

# Progress and Prospects of Shale Gas Exploration and Development in Sichuan, China

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**Abstract**—Shale gas is a huge amount of clean energy resources. America's Shale Gas Revolution has inspired a boom in global exploration and development of shale gas. China has rich shale gas resources. To cope with severe energy demand and climate change challenges, China is strongly promoting the shale gas exploration and development, especially in Sichuan has achieved initial results. Except North America, Sichuan commercially developed shale gas at the earliest. Therefore, Sichuan's shale gas exploration and development to a large extent reflect and affect the future development prospects of China's shale gas. This paper systematically summarizes the practice of Sichuan shale gas exploration and development, analyzes the development prospects of shale gas in Sichuan, and puts forward suggestions on the development of Sichuan shale gas.

**Index Terms**—China, development prospect, progress, Sichuan, shale gas.

## I. INTRODUCTION

There are certain differences in the definition of shale gas between China and North American. In China, it refers to the natural gas occurred within organic-rich shale formation, in the state of absorbed gas, free gas and dissolved gas, Which is mainly self-generation and self-accumulation continuous gas reservoir. It is unconventional natural gas, which can be obtained through volume fracturing transformation. The development of shale gas has the advantages of long service life and long production time, Most of shale that producing gas is widely distributed, and the thickness is large, and generally contain shale gas. As a new kind of energy, it is not only a potential alternative to conventional natural gas, but also a clean and environmentally friendly energy. Sichuan is one of the major natural gas producing areas in China, shale gas resources are also very rich. According to the data [1] from the China Land and Resources department, China shale gas forecast geological resources total  $134 \times 10^{12} \text{m}^3$ , recoverable resources of  $25.08 \times 10^{12} \text{m}^3$  (Not containing the Qinghai-Tibet region). The Sichuan shale gas resource is about  $27.5 \times 10^{12} \text{m}^3$ , 21% of China; recoverable resources of  $4.42 \times 10^{12} \text{m}^3$ , 18% of China, both are among the first in China. Since 2005, China use for reference the experience of North America, first to carry out the evaluation of shale gas geological conditions in Sichuan and the pilot of exploration and development [2], [3]. Not only achieved significant progress on the geological understanding, has also

made a breakthrough in exploration and development practice. In addition to outside North America to become the world's first discovery of shale gas area. Based on the current situation of Sichuan shale gas exploration and development, this paper discusses the mode and Prospect of Sichuan shale gas exploration and development, with a view to promoting the development of shale gas.

## II. SICHUAN SHALE GAS RESOURCES DISTRIBUTION

As one of the four major petroleum and natural gas accumulation basins in China, Sichuan basin has superior metallogenic condition, which is also shale gas major accumulation field, which covers 181,000 square kilometers, while there are 125,800 square kilometers in Sichuan Province.

Sichuan has experienced the depositional evolution of marine and terrestrial facies, and three types of shales rich with marine, transitional, and terrestrial organic matters were well development and five sets of favorable shale gas enrichment strata [4]: the Cambrian Qiongzhusi Fm, the Ordovician Wufeng – Silurian Longmaxi Fm, the Permian Longtan Fm, the Triassic Xujiahe Fm, and the Jurassic Zhiliujing Fm. Research shows a bright future will be seen from the discovery of shale gas in the Ordovician Wufeng – Silurian Longmaxi Fm and Cambrian Qiongzhusi Fm, both are marine. The Cambrian Qiongzhusi Fm is mainly a shallow shelf sedimentary facies, in addition to due to erosion and loss in southwest edge of Sichuan Basin and the rest of the development than the whole. The thickness distribution in 300 ~ 500m, Qiongzhusi group of top circles buried deep in general 4 ~ 5 km, and Eastern Sichuan buried depth are large, generally more than 5km. The Ordovician Wufeng – Silurian Longmaxi Fm are mainly a set of shallow water, deep water shelf facies, with fully development in eastern and southern sichuan, stable distribution, thickness is in commonly 100 ~ 500 m, the maximum thickness is 700m. This Fm is buried in 2 ~ 3 km, while the East Sichuan deep more than 4 km [5]. Southern Sichuan Ordovician Wufeng – Silurian Longmaxi Fm black shale thickness greater than 308 m, the type of organic matter is a propel type TOC values average 2.94%, up to 8.75% [4], and started the preliminary industrial scale production.

