

Methodology Article

The Study of Sedimentary Facies in Daqing Oilfield from the Perspective of Science of Science

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Abstract: The sedimentary facies research in Daqing oilfield has gone through a process of generating ideas, conducting research, and achieving results, the achievements of which have been widely applied in oilfield production¹. The research is a very typical case in the history of petroleum science and technology with strong science of science significance, which is in conformity with the universal law of science of science on the emergence, development and maturity of new science and technology. It came into being along with the actual needs of the development and production of Daqing oilfield, and was gradually formed and has been gradually improved through step by step exploration and accumulation under the guidance of scientific methodology. The principle of science of science points out that there are three necessary conditions for the existence and development of a new theoretical doctrine, the case of Daqing oilfield fully complied with the principle: it not only contains the scope of the original theory, but also can solve the problems that the original theory are unable to solve, and may further predict the future development, so it has a strong vitality. Meanwhile, science of science also points out that it is almost impossible for a new science and technology to emerge smoothly without obstacles and setbacks. This study is just such a case, which was initially accused of heresy, not accepted by some authorities. However, after being tested through repeated practice, it has finally established its status, and has still been playing an important role in the development process of Daqing Oilfield.

Keywords: Science of Science, Subdivision Sedimentary Facies, a Fluvial- delta Depositional System in Continental Basins, Daqing Oilfield

1. Introductions

In the early stage of development of Daqing oilfield, geologists found many basic problems in the production process of the oilfield, which involved deepening the understanding for the regional sedimentary background. With the help of experts from the Institute of Geography of the Chinese Academy of Sciences, the two sides cooperated in the research and achieved the results of the far-reaching "subdivided sedimentary facies" research in the future. This paper is the investigation and discussion for science of science in this process.

2. Achievements of Sedimentary Facies Study in the Early Development of Daqing Oilfield

The study of subdivision sedimentary facies was an important breakthrough in the development geology of Daqing Oilfield in the mid-1970s [1], which subverted the traditional view of "pan-lake theory" in Songliao Basin and established the "large fluvial-delta sedimentary model". It played an important role in understanding the dynamics of oilfield production, guiding the water injection scheme of oil extraction, cultivating relevant potentials, and forecasting the

production trends to enhance oil recovery test, the profound influence of which had promoted the study of sedimentary facies in other oilfields all over the country. From the exploration discovery to the practical development of Daqing oilfield, the early geological conclusion was based on the theory that the Songliao Basin was the inland lake basin sediments of the Mesozoic Jurassic and Cretaceous eras. Based on this idea, the horizontal cutting water flooding development plan assumed that after injecting water into the water injection wells, the groundwater would form a continuous water line pushing towards both sides, which would push the crude oil to the production wells and to be drained through the oil wells. However, oilfield production and development practice was not that simple, as the water line was not shaped, the injected water was streamed more into a single layer rush, with water being seen irregularly in production wells, showing a large number of "South Waterlogging North Drought", an inconsistency between the dynamic phenomenon and the static data of references. By the 1970s, this issue became more prominent, which called for an urgent need of new theories for explanation and guidance.

Once during the exploration, Wang Hengjian¹, a young paleontologist of the Daqing Research Institute, saw mountain rocks, mud and sands tumbling down in the water of the Nenjiang River, forming an accumulated layer at the foot of the mountain. The phenomenon inspired him to study modern sedimentology, the idea of which was supported by the leaders of the institute, who went to the Nanjing Geography Institute of Chinese Scientific Academy branch, the authoritative institution specializing in Lake and sedimentology in China, hoping to find solutions and enlightenment for them.

In 1972, the two institutes began to cooperate in a research project on *The Ancient Sedimentary Environment of the Middle Oil-bearing Strata Assemblage in the Northern Songliao Basin* [2]. Starting from the developed oilfield which contained a relatively large number of data, the two teams directly observed and studied the cores of 85 Wells, applied the mechanism of geomorphology and sedimentology, interpreted and dissected the geometry and sedimentary characteristics of a large number of sandstone bodies with logging curves, and classified the genetic types of different sandstone bodies. After more than three years of tackling key problems, they made a breakthrough in proving a new understanding that "the northern part of Daqing Oilfield is a large fluvial-delta deposition". They also pointed out that the sedimentary forms of Daqing placanticline from the north to the south are: the Lamadian sand body is meandering river deposit, the sand body from Saertu to Xingshugang is distributary channel deposit, and Xingshugang sand body is the underwater part of the delta. Under the guidance of this theory, a trinity research method of sedimentary microfacies has been formed based on sedimentation, heterogeneity, and the rule of oil-water movement [3]. This research established the theoretical basis and geological basis for the comprehensive adjustment and "the successive stable production" of Daqing Oilfield in the 1970s, and contributed significantly to the long-term stable production of 50 million

