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Original research paper

Characteristics of source rocks, resource potential and exploration direction of Sinian-Cambrian in Sichuan Basin, China☆

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Abstract

The Anyue giant gas field was discovered in the Sinian-Cambrian Central Sichuan region of the Sichuan Basin in 2013, with geological reserves up to $1 \times 10^{12}m^3$, which is the first time for the exploration of natural gas paleo-reservoirs in the world. The gas source studies suggest that the Sinian natural gas is originated from the Sinian and Cambrian hydrocarbon source rocks, and the systematical study on the Sinian and Cambrian ancient source rocks has important scientific and practical significance for the global oil and gas geologic domain of the ancient stratum. Based on the drilling data and field profile observation of Sinian and Cambrian in Sichuan Basin, with adoption of the interpretation data of 28000 km-seismic and new drilling data, combined with geochemical analysis of source rocks of 2315 samples, this paper systematically studied the high quality hydrocarbon source rock center, where the source rocks are mainly distributed along the Mianzhu-Changning craton inner rift, with a accumulative thickness reaching 200−450 m, and 50−100 m for the thickness of source rocks in other areas. The hydrocarbon source rocks of the Sinian-Cambrian contributed about 56 %−63% of natural gas resources of the whole basin. Systematical evaluations have been conducted to the mudstone source rocks and their distribution in the III-section of Sinian Dengying Formation, where TOC value is ranging from 0.04% to 4.73%, with an average of 0.65%. The thickness of the source rocks in Central Sichuan region is ranging from 10 to 30 m. The oldest Sinian source rocks that can form large gas fields in China were systematically studied for the first time, and the total gas production intensity of the Sinian source rocks in the great Central Sichuan region is $(15−28) \times 10^8$ m^3/km^2, where the gas source conditions for the formation of large gas fields are available. By using the genetic method and analogy method, the amount of natural gas resources of the Sinian-Cambrian in the basin are re-evaluated as $(4.65−5.58) \times 10^{12}$ m^3, and the resources potential of natural gas is huge. The amount of natural gas resources in the Central Sichuan block accounts for about 66% of the total basin resources, which is the preferred selection for current exploration.

Keywords: Source rocks; Resource potential; Sinian; Cambrian; Sichuan Basin

1. Introduction

Since discovery of Weiyuan Gas Field, many scholars have done a large number of researches on source rock in Sinian System and Cambrian System in Sichuan Basin, Qiongzhusi Formation in Cambrian System is the primary source rock stratum in Sinian gas reservoir [1−6]. Research on source rock in Sinian System shows that algae-rich dolomite in Dengying Formation is capable of hydrocarbon generation to a certain

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extent but the hydrocarbon generation capability has been low, having had no condition for large gas field [1−3]. A super large gas field with capacity of trillions of cubic meters has been discovered in Sinian System-Cambrian System in Gaoshiti-Moxi Region in the middle of Sichuan in exploration for past two years, being the first time for the world to make such discovery in natural gas exploration from ancient stratum [7,8]. It is observed from research of gas source that natural gas in Longwangmiao Formation in Cambrian System is primarily from source rock in Qiongzhusi Formation in Lower Cambrian System and that the natural gas in Dengying Formation in Sinian System is from source rock in Sinian System and Cambrian System [8−11], indicating that source rock in Sinian System contains favorable source rock available for large gas field.

In recent years, some scholars have made scientific researches on source rock in Sinian System and Cambrian System, the author has also made a study of it with focus on geochemical evaluation of source rock and particular emphasis laid upon distribution of source rock in Qiongzhusi Formation [6−14]. Source rock in Sinian System and Cambrian System as well as resource distribution are to be subjected to systemic research. With in-depth exploration and rich data obtained in succession together with discovery of faulted depression in Mianzhu-Changning craton, the geological knowledge has changed to a great extent [8−17], for example, ancient uplift in Gaoshiti-Moxi has control action on large gas field and source rock Sinian System makes a contribution to large gas field. It is necessary to make systemic research on source rock and resource in Sinian System and Cambrian System so as not only to offer data on resource for further expansion of hydrocarbon exploration but also to enrich the geological theory on hydrocarbon reservoir formation in ancient stratum, being of great significance to hydrocarbon exploration in ancient stratum from Mesoproterozoic Erathem-Neoproterozoic Erathem to Lower Paleozoic Erathem in the world.