## III. ADVANTAGES OF SHALE GAS DEVELOPMENT IN SICHUAN

### A. Resources Advantage

6 organic rich bottom-up shale formations are formed in Sichuan basin, among which the gas shale in the two marine

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strata, Qiongzhusi formation and Longmaxi formation, have the resources advantages of developing priority, with the approved appropriate depth, thick effective shale, broad distribution area, high organic abundance, and good gas-bearing property.

#### B. Personnel and Technology Advantages

The shale gas development in Sichuan Province has great advantages in personnel and technology, having several shale gas research centers, state and provincial key labs, and one university focusing on Petroleum and Natural Gas.

#### C. Capital Advantage

Under the tilt of national policy, the Ministry of Land and Resources and the Ministry of Science and Technology increase the capital investment in Sichuan shale gas exploration and development. At the mean time, Sichuan Provincial Government strongly supports the work, and will give capital support on the shale gas exploration and development, and industry construction. China National Petroleum Corporation (CNPC) and Sinopec Group also plan to invest enormous capital.

#### D. Infrastructure Advantage

In Sichuan Province, large numbers of surface gas pipeline networks are built, and some shale gas pipeline networks are finished, connected to the city gas pipeline network, which are good for the transportation, sales and usage of shale gas.

### IV. PROGRESS OF SHALE GAS EXPLORATION AND DEVELOPMENT IN SICHUAN

Back in the sixties and seventies of the 20th century, Sichuan is in the southern natural gas exploration won the shale gas in black shale of the lower Paleozoic [6]. Limited to the conditions of oil and gas exploration and deployment purpose, has not brought to the enough attention and further in depth study in time. Until around 2000, with the rise of the American shale gas revolution, Chinese scholars began to focus on the development of China's shale gas. In the early days of the North American shale gas resources in the development process of tracking, based on the study, since 2005, China's major oil companies, petroleum and geological universities, the ministry of land and resources and the choice

of the national energy administration and other relevant government agencies [7] from old data review, outcrop geological survey, conducted shale gas formation and enrichment of geological research and shale gas resource potential evaluation with take the Si-chuan area as the main target [8]. In 2007, the first shale gas comprehensive geological evaluation of China was carried out here; in 2008, the first shale gas parameter well was finished; in 2010, the well Wei201, the first shale gas vertical well of our country, began to produce and sell shale gas; in 2011, the first shale gas horizontal well Wei201-H1 began to produce; in 2013, the first "industrialized" experimental platform of our country was drilled; in 2014, the first shale gas pipeline was established.

After ten years of exploration and development of shale gas exploration and development practice, technology and theoretical exploration, Sichuan has made great progress in the development of shale gas resource potential evaluation, the key core technology and equipment system, the basic theory of construction and so on, the resource availability, technical feasibility and economic feasibility and economic feasibility a-re fully demonstrated, which has laid a good foundation for development, and the basic conditions for large-scale commercial development. China's largest energy company — China National Petroleum Corporation (CNPC), owns most of Sichuan shale assets, leading the shale development pattern in Sichuan. At present, CNPC in Sichuan has been clear that the gas bearing area of 207.87 km<sup>2</sup>, proven geological reserves of shale gas 1635.31 × 10<sup>8</sup> m<sup>3</sup>, technology can be used to reserve 408.83 × 10<sup>8</sup> m<sup>3</sup> [9], This will have an important role in promoting the development of shale gas resources in Sichuan and China. The latest data [10] show, in August 2015, CNPC in Sichuan has been put into operation 47 wells, daily output shale gas reached 362 × 10<sup>4</sup> m<sup>3</sup>. And just two months ago, CNPC gas group company in Sichuan daily output just broke through 200 × 10<sup>4</sup> m<sup>3</sup>.