tons per year in Daqing Oilfield. On hearing the news, Shengli, Jilin, Nanyang, Karamay, Liaohe and other oilfields came to Daqing for experience from 1974 to 1976, and successively started the research on subdivision sedimentary facies in their oilfields respectively.

The above mentioned study of the sedimentary facies in Daqing oilfield is a typical case with science of science significance in the history of petroleum science and technology.

What is "science of science"? It is the study of the law of the development of science and technology, the contents of which mainly covers a series of problems, including revelation of conditions for forming new theories, new technologies, and new methods, the driving force for development and its evolution, and how science and technology are combined with social production practice, and how to serve social production. It belongs to the category of philosophy of science and technology [4].

Since the rise of modern petroleum industry in 1895, the history of petroleum development has been full of legends and unconstrained fluctuation for more than 150 years. However, from the perspective of science of science, it is actually a history of integrating various new theories, new technologies, new studies and new methods of science and technology into the petroleum field. Some of these outsiders have been combined with the original technology, and some have subverted, replaced and transformed the original technology. No matter where they are from, all of them are heralds pushing forward the development of oil production.

The occurrence and development of science and technology have their own rules, which are not controlled by our will. The development and application of lithofacies palaeogeography in oilfields follows a similar rule.

3. The Inevitable Development of Discipline and Technology

The development geology work of Daqing oilfield has been carried out under the guidance of philosophical thought from the very beginning, with an emphasis on the importance of primary data, the understanding of payzones according to the objective reality of things, the objection to subjective assumptions, the objection to "rough estimation of large average" (data), the intensive study of "oil-bearing sand bodies", the "contrast of zones" by the masses, etc., for which our research and development personnel have done a lot of hard and meticulous basic research work.

After repeated practice, the researchers of the Stratigraphic Correlation Team (a research section of the Geological Command Post, the predecessor of Daqing Institute of Sciences) put forward a set of cyclic correlation methods based on hierarchical control and formation as a unit, which broke through the past tradition of recognizing pay zones in large sections in a general way. By 1961, they divided the underground pay zones into five oil-bearing series, 14 complex pay zones, 45 single pay zones and more than 2000

“oil-bearing sand bodies”. The special “pay zone” distribution map was made for each zone, which marked the shape, size, location, thickness, permeability and other basic information of each “pay zone” and their interconnection between the upper, lower and other layers. These core achievements have played a vital role in the development and construction of Daqing Oilfield, and have won two national awards. Nonetheless, this does not mean that we have fully understood pay zones and there is no need for further development.

By the early 1970s, when the oilfield had been put into production for only more than ten years, the water content of crude oil gradually increased, and some blocks were in the middle water cut stage. With the development of water flooding, the relationship between oil-water displacement and the status of oil-water distribution has become extremely complicated in pay zones, and many unexpected and unexplained new situations and new problems arose.

The situation of Daqing was just like the first half of a sentence in an old Chinese poem: “After endless mountains and rivers that leave doubt whether there is a path out...” When production in Daqing Oilfield was in such seriousness, how would the oilfield geologists face it? How could people find solutions? This was the reality people had to face at the time.

Luckily, the pioneering research work on lithofacies palaeogeography carried out by Nanjing Geographic Research Institute significantly conformed to the needs of this situation, which demonstrated the law of continuous evolution of science and technology. On the basis of existing work in Daqing, the lithofacies palaeogeography method was introduced, and the sedimentary environment of the underground pay zones in Daqing oilfield were analyzed by using the principles of geomorphology and sedimentology [5, 6]. Meanwhile the various types of oil-bearing sand bodies were recognized in nature and genesis. As a result, reasonable answers were provided to some difficult problems that could not be explained before, and according to this new understanding, some scientific predictions of production changes that would occur could be made to guide the adjustment of oilfield development, and the design of measures operation and development test, making the geological research work of the oilfield development remain to be ahead of the production and construction, which had well elaborated the fundamental, strategic and guiding role of geological science. Thus the situation described in the later half of the sentence in the above old poem appeared, and then the geologists of Daqing oilfield “suddenly encounter the shades of willows, the bright flowers and a lovely village.”

