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Practical Geophysical Technology and Application for Lithological Reservoirs

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Preface

The discovery of lithological reservoirs accounts for an increasing proportion and a large proportion of proven reserves submitted each year are from lithological reservoirs. After many years of exploration, petroleum geologists have revealed the diversity and complexity of continental basin deposits. This kind of diversity comes from the multi-stage tectonic activity of basin-forming and the complexity of basin reconstruction, which leads to the formation of several types of basins, such as depression, fault depression, and foreland, has been formed. Since Mesozoic, the continental basin has experienced a variety of climatic conditions, including humid climate, arid climate, marshy environment, offshore environment, and saline environment. The superposition of these factors makes the lithological types of continental basins in China rich and varied, and the lithological traps are complicated and changeable. The terrestrial sedimentary reservoir model and theory of structural traps have been difficult to meet the needs of guiding lithological reservoir exploration. Compared with conventional structural reservoirs, lithological reservoirs have more concealment, more complex accumulation rules, more difficult to explore, and higher requirements for exploration technology. The purpose of compiling this book is to develop and innovate the theory of characteristic lithological reservoir, to form the corresponding prediction technology and exploration method, and to obtain the results of universal guiding significance for the exploration of the entire lithological reservoir.

In the field of lithological reservoirs, there are still a series of problems, in theory, technology, and exploration. In theory, there is no systematic understanding of sandstone control factors, reservoir control factors, enrichment conditions, and reservoir-forming laws. In terms of technology, the description of the sandstone body and reservoir prediction, oil and gas layer protection, low permeability fracturing, and high yield are not fully matched. On the exploration, lithological reservoir exploration procedure, especially the determination of the secondary exploration zones and industrialization mapping requirements is not clear on the field research and application of the east of the basin in China, especially in the exploration of the Songliao basin is more. A complete set of techniques has been established from true 3D structure and sequence interpretation to visual good placement design. Compared with the basins in western China, due to the complexity of basin structure and the diversity of reservoir and reservoir types, the supporting methods and technologies for lithological reservoirs have not been established yet. Based on the successful exploration experience of lithological reservoirs in eastern China, this book summarizes the relevant techniques to promote the exploration of lithological reservoirs.

After many years of exploration of lithological reservoirs, under the guidance of the analysis of accumulation controlling factors and distribution law of lithological reservoirs, this book has summarized a set of exploration methods for lithological reservoirs based on geological analysis by using geophysical techniques, which have been applied and popularized in practice and achieved good results.

With the continuous improvement of the exploration degree of petroliferous basins in China, it has become an important research direction to strengthen the application of sequence stratigraphy techniques and methods and to study the formation conditions and distribution laws of lithological reservoirs. The establishment of a set of relatively perfect theory and matching technology has a very broad application prospect for promoting the exploration of lithological reservoirs. Studies at home and abroad have proved that sequence stratigraphy is an effective method to search for lithological reservoirs, and it is an important research direction to combine sequence stratigraphy theory with modern seismic interpretation techniques, especially with various seismic reservoirs prediction techniques.

The preface, Chap. 1 and 2 were written by Huandi Wang; Chap. 3 and 4 by Huandi Wang, Ming Li, Yadong Wu; Some of the illustrations are provided by Jianrong Gao. The whole book is modified and revised by Huandi Wang.

We take this opportunity to thank many people who have helped, in different ways, in the preparation of this book. In particular, We would also like to express our appreciation to Lisa Fan, senior editor of Springer International Publishing Company for her patience and understanding. Due to the proficiency limitation of the author, we expect the kind comments and opinions from readers regarding any mistakes or incorrectness in this book will be corrected in our next edition. Thank you.

Beijing, China

Huandi Wang
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Contents

Chapter 1
Introduction

Concerning concepts of the lithological reservoir has put forward very early, and its connotation, characteristics, and classification are replenished and perfected constantly, but in the past have found lithological reservoir, with a certain chanciness, mostly tend to be following the find structural reservoirs exploration ideas and methods, and found nothing to do with structure or on the background of the tectonic lithological reservoir. In recent years, with the increasing number and scale of lithological reservoirs discovered at home and abroad, explorers have gradually differentiated them from structural reservoirs in practice, developed related theories, and explored methods and techniques suitable for lithological reservoir exploration.

1.1 Study on the Formation of Lithological Reservoirs

Since the 1960s, some countries in North America, Western Europe, and other countries have been forced to look for oil in hidden traps due to the sharp decline in the oil reserve-production ratio. Therefore, to find and capture the hidden traps, which are mainly lithological and stratigraphic, becomes the main target to explore oil and gas potential in exploration mature basins.

Lithological reservoirs were first classified as obscure reservoirs, a relatively fuzzy concept. Subtle reservoirs were first proposed by Karl in 1880. Wilson proposed in 1934 that non-structural traps are "reservoirs closed by changes in porosity in rock formations". Lai put forward the concept of stratigraphic trap and published a paper entitled "stratigraphic oilfield" in 1936. In 1972 Halbert called the reservoirs formed by stratigraphic traps, unconformable traps, and paleotopographic traps as subtle reservoirs. For nearly 30 years, with the development of world petroleum exploration technology and the deepening of the scientific research work, the hydrocarbon reservoirs are defined to further expand to: under the condition of existing exploration method and technology level, more difficult to identify and describe the reservoir

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type, it covers the stratigraphic and lithological reservoirs and complex fault-block reservoirs and low amplitude gentle anticline oil–gas reservoir type, etc. (Li et al. 2014).

