Coalbed Methane in China

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Foreword by Yan Song

The CBM National Basic Research Program of China (973 Program) will publish the *Basic Research Series of CBM Reservoir Forming Mechanism and Economic Development* (11 volumes), involving basic theories and applications in status quo and research, generation and storage, reservoir and accumulation, resource potential, and seismic exploration, economical, and efficient development of coalbed methane. It covers a wide range of areas, and is a very meaningful systematic science project. Asked by the Project Chief Scientist, I am happy to give the following text to show my support and congratulations.

CBM is an important unconventional natural gas resource. In the 1980s, the United States realized the commercial exploitation and utilization of CBM and established a coalbed methane industry with considerable scale. China is a country having abundant coal resources with quite rich CBM. According to the latest forecast, in the coalfield shallower than 2000 m, the CBM resources are 31×10^{12} m^3 (excluding the CBM in lignite), which is roughly equivalent to the conventional onshore natural gas resources in China. If the coalbed methane in lignite is calculated, the amount will be even more impressive. In terms of occurrence conditions and economic and social development demand of fossil energy resources in China, CBM is the most realistic replacement energy in China in the new century after coal, oil, and natural gas. At the same time, the development and utilization of CBM can eliminate the hazard of coalmine gas explosion and protect the environment.

Since the 1980s, China has carried out modern CBM technology research, development, and application. As of the first half of 2004, nearly 250 CBM wells have been drilled, and more than 10 CBM test well groups have been built in Liulin, Panzhuang, Dacheng, and Huainan, etc. Among them, three well groups have produced commercial CBM in Liujia, Fuxin; Panzhuang, Jincheng; and Shizhuang, Qinshui. In basic researches on coal reservoir characteristics and resource evaluation, and anthracite CBM development, etc., achievements have been made. However, in general, China's CBM industrialization process is slow and cannot meet the needs of national economic and social development.

CBM is different from conventional natural gas in geochemistry, reservoir, accumulation mechanism, flow mechanism, gas well production performance, etc. It is necessary to proceed with exploration and development of CBM using different theories and methods from conventional oil and gas. In addition, as China is a combination of several major plates after repeatedly colliding, and it is still affected by the joint action of the Eurasian, India, and Pacific plates. The coalification periods are more and long, and late reconstruction is frequent and strong, which makes the complexity and diversity of CBM geological conditions in China. Therefore, the US CBM theory developed on the single North American continent plate is not fully adapted to China's situation.

It is an urgent task for Chinese scientists and technicians to establish the basic CBM theory in line with China's geological features and providing scientific and technological support for building China's CBM industry. Supported by the Ministry of Science and Technology of the People's Republic of China, the 973 Program "Basic Reasearch on China Coalbed Methane Reservoir Forming Mechanism and Economic Development" was proposed, which gathers experts, scholars, and elites from the oil industry, coal industry, Chinese Academy of Sciences

and higher institutes in China. It follows a new scientific research concept of multidisciplinary cooperation, and the combination of production with research, and changed the passive situation where departments and disciplines work separately.

The project focuses on national goals and key scientific issues and organizes various forces to carry out extensive and in-depth basic research from a high starting point on main scientific issues of CBM industrialization in China, such as the cause, reservoir performance, dynamics, genesis, accumulation, geophysical response, gas flow, and output mechanism of CBM. These results have theoretical guidance for the formation and development of China's CBM industry and represent the overall level of present basic researches on CBM in China.

Timely collection and publication of research results can demonstrate the situation of China's basic research on CBM and is an important link to strengthen academic exchanges, disseminate knowledge, and accelerate the transformation of scientific research results into real productivity. New scientific theories and technical methods will accelerate the industrialization of CBM in China and contribute to the development of CBM in the world. Let us all work together to meet the growing demand for clean energy in China's economic and social development.