4. Products Under the Guidance of Scientific Methodology

When conducting research in the lithofacies palaeogeography, the following steps and methods should be followed basically in the research work [7]:

The first step is to observe the core carefully to find direct evidence.

The core is the most direct first-hand data, which carries abundant information of stratum, lithology, physical property, stratification, oil-bearing property, electrical property, paleontology, structure, sedimentation, etc. Researchers from Nanjing Institute of Geography have also applied the newly mastered logging curve interpretation method, which greatly enhanced the speed and efficiency of contrast. They have observed the cores of 85 wells successively in Daqing and have obtained abundant primary data. Their work has laid a solid foundation for the following theoretical research.

The second step is to combine faces demarcation in single well with the whole payzones anatomy from point to plane

It is necessary to start with the observation of single well core. However, it is still imperfect to recognize the facies zone of a region only by means of single well facies delineation. It is necessary to combine the parts and the whole together for repeated verification to get a true understanding of the subsurface.

After making achievements in the work in the dense well pattern area of the oilfield, the research group expanded their field of vision and further studied the problem of sedimentary system. Macroscopically, they explored the spatial and temporal evolution of the whole basin so as to get a complete picture of the sedimentary pattern of the Songliao basin. Afterwards, they would in return recognize the local area in parts so as to reduce mistakes. Together with researchers from Daqing Oilfield, they carried out such work in a systematical way, and finally concluded that the Changyuan depositional form of Daqing, from the north to the south would be: Lamadian sand body is meandering river deposit, the sand body from Saertu to Xingshugang is distributary channel deposit (upper continental part of river delta), Xingshugang sand body is the underwater part of the delta. This complete a fluvial delta depositional system in continental basins has been verified and proved to be correct by repeated practice afterward.

The third step is “uniformitarianism”

The team carried out several comparative investigations of modern deposits in the field. They investigated the Nenjiang Point Bar, the beach deposits of Hongze Lake in northern Jiangsu, and the deposits of Poyang Lake and Ganjiang Delta. During the investigation, they carried out the observation and discussion at the same time, hence almost all the difficult problems encountered in the work were solved one by one on the spot. Many people recalled that they were deeply benefited from the experience. In order to establish China’s own lacustrine sedimentary model in a more extensive scale, they decided to select three (shallow, middle and deep) fault lakes in Yunnan Province, namely Fuxian Lake, Erhai Lake and Dianchi Lake, as the research focus after a long-term investigation and comparison in 1978. They comprehensively studied the sedimentation and environment of fault lakes and have provided analogical models for the exploration and development of oil in different types of oilfields.

The forth step is to learn the best from multiple others

The research group has attached great importance to collecting and studying information at home and abroad as well as raising their theoretical level.

In the 1970s, the study of sedimentation in the Mississippi River Delta began to rise in the United States. It was a breakthrough in sedimentology, which led to the study of river deltas in various countries. The research group had organized the translation of hundreds of thousands of words of foreign literatures at the time, during which the famous book "Terrestrial Clastic Sedimentary Environment" was translated and published.

The research team also visited many famous scholars in order to understand the achievements of modern sedimentology from a deeper and wider perspective, and to serve the ongoing study of sedimentary facies in Daqing. For example, for understanding the formation environment of various colored mudstones in the core, they invited Professor Xi Chengfan² of the Institute of Soil Research of Chinese Academy of Sciences to explain the formation causes of various soils; in order to determine the formation environment of mudstones from the rock characteristics, they asked Professor Ren Meiyong³, Dean of the Department of Geography of Nanjing University and Member of the Chinese Academy of Science, to explain the sedimentary characteristics for sea and lakes, current lake and closed lake, as well as the various continental environments. They also invited Professor Yan Xinshang⁴ of Tongji University and Professor Chen Jiyu⁵ of Shanghai Normal University to explain the formation principle of delta, estuary theory, and so on. These efforts not only enabled the group members to have a better understanding of the research level at home and abroad, with enriched theoretical knowledge and enhanced confidence, but also enabled the members of the research group to find and seize the key to the study of lithofacies and paleogeography in Songliao Basin.