Because of the geological background, trap mechanism, exploration theory and technique of the lithological reservoir, and the huge reserves and broad resource prospect, it is necessary to define and study the lithological reservoir conceptually. At present, lithological traps are generally defined as follows: lithological traps are traps that lack four-azimuth closure and cannot be found by the exploration strategy of looking for structural traps. If they are related to the structure, they develop in an unexpected place (such as the position of the lower flank of the structure). It is a trap that cannot be defined solely by structural closure, including a single lithological trap, stratigraphic trap, and lithological composite trap with a structural background. The upper of Fig. 1.1 shows lithological composite trap with the structural-lithological reservoir as background. This kind of trap is the majority, the structural background is favorable to the enrichment and preservation of oil and gas. The underpart of Fig. 1.1 shows a single lithological trap, the developed sandstone body is surrounded by mudstone strata, forming a relatively independent and single lithological reservoir.

In the current lithological trap classification, the main mechanisms of trap formation can be divided into the following categories: lateral facies change trap, lateral sedimentary tip out the trap, overlying/concealed outcrop trap, channel/gully filling trap, diagenetic trap, fissure trap, and hydrodynamic trap. Specifically, it can be divided into 18 types: lateral pinch-out, lateral facies change, channel filling, regional sub-outcrop, valleys, structure filling flanking the overlap on the unconformity, cementation, regional unconformity of overlap, cracks on the deep basin gas, edge cutting, palate structure sub-outcrop, dolomitization/corrosion, coal bed methane adsorption, clastic rocks configuration, incised valley filling, hydrodynamic, asphalt sealing, etc. (Wang 2005).

Among these trap types, lateral sedimentary pinch-out, lateral facies change, channel filling, and regional concealed outcrop are the most common, accounting for about 57% of the total. However, the number of traps with high frequency is not necessarily the most abundant. The types of traps with large reserves of individual traps include the overlapped traps on structural flank unconformity, the overlapped

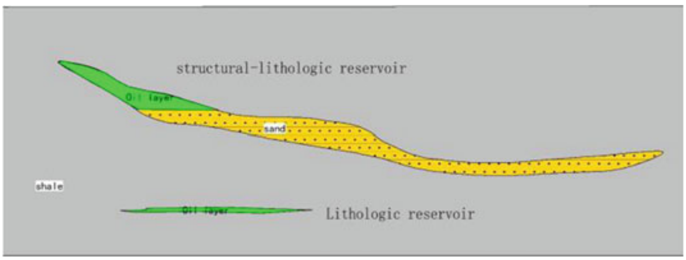

Fig. 1.1 Lithological reservoir

traps on regional unconformity, the bituminous plugging traps, and the deep basin gas traps.

The existing data show that most of the formation traps have a tectonic dip of less than 2, which can account for 60% or even more of the total. At the same time, due to the large formation trap area but small effective formation thickness, coupled with the lack of natural oil–gas driving energy, more than 70% of reservoirs in the formation lithological trap have been subjected to secondary oil recovery or enhanced oil recovery technology.

According to the reservoir characteristics of lithological traps, sandstone reservoirs account for 63.44% and carbonate reservoirs account for 26.25% of the 320 traps in the United States. According to the statistics of 1177 traps in the former Soviet Union, sandstone reservoirs account for 85% and carbonate reservoirs account for 15%. Besides, according to the statistics of 174 known lithological reservoirs in the production age, they are distributed from Ordovician to Tertiary, but most lithological reservoirs are distributed in Cretaceous, Tertiary, Carboniferous, and Permian, accounting for 80% of the total number of lithological reservoirs in these four eras. According to the basin background statistics, the lithological traps found in foreland basins, craton basins, passive continental margin basins, and rift basins account for nearly 85% of the total, among which foreland basins are the most developed, accounting for 55% (Wang 2005).

In the late 1970s, China began to pay more attention to subtle reservoirs, and relevant papers and monographs have been published. In these works, based on the foreign counterparts' understanding of concealed reservoirs, domestic scholars have systematically defined and described the concept, classification, characteristics, and distribution rules of concealed traps according to the characteristics of domestic reservoirs. Based on the distribution and exploration situation of oil and gas in China, most of the examples and research work of hidden traps are mainly concentrated in the eastern oil-bearing basins.

Before the 1990s, the exploration of concealed oil and gas reservoirs in China has not received much attention and attention, and structural oil and gas reservoirs are still the focus of exploration. From the middle and late 1990s, the exploration of concealed oil and gas reservoirs in China started from the old oil areas in the east to the new areas in the west. In particular, CNPC and Sinopec, two major oil companies, organized a large number of competent scientific researchers to participate in the exploration. In petroleum exploration meetings in recent years, relevant experts have put forward several suggestions to develop the concealed trap exploration technology mainly based on lithological traps and strengthen the exploration of lithological reservoirs, which further clarified the exploration potential and future exploration technology requirements of lithological traps.

Many scholars have put forward their views on lithological traps and some related concepts. See Jianyi (1984) in the "east China continental basin formation-lithological trap hydrocarbon accumulation (with) distribution and the exploration of the research program" the article expounds on the formation of lithological trap and concealment of the formation of the geological background and distribution, and in the non-structural reservoirs (1986), the formation of lithological trap difference