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Foreword by Yan Song

CBM, commonly known as methane gas, is a self-generated, self-contained, unconventional natural gas that is present in coal seams in an adsorbed state. The development and utilization of CBM is a two-pronged thing. It can not only be used as a supplementary resource for conventional oil and gas, but more importantly, greatly improve the safe production conditions of coalmines and reduce or even eliminate coalmine accidents.

As a kind of unconventional natural gas resource with huge resources, CBM has gradually evolved from research to development and utilization. The United States is the first country to develop and utilize CBM. The CBM industry started in the 1970s and achieved large-scale commercial development in the 1980s. The production of CBM is growing rapidly. The annual output raised from less than 1×10^8 m^3 in 1980 to 100×10^8 m^3 in 1990. In the early 1990s, stable production was 200×10^8 m^3. In 2002, the annual output was 450×10^8 m^3, accounting for 7.9% of the annual production of natural gas in the United States. The development of CBM is quite successful in the US, specifically the San Juan Basin in Colorado and New Mexico and the Black Warrior Basin in Alabama. CBM wells are generally considered to be low yield, but some are quite productive. For example, in 1996, I visited the San Juan Basin under the control of ARCO, where 110 CBM wells were with daily gas production of 660×10^4 m^3. Therefore, it is of great theoretical and practical significance to study the high-yield regulations in the low production of CBM. Drawing on the successful experience of the United States, Australia has also carried out exploration and testing of CBM and achieved certain results. In addition, Czech, Poland, Belgium, the United Kingdom, Russia, Canada, and other countries have carried out exploration and development tests for CBM. At present, the world's research on CBM is deepening, and the development area is expanding, and the position of CBM in energy is rising.

China is a large coal resource country with abundant CBM resources (according to the estimate from the "7th Five-Year Plan," the resource shallower than 2000 m is 31×10^{12} m^3). China's CBM exploration and development is obviously behind the United States. Since the 1980s, the United States' CBM production technology has been actively introduced to carry out exploration and development experiments. However, the overall results are not significant. The main cause is that China's CBM geological conditions are complex, and the forming mechanism of CBM reservoirs is still not clear. The exploration and development of CBM are quite different from conventional natural gas, and there is a lack of perfect and mature theory. Therefore, the basic theoretical research on the exploration and development of CBM in China will be the premise to promote faster development of the industry. As a national key scientific and technological project, the "Development Research of Coal-forming Gas" performed 20 years ago, is a good example of proceeding the development of natural gas industry in China. I have worked with other scientists, appealing to the Ministry of Science and Technology of the People's Republic of China for the project establishment of CBM research. Today, this wish has finally been realized. The "Basic Research on CBM Reservoir Forming Mechanism and Economic Development" has been officially implemented. This is a good news and a great event that should be celebrated. The project will solve some major problems in the exploration

and development of CBM in China, deepen the understanding of the mechanism of CBM accumulation and reclamation, and give birth to a promising future of CBM development.

I am happy to be appointed one of the experts to track the project. From the initiation of the project to the start of research, I have been paying attention to its progress and research results. The early achievement is remarkable, including many new discoveries, new understandings, new ideas, and innovations. Song Yan and Zhang Xinmin, two chief scientists, plan to publish the series of the *Basic Research Series of CBM Reservoir Forming Mechanism and Economic Development* (hereinafter referred to as "Series") (11 volumes). The "Series" contains all aspects of CBM exploration and development, including the references collected and analyzed —the theory basis "CBM Reservoir Forming Mechanism and Economic Development," and the results of various research projects and topics. The "Series" studies many basic and critical issues related to technology, theory and methods of CMP exploration and development from CMB forming dynamics process and resource contribution, heterogeneity, and control mechanism of physical properties, adsorption characteristics and gas storage mechanism, dynamic and accumulation conditions and model, CMB recoverable resources, seismic response of CMB reservoirs, basic theory and technology of CMB development. It is a project that has not been reached before. The purpose of the series is to provide a systematic theory of CMB exploration and development with Chinese characteristics, which is lacking in China. In addition, the chief scientists intend to fully demonstrate the outstanding achievements of China's CMB research to scholars in geosciences and CMB for mutual learning and exchange. The "Series" is knowledge accumulation, regular summaries, and innovations in this field. The publication of this series will be of great benefit to scholars, professionals, and college students engaged in CMB work, and will inevitably have an important impact and promotion on the CBM industry.

