The Petroleum System Characteristic of Permian Changxing Formation and Triassic Feixianguan Formation in Sichuan Basin, SW China*

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Abstract

A number of medium-giant gas fields have been discovered in Permian Changxing reef and Triassic Feixianguan oolitic reservoir in NE Sichuan, SW China. Based on a series of geochemistry studies, petroleum system characteristic was discussed. We pointed out that the natural gas in reef and oolitic reservoir is derived from multi-source rocks, where the gas source supply is sufficient. Three evidences discussed are as follows. (1) The gas component and its isotope characteristics are the direct basis for the determining the origin of the natural gas; the carbon isotope is the most effective and practical index. According to the cross-plot of natural gas $\delta^{13}C_1$-$\delta^{13}C_2$, the $\delta^{13}C_1$ and $\delta^{13}C_2$ values of natural gas in oolitic reservoir distribute between those of coaled natural gas generated from Longtan coal measures and those of oil cracking gas derived from the deep source rocks of Silurian and Cambrian. (2) According to the accumulative time effect of argon isotopes, the value of $^{40}Ar/^{36}Ar$ can be used to estimate the age of natural gas source rocks. The value of $^{40}Ar/^{36}Ar$ in Puguang gas field was found to range from 1280m to 1690m, which reflects that the gas source age ranges from 383 Ma (Later Devonian Period) to 323 Ma (Earlier Carboniferous Period). However, these two sets of source rocks in the Sichuan Basin are absent, so the test results are inconsistent with geologic conditions. A more reasonable explanation is that the natural gas in oolitic reservoirs should come from several sets of source rocks, which were deposited prior to 383 Ma (Cambrian and Silurian) and more recently than 323 Ma (Carboniferous) instead of a single source. (3) Gas source rocks can also be identified with carbon isotope fractionation variation index. The $\delta^{13}C_2$ value of natural gas is 1-2‰ lower than that of kerogen, while the $\delta^{13}C$ value of solid bitumen is consistent with that of kerogen. A chart of the $\delta^{13}C$ value is achieved to demonstrate the correlation among natural gas, solid bitumen and kerogen. Natural gas in oolitic reservoir is correlative with the source rocks of Upper Permian, Lower Permian, Silurian and Cambrian. Obviously, the natural gas in reef and oolitic reservoir has multi-Source genetic characteristics.

Introduction

The study indicates that gas accumulation characteristics in reef and oolitic reservoir. Reef and oolitic reservoirs in both areas are controlled by the high-energy facies belts on the south and north sides of Kaijiang-Liangping Bay, with only slight changes in width and spatial location corresponding to variations in paleoenvironment and paleotopography at different geological periods. The lithologies and spatial types of the reef and oolitic reservoirs are similar, as are their other properties such as porosity and permeability, also have only slight differences. The oolitic reservoirs of the Feixianguan Formation in the LG area have a porosity of 2%–12% (5.8% on average) and a permeability of 0.06 mD-223.7 mD (27.7 mD on average); the oolitic reservoirs of the Feixianguan Formation in the Luojiazhai-Puguang area have a porosity of 2%–12% (7.8% on average) and a permeability of 0.01 mD–446 mD (54.4 mD on average). The gypsum rock units in the Lower Triassic Jialingjiang Formation and Middle Triassic Leikoupo Formation are thick (117m - 557m) and widely distributed and act as the effective caprock for reef and oolitic gas accumulations. The type and salinity of formation water also support the strong preservation conditions of the reef and oolitic series of strata.