Table I reveals Sichuan's shale gas exploration progresses [4], [9], [11]-[16]. It shows the course of development of shale gas in Sichuan, including early cooperation with foreign companies to carry out resource investigation and evaluation, exploration and development test, subsequently carried out independently industrialized mining, Achieve commercial development and seek new breakthroughs.

TABLE I: THE DEVELOPMENT OF SICHUAN SHALE GAS [4], [9], [11]-[16]

| Date      | Exploration party   | Activities   | Significance  |
|-----------|---|--|---|
| 2007 [11] | China National Petroleum Corporation and Newfield Exploration Company | Signed the "joint research of shale gas in Weiyuan   | Chinese first shale gas development foreign co-operation agreement, marks the beginning of China's Shale Gas Cooperation Research |
| 2008 [12] | China National Petroleum Corporation                                  | Drilling the Changxin 1 wells in the Changning area of Sichuan   | It is the first shale gas geological well in China  |
| 2009 [4]  | China National Petroleum Corporation and Royal Dutch Shell            | The exploration and development of cooperation started In the Fushun Yongchuan area                                      | Chinese first international cooperation development projects for shale gas exploration  |
| 2010 [4]  | China National Petroleum Corporation                                  | Drilling in the Sichuan Weiyuan area W201 wells in the Lower Silurian Longmaxi shale in industrial gas and began selling | China shale gas breakthrough for the first time   |

|           |  |   |  |
|-----------|--|---|--|
| 2011 [13] | China National Petroleum Corporation   | Get the W201-H1 Well  | China's first shale gas horizontal well  |
| 2012 [14] | China National Petroleum Corporation   | The first horizontal well N201-H1 in Changning area is well over and get the high yield gas flow  | It have commercial value that is first case in china   |
| 2013 [15] | China National Petroleum Corporation.<br>Sichuan Energy Industry Investment Group Co., Ltd.<br>State-Owned Assets Supervision and Administration Commission of Yibin.<br>GuoLian Industry Investment Management (Beijing) Co. Ltd. | Established Changning Sichuan Natural Gas Development Co., Ltd.   | The first private capital shares of oil and gas upstream companies, opened the central enterprises and local enterprises to jointly develop a precedent for the development of shale gas resources |
| 2014 [16] | China National Petroleum Corporation   | Shale gas trial production line in Changning put into operation   | Chinese's first shale gas outward transmission line  |
| 2015 [9]  | China National Petroleum Corporation   | CNPC submitted shale gas proven reserves is whether approved through the Ministry of land and resources, it's the prerequisite for shale gas mining right in the area | The first mining rights obtained by Sichuan  |

#### V. THE PROSPECT OF SHALE GAS EXPLORATION AND DEVELOPMENT IN SICHUAN

Sichuan Qiongzhusi group and Longmaxi formation black shale not only has many favorable geological conditions for the formation of shale gas reservoir, but also have extremely rich resource. They have great exploration and development space. Although comparison to the North American region they have some common points (Table II), like both are mainly based on marine strata, be roughly the same in the content of TOC. However, the Sichuan geological structure is relatively complex, and the distribution of the shale is unstable, and the shale gas is buried deep, generally more than 3000 meters [17]. A lot of basic geological problems of Sichuan include the stability, occurrence, depth and thickness of the Sichuan rich organic shale layer need to be further identified.

Now widely used in shale gas geological resources and technology can be adopted in the [1] data source from the national shale gas resource potential survey and evaluation, the selection of the calculation parameters of low density, basic data is not sufficient. Need to further investigate and improve the credibility of the data. Oil companies began to carry out the work of oil and gas exploration and development in Sichuan fifty years from the last century, made the basic geological data, but they have no obligation to share these data or open to the society. Due to the inability to obtain reliable geological data, social capital is lack of the enthusiasm to participating in the shale gas block bidding, because the company had to carry out basic geological projects, increase the cost of basic geological research, reduce the return on investment.