The chiefs and authors of the "Series" are young or middle-aged mainstay. The project gave them an opportunity. They are energetic, knowledgeable, diligent, and innovative. The "Series" drafted by them is solid and knowledgeable.

I would like to wish that the *Basic Research Series of CBM Reservoir Forming Mechanism and Economic Development* will be successfully published in succession, and become a comprehensive literature of CBM theory and practice.

August 2004

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Preface

With the rapid development of the national economy, China's demand for energy continues growing, and the contradiction between oil and gas supply and demand has become increasingly prominent. From a net exporter of crude oil in 1993 to an importer, China's demand for crude oil import has increased year by year as domestic demand continues growing. In 2007, China's net crude oil imports were 15928×10^4 t, a year-on-year increase of 14.7%. The external dependence of crude oil reached 46.05%. According to the forecast, like crude oil, natural gas will have a supply gap in recent years. CBM is an unconventional natural gas resource-rich and less developed in China. The total resource of CBM with a depth of less than 2000 m in China is 32.86×10^{12} m^3, of which the technically recoverable resource is 13.90×10^{12} m^3. The prospective resources of CBM are roughly equivalent to the conventional natural gas in China. CBM is a clean energy source that is second after conventional natural gas. The development and utilization of CBM have important practical significance for ensuring the long-term rapid development of China's natural gas industry.

Coalmine safety is very important for the development of coal industry. Since 2001, with the increase of CBM (gas) extraction, the government has attached great importance to and invested a lot of human and financial resources. The death toll caused by coalmine accidents has generally declined. However, the number of coalmine accidents and casualties remains high. In 2006, there were 2945 coalmine accidents and 4746 deaths, including 327 gas accidents and 1319 deaths, accounting for 11.1% and 27.8% of industrial accidents in the coal industry, respectively. Statistics show that the number of people killed in gas accidents in recent years accounted for about 25% to 40% of the deaths from industrial accidents in the coal industry in China, causing huge economic losses. By "first producing gas and then coal," a coordinated development model between CBM and coal can be established, and the common development of CBM industry and coal industry will be realized, which will provide an important guarantee for the harmonious development of the national economy and society.

Environmental protection is an important part of a sustainable development strategy in China and the world in the twenty-first century. The air pollution caused by coal-based primary energy consumption structure is very serious, which leads to extensive acid rain and deteriorated urban air. The distribution of acid rain accounts for 8.4% of China's land area. The main component of CBM is methane (CH_4), while the "greenhouse effect" of methane is 22 times that of carbon dioxide (CO_2). In China, a large amount of CH_4 is directly discharged into the atmosphere due to coal mining. The higher CH_4 emissions make China face increasing pressure from the international community. As an energy, the CO_2 released by CBM burning the same calorific value is 50% less than oil and 75% less than coal. The pollutants produced by CBM combustion are generally only 1/40 of oil and 1/800 of coal. Accelerating the development of the CBM industry and rapidly increasing the proportion of natural gas in the national primary energy consumption structure can effectively reduce CH_4 and CO_2 emissions, which is an important way to improve and protect the living environment in China.

Based on the needs of national energy development, in 2002, the Ministry of Science and Technology of the People's Republic of China established the National Basic Research Program of China, the "Basic Research Series of CBM Forming Mechanism and Economic Development," which mainly addresses the subject issues of CBM exploration and

development. The project was completed in November 2008. This book reflects the comprehensive research results of the project.

In terms of basic theoretical research, this book reveals the laws and mechanisms of CBM genesis, occurrence, accumulation, and permeability in China, systematically establishes CBM geological theory system and enriches and perfects natural gas geological theory. It is fundamental to CBM resource evaluation, accumulation prediction, and economic development.

