reservoirs exist in the synclinorium of Jianwu, Mu'ai and Yiliang in the north of Northern Yunnan–Guizhou Depression [5–9]. These reservoirs, in nearly NEE–EW trending, presents the mountain–hill geomorphic features similar to Yunnan–Guizhou Plateau.

The organic-rich shales in Zhaotong demonstration zone was deposited in the same sedimentary environment and represents similar reservoir properties to the Haynesville, Barnett and Marcellus shales in North America [10–12], but they are older and higher in evolution degree. However, its geological engineering and surface conditions are significantly different

due to different hydrocarbon generation, burial environment and evolution history in the late stage. The shales in Zhaotong demonstration zone remained in depression after being reformed due to multi-phase orogenic events since the Indosinian epoch, representing intense and abrupt lateral deformation as well as complicated geological stress background and natural fractures. The shale gas reservoirs have already entered into an overmature stage when hydrocarbon generation tends to be stagnant. Accordingly, the occurrence pattern of shale gas is dominated by the preservation and re-accumulation of primary gas pools. In addition, the formation pore pressure of shale gas pools drops and represents non-continuous distribution pattern due to the loss and destruction of shale gas. The shale gas pools in North American that are developed in stable craton platform are mostly at a moderate–high evolution stage and contain a plenty of wet gas and dry gas, while those in Zhaotong demonstration zone are dominated by primary gas pools with weak deformation and high formation pore pressure, which are continuously distributed in a large area and associated with shale oil and tight oil. In terms of surface topography, Zhaotong demonstration zone represents mountain–hill geomorphology with a large number of high mountains and deep valleys, sparse flat bars and concentrated population, while North America represents a great plain with a vast territory and a spare population. Therefore, in the complex marine mountain shale gas exploration area of South China represented by Zhaotong demonstration zone, two key indicators, i.e. shale gas preservation conditions and pore pressure, are particularly critical and important for the enrichment and occurrence of shale gas.

Compared with Changning, Weiyuan and Fuling shale gas demonstration zones in the Sichuan Basin [13–15], the shales in Huangjinba of Zhaotong demonstration zone have the same

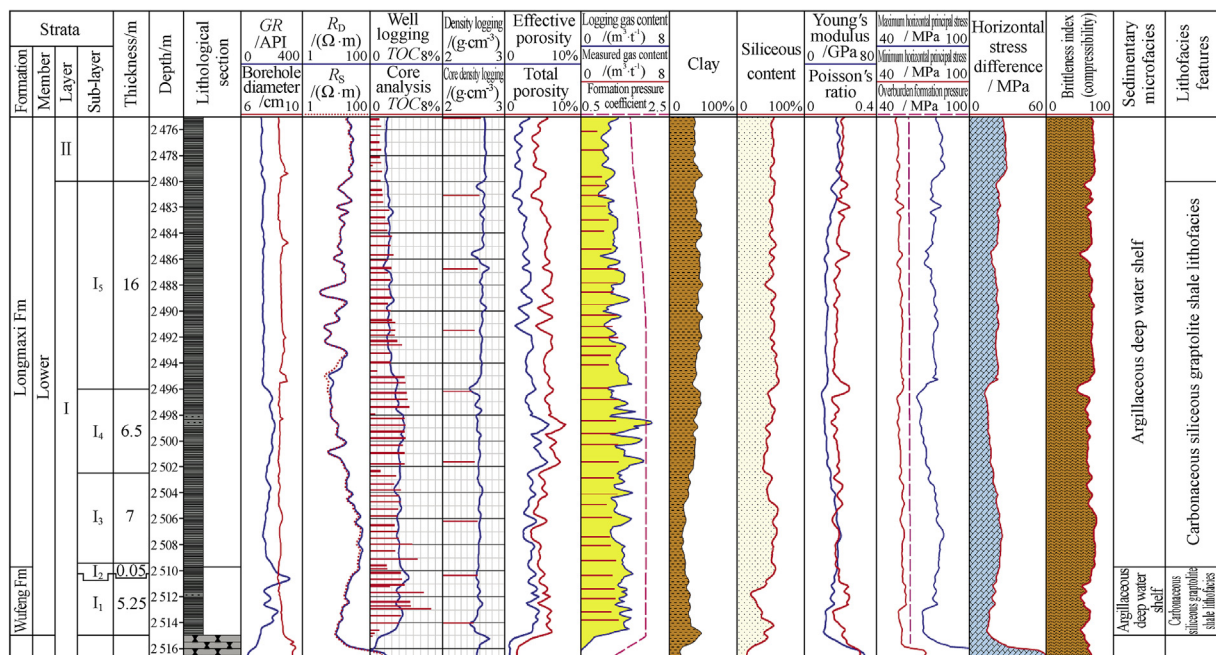


Fig. 1. Division of the lower member of Wufeng–Longmaxi Shale gas reservoirs in Zhaotong demonstration zone.

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