Sichuan has a certain foundation in the development of the technology and equipment of shale gas exploration and development, but has not yet formed a supporting technology for the development of shale gas system. Especially for different geological conditions and to achieve economic

development of key technologies such as fracturing fluid formula is still monopolized by foreign companies.

The economic development of shale gas is different from conventional oil and gas fields. Because of the characteristics of shale gas, such as low gas pressure, low single well production, low recovery, high input, low output, production cycle is long, Sichuan is currently a well drilling cost early need 80-90 million, the latter can be reduced to 70million , only realize the factory production, the cost will be reduced to 50-60 million, a successful shale gas development projects need to drill thousands of wells, investment up to 10 billion yuan, such a high investment, so that shale gas exploration profitability is difficult.

South Sichuan region is the best area of shale gas potential, but also the most densely populated Sichuan, the economy is the most developed, the lack of water resources, the exploration and development may populate land resources, water resources and environmental. firstly, under the same gas production conditions, shale gas field area is about 10 times that of conventional natural gas, the number of drilling is conventional natural gas to a hundred times even more, coupled with the supporting of the well site, highway, reservoir, gas gathering station and will occupy more land. Secondly, the hydraulic fracturing fluid in a shale gas well is generally about 30thousand party, the demand for water resources is huge. So it need pay attention to the conflict between shale gas development and agricultural water, ecological water and water residents. thirdly, Shale gas fracturing operation, the part of the waste water will return to the ground, Sichuan, a shale gas wells will eventually need to deal with the waste water of about 3600, is 10 times the conventional oil and gas drilling projects, no doubt to the development of regional industrial wastewater treatment capacity and environmental costs of enterprises has brought great challenges.

The existing regulatory mechanisms, it is difficult to meet the needs of future development of large-scale shale gas.

Currently, the main shale gas development in Sichuan is relatively simple, the relevant laws and regulations and management methods are still relatively lack, especially in China. At the same time, the functions of the regulatory authorities, the duty is not clear and other issues also put forward new requirements to improve the regulatory mechanism.

TABLE II: SICHUAN AND NORTH AMERICAN SHALE GAS RESOURCE CONDITIONS AND CHARACTERISTICS OF A BRIEF COMPARISON TABLE [17]

| Contrast condition              | Sichuan                       | North America  |
|---------------------------------|-------------------------------|--|
| Era and sedimentary environment | Cambrian and Silurian, Marine | Devonian-Carboniferous, Marine<br>Triassic –Cretaceous, Marine |
| Shale thickness                 | 20-300m, small                | 49-610m, large   |
| TOC                             | 0.3%-10%                      | 0.5%-25%   |
| Permeability                    | lower                         | lower  |
| Ro                              | 2.0%-5.0%                     | maturity moderate  |
| Brittle mineral content         | lower                         | Silicon content more than 35%                                  |
| Save condition                  | Complex, Multiple reformation | Simple, Uplife once  |
| Buried depth                    | burden depth more large       | moderate buried depth (800-2000m)                              |
| Ground condition                | Complex and difficulty        | Simple and easy  |
| Ground condition                | imperfect                     | perfect  |

## VI. ADVICE

Therefore, the great prospects for the development of shale gas in Sichuan are beyond doubt, but the complexity of geological and development conditions also cannot be ignored. All these decided that the exploration and development of shale gas in Sichuan will not be accomplished overnight, it needs a long exploration. Mainly from the following several aspects:

Firstly, adhere to deepen the understanding of the geological and research in key technology; the evaluation of exploration and development in the area of commercial scale production of shale gas is summarized, especially the "factory" production. A set of evaluation index system is put forward to promote the development of shale gas exploration and development. Strengthen the construction of key laboratories in Sichuan Province, unified planning, focus on the strength of the horizontal well drilling and completion, water fracturing, micro seismic, geological evaluation and other fields to increase the intensity of key technologies, the formation of a set of targeted mature technology system, for the follow-up exploration and development for technical support.