1. Established a CBM genetic-type classification and tracer index system. It's proposed that secondary biogas is one of the important genetic types of CBM in China. The evidence of the existence of secondary biogas was determined. The generation conditions and formation mechanism of secondary biogas have been investigated.
2. Based on the theory of adsorption potential, models of coal adsorbing methane and sectional coal adsorption isotherms of different coal ranks at different temperatures and pressures were established. They reveal the adsorption during the formation of CMB, and provide a theoretical basis for understanding CBM accumulation mechanism, conducting CBM resource evaluation and development technology.
3. Defined the concept of CBM reservoir. Structure, caprock, and hydrodynamic conditions are controlling factors. Structure and hydrodynamics are controlling mechanisms on CBM reservoirs. This is a scientific basis for predicting CBM enrichment.
4. Established the theory of elastic energy and controlling effect of coal reservoir. It is pointed out that the mechanism of permeability changes when producing CBM is the combined effect of closed fractures caused by increasing stress and shrinked coal seams caused by gasification. That is to say, the theory of elastic self-regulation effect of coal reservoirs guides how to select favorable targets and drainage system.

In terms of method and technology, this book has formed a series of technologies covering CBM recoverable resource prediction, comprehensive geological evaluation, geophysical exploration, and optimization of production design, and served the implementation of coalbed methane development. Field application has proved effective.

1. Established a new "CBM resource classification system," which is consistent with conventional natural gas and international codes. A concept was proposed for technically recoverable resources of CBM and the systematic, scientific, and operable method for predicting CBM recoverable resources was developed for the first time in China. It is predicted that the technically recoverable resources of CBM are 13.90×10^{12} m^3 in China.
2. Established a prediction and evaluation method of CBM exploration and development zones, and found high, medium, and low metamorphic and unmetamorphic (lignite) favorable coal zones which are targets for the exploration and development of CBM resources.
3. Developed three-dimensional three-component seismic and AVO response detection techniques, which made good results in the CBM experimental area in Huainan. The technologies are worth promoting.
4. Independently developed a numerical simulation system for CBM reservoir evaluation, hydraulic fracturing, and pinnate horizontal well optimization design, which filled the gap in this field in China, and made good results in southern Qinshui Basin.

The book consists of 11 chapters. The first chapter introduces the status quo and research of CBM exploration and development. Chapters from the second chapter to the ninth chapter introduce the theory and evaluation technology. The tenth chapter and the eleventh chapter discuss the production mechanism and technology. The book is integral and covers the basic research results from exploration to development of CBM.

The preface and the first chapter of the book were written by Song Yan, Zhang Xinmin, and Liu Shaobo; the second chapter by Tao Mingxin and Xie Guangxin, et al.; the third chapter by Tang Dazhen and Wang Shengwei; the fourth chapter by Zhang Qun, Sang Shuxun, et al.; the fifth chapter by Qin Yong, Hou Quanlin, Song Yan, et al.; the sixth chapter by Song Yan, Liu Honglin and Hong Feng, et al.; the seventh chapter by Zhang Xinmin, and Zhao Jingzhou, et al.; the eighth chapter by Peng Suping and Huo Quanming, et al.; the ninth chapter by Liu Honglin, Zhang Xinmin, Qin Yong, Tang Dazhen, et al.; the tenth chapter by Hu Aimei and Zhang Sui'an, et al.; the eleventh chapter by Wan Yujin and Zhang Shicheng, et al. The final version was completed by Song Yan, Zhang Xinmin and Liu Shaobo.

In preparation of the book, thanks to the Ministry of Science and Technology of the People's Republic of China; China National Petroleum Corporation; PetroChina Company Limited; Xi'an Research Institute, China Coal Technology Engineering Group (Xi'an Research Institute); all responsible units, departments, and expert group. With joint efforts of all researchers, the project has been successfully completed, achieved expected goals, effectively implemented basic research innovation, and served the industry. It is expected the publication of this book can promote the basic research and application of CBM and the development of CBM industry in China.

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