The fifth step is to absorb everything and to corroborate each other

The study of sedimentary facies has been carried out not only in Daqing but also in other oilfields in China. As most of the oilfields discovered in China were formed in the Mesozoic and Cenozoic paleolake basins, so the lake sedimentary model has both special and general characteristics. This research, which was started in Daqing, has been popularized to all oilfields in China, being generally effective. In return, the practice of the research in other oilfields has promoted the further development of this research in Daqing oilfield [8].

5. Revelation

In the history of science and technology, it is almost impossible for a new doctrine and new technology to emerge without obstruction or opposition. It is not at all surprising that new theories and technologies are often regarded as heresies. Sometimes the great resistance can almost kill it in the cradle. However, new theories and new technologies that conform to the strict scientific sense all have strong vitality, and their healthy growth and mature development are guaranteed [9]. The study of sedimentary facies in Daqing has gone through such a process.

Principles of science of science point out that there are three

conditions for the existence of a new theory: first, it can contain the scope of the original theory; second, it can explain the phenomenon that the original theory could not explain; third, it can make further predictions of future development [10]. The theory of fluvial delta deposition in the Songliao basin is consistent with the above principles. It has not subverted the original study of zones correlation and oil sand bodies, but has deepened and developed it further, from which many problems in development dynamics, such as single-layer inrush of injected water, "flooding in the South and drought in the north", irregular water breakthrough in oil wells, and even the existence of some kind of perceptual experience of the underground "water pipe" can be explained. According to geologists' recollections, the "chicken feet" maps drawn by various subdivided sedimentary facies have been similar to those drawn by Wang Dianyu⁶, an old geologist before the study of sedimentary facies. At first, these maps were only similar on the morphology, which were not deeply understood with reference to the sedimentary mechanism. Only after learning the knowledge of sedimentary facies method, he "suddenly felt enlightened". As a famous saying in Chinese goes, "when you feel a thing, it does not mean you understand it, and only when you fully understand one thing, you can feel it profoundly."

As for the function of prediction, it goes without saying. The study of subdivision sedimentary facies has continued to play a guiding role in oilfield dynamic analysis, adjustment and tapping potential, reservoir research, and even enhanced oil recovery test since the 1970s.

Many years ago, a humble young paleontologist who was inspired by his observation of river bed deposits in the wild, decided to study modern sedimentation, which has triggered a significant revolution in Daqing's geological understanding, while its subsequent influence and effect was unimaginable to the young man at the time. This kind of cases are not uncommon in the history of science, which tells us that everything should proceed from reality, not simply follow the books or your superiors, but to explore to create, as there are no limits for the development of science and technology.

The study of sedimentary facies in Daqing oilfield has been recognized and highly praised by peers at home and abroad. During the Eleventh World Petroleum Congress held in London in 1984 and the International Conference on Petroleum Geology and Petroleum Engineering held many times in the following years, Chinese experts introduced the achievements and attracted the attention of their counterparts all over the world. They believed that the research work in China was more advanced than that in the United States. Sedimentary facies research has won many national and provincial awards in China, but there is little or no mention of the contribution of Nanjing Geographic Institute. This injustice can only be attributed to "a common phenomenon in the history of science and technology".

6. Conclusions

The research process of sedimentary facies in Daqing

shows the following conclusions:

- (1) The occurrence and development of new science and technology must have some suitable opportunities and conditions, and the need for production is a great original power.
- (2) The occurrence and development of new science and technology must follow certain methodological guidelines, including starting from reality, grasping the first-hand information; integrating part with the overall situation; opening research, embracing the strengths of a hundred schools of thought and so on.
- (3) Production practice is the most important and direct test of scientific understanding.
- (4) In-depth cooperation between enterprises and scientific research institutions will result in win-win results.

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Brief Introduction of Related Personnel

1. Wang Hengjian, Former Geologist, Geological Department of Daqing Oilfield Administration.
2. Xi Chengfan, Researcher of Soil Research Institute, Chinese Academy of Sciences.
3. Ren Meijiao, Academician of Chinese Academy of Sciences, Director of Geography Department of Nanjing University.
4. Yan Xinshan, Professor, Department of Geography, Tongji University.
5. Chen Jiyu, Professor, Department of Geography, Shanghai Normal University.
6. Wang Dianyu, Former Geologist of No. 4 Oil Production Plant of Daqing Oilfield and General Geologist of Nanyang Oilfield, Henan Province.

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