Secondly, to the south of Sichuan marine shale gas as the key point, highlight the resources survey and evaluation, pro-mote the existing production areas, the formation of a certain scale of shale gas production. Led by the government, the integration of government, enterprises, universities, research institutes, and other advantages, to carry out a

combination of basic, public welfare, forward-looking strategic survey and resource evaluation of shale gas resources, to improve the understanding of the potential of shale gas resources. Establish Marine shale gas in Sichuan investigation and selection of technical standards, on the basis of this evaluation optimization favorable target areas of exploration and development and enrichment region. The special needs of innovative methods of work, efforts to coordinate the relevant units of information sharing, sharing of results, to achieve the province's shale gas geological data and comprehensive utilization of research, to avoid duplication of investment, promote scientific deployment, reduce the subsequent exploration risk.

Thirdly, to strengthen the transitional facies and continental shale geological evaluation; forth, to accelerate market-oriented reforms, stimulate market activity, attracting more social resources to enter the field of shale gas exploration and development.

Forth, to accelerate market-oriented reforms, stimulate market activity, attracting more social resources to enter the field of shale gas exploration and development. Formulate policies to encourage the mining right person and all kinds of enterprises at home and abroad to develop shale gas joint venture, cooperation. At the same time, the government actively carry out shale gas exploration tender to attract more enterprises to participate. Through the introduction of various types of social investment, the main active participation in the exploration and development of shale gas, the implementation of diversification of investment, not only can effectively share the cost of mining, and reduce the risk, but also form an orderly competition mechanism, can accelerate the development of shale gas exploration and development. In addition, Sichuan sedimentary strata vertical development have multiple sets of hydrocarbon source rocks, include marine organic rich shale, land and sea over phase of coal seam, so shale gas not isolated, simple in the form of a kind of resources exist in a region, both may development shale gas, coal seam gas, also maybe development of the coal seam. The government can take measures to adjust measures to local conditions in some areas to carry out shale gas and coal-bed methane, coal bed methane, and coal comprehensive exploration and development experiments to explore the realization of complementary benefits, and promote the efficient development of shale gas.

Last but not least, to improve the regulatory capacity. The government should strengthen the assessment of the impact of shale gas exploration and development on the environment, supervision of enterprises strictly enforce existing laws and regulations, environmental protection, building green mines. In advance to carry out water resources demonstration work, explore the operation mode of the fracturing and fracturing wastewater treatment method, to prevent a large number of water shortage and the lack of water resources in the local area, to avoid the contradiction of water consumption in large scale development phase. Shale gas development construction accounts for as little as possible of cultivated land, in the construction of well site, only to project the mouth of the well section and hardening, is helpful to the recovery of land reclamation and ground environment. To establish an effective supervision system, study the specific monitoring

method, increase scientific propaganda, strengthen communication between the community and residents in the mining area, improve the transparency of the supervision work, and reduce the risk of social stability.

## VII. CONCLUSION

Sichuan shale gas exploration and development started late, but it is the world's regions outside of North America in addition to the first to get shale gas exploration breakthroughs and achieve commercial-scale development. Sichuan shale gas geological conditions research and development of key development technology has a good foundation, obtained exploration breakthrough and commercial discovery in Paleozoic Marine Strata, is entering an annual output of  $20 \times 10^8 \text{ m}^3$  capacity building phase.

Sichuan developed marine facies, transitional facies, continental facies, 3 types of organic rich shale, huge shale gas resource potential. Sichuan Paleozoic marine shale wide distribution area, large thickness, rich in organic carbon content, high maturity, shale gas formation and accumulation condition is superior, is the focus of the development of shale gas in China.

Sichuan shale gas resources development prospect is good, the current exploration and development level is low, there are significant differences in the geological and development conditions of typical shale gas producing areas in North America. Future development needs to be aimed at the characteristics of Sichuan, strengthen the basic geological conditions and key development technology research, accelerate market-oriented reforms, improve the regulatory capacity, to achieve the scientific and orderly development of shale gas in Sichuan.

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