The paper presents systemic evaluation of source rock and resource potential in Sinian System and Cambrian System in Sichuan Basin based on systemic analysis of 45 wells in Sinian System and Cambrian System, 24 data on cross section in field thereof as well as 28000 km of seismic data and experimental analysis of 2315 sample-times and statistical analysis of data on more than 1000 sample-times. The research has determined the high quality source rock center in Lower Cambrian System again, namely it is mainly distributed along faulted depression of Mianzhu-Changning craton, with percentage of contribution made by source rock in faulted depression toward natural gas resource in Sinian System-Cambrian System to that by entire Basin being up to 56%−63%. It is the first time to make systemic research on the most ancient source rock in Sinian System capable of formation of large gas field in China, the total gas generation intensity of source rock in Sinian System in the middle of Sichuan Basin is $(15-28) \times 10^8$ m^3/km^2, based on which the paper points out the resource quantity of natural gas in Sinian System and Cambrian System and indicates the direction for next exploration.

2. Characteristic of source rock in Sinian System

2.1. Geochemical characteristic

2.1.1. Third member of Dengying Formation

Third member of Dengying Formation in Gaoshiti-Moxi region is primarily composed of black shale together with a small amount of thin and gray dolomite bearing mudstones distributed in a sporadic way, with moderate thickness from 10 m to 30 m, Well Gaoke 1 is thicker in thickness, with black mudstone encountered in 35.5 m in drilling. Third member of Dengying Formation around basin is thinner in thickness, with lithology being blue and gray mudstone in most cases, for example, the black mudstone in third member of Dengying Formation at section in Xianfeng Village is about 20 cm in thickness, the blue and gray mudstone thereof is about 40 cm in thickness, with higher richness of organic matter, *TOC* from 0.04% to 4.73%, averaging at 0.65% [10,11], those with *TOC*>0.5% accounts for 59.8%. Kerogen carbon isotope values are within the range from −33.4‰ to −28.5‰, averaging at −32.0‰, the organic matter is mainly composed of sapropel (type I). Equivalent R_O values are from 3.16% to 3.21%, having driven to over maturity stage.

2.1.2. Argillaceous carbonate rock in Dengying Formation

The paper shows that a large number of samples have been collected from field and underground to make scientific researches on algae rich argillaceous carbonate rock in Dengying Formation, it is observed from analysis that it also has favorable potential to generate hydrocarbon. 415 samples are from 0.20% to 3.67% in *TOC* content, averaging at 0.61% [10,11], it is also observed from statistics of underground samples and outcrop samples that outcrop samples are smaller than 0.5% in residual organic carbon content due to being damaged by long term weathering and that although underground samples primarily collected from Gaoshiti-Moxi region and Weiyuan region are on the low side in organic carbon in most cases, some members therein are higher in organic matter abundance (Fig. 1). Statistics show that those with *TOC* content more than 0.2% account for 31.3%, in which those with *TOC* content from 0.2% to 0.5% account for 54.4%, those with *TOC* content from 0.5% to 1.0% account for 31.8%, those with *TOC* content more than 1.0% account for 13.8%. Kerogen carbon isotope values are from −32.8‰ to −23.8‰, averaging at −29.4‰, the organic matter is mainly composed of sapropel and humus (mixed type), with high maturity, equivalent R_O from 1.97% to 3.46%, having driven to over maturity stage.

Thermal simulation experiment on algae enriched from rock shows that its maximum gas generation rate is 3471L/t_{Algae}; the thermal simulation experiment on algae rich dolomite shows that its total gas generation rate is 69L/t_{Rock}, indicating that algae rich dolomite in over maturity stage still has higher potential for hydrocarbon generation. Slice analysis shows that there is a large amount of proto bitumen existing in algae rich dolomite under microscope, indicating that algae rich dolomite also has potential for gas generation.