Discussion

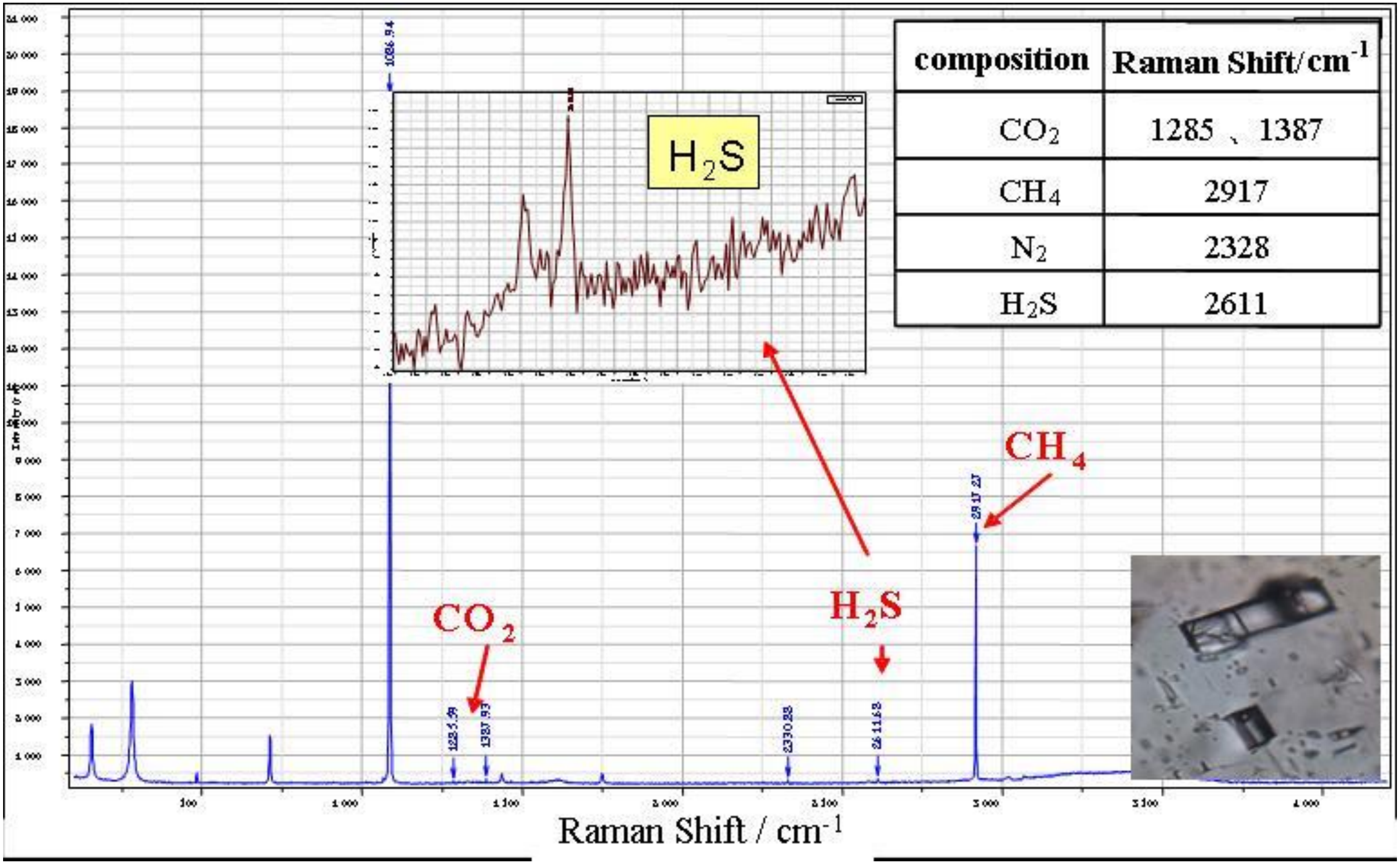
Gas accumulation processes experienced three phases, with liquid hydrocarbon charging at an early stage, cracking into gas at a high to over mature stage, adjustment of gas reservoirs at an uplifting stage and final reservoir generation at a late stage. The homogenization temperatures of fluid inclusions in the reef and oolitic reservoirs in the LG and Luojiazhai-Puguang areas generally include three phases. The homogenization temperature for phase I was low (<120°C), indicating liquid hydrocarbon inclusions and early charging of liquid hydrocarbons. The homogenization temperature for phase II was 130°C - 150°C, reflecting gas-liquid two-phase hydrocarbon inclusions as well as mixed charging of liquid hydrocarbons and their associated gas with gaseous hydrocarbons sourced from coal measures. The homogenization temperature for phase III was higher than 160°C, indicating brine-bearing gas hydrocarbon inclusions. In addition, the Laser Raman detection result shows H_2S-bearing high temperature gas hydrocarbon inclusions (Figure 1) (dominated by methane) as well as liquid hydrocarbon pyrolysis and gas generation and accumulation events (a number of gas hydrocarbon inclusions containing no H_2S were developed in the LG area, reflecting generation and charging of hydrocarbons derived from coal measures). Tectonic activities in the Himalayan period caused gas reservoirs to be destroyed or reformed. Gas reservoirs were subsequently shaped after the Himalayan period.

Oil and gas transport along fault and fracture pathways in the process of gas accumulation. The Luojiazhai-Puguang area is located at the junction of the northern part of the high and steep structural belt in eastern Sichuan and the faulted fold belt of Daba Mountain. The region has large structural relief and has developed two groups of faults oriented roughly NE-SW and NW-SE. The throw and extent of the faults are relatively large, faulted downwards to the Ordovician and Cambrian and disappearing upwards in the Middle Triassic Jialingjiang Formation and Leikoupo Formation Several sets of source rocks are in communication with these large faults, and periods of past fault activity match well with the periods of hydrocarbon expulsion from source rocks. As a result, an advantageous fault pathway transport system is in place that provides favorable gas source supply and transport conditions. The LG area is located on a generally monoclinal background with little structural relief. Faults in this area are few, small in scale, and those that exist mainly connect through the Longtan Formation-Changxing Formation The natural gas transport system consists mainly of non-equilibrium fractures (Figure 2). Therefore, reservoir blocks and intervals differ greatly in saturation due to variation in direct contact with source rocks. Due to the lack of larger scale faults, it is difficult for reef and oolitic reservoirs in the LG area to connect to deep source rocks such as in the Lower Permian, Silurian, and Cambrian, and as a result, most natural gas comes from Upper Permian source rocks. The gas source supply and dominant transport conditions are inferior to those in the Luojiazhai-Puguang area, so the saturation and scale of gas reservoirs are relatively poor. The saturation of gas reservoirs in the LG area (averaging 68.3%) is generally less than that in the Luojiazhai-Puguang area (averaging 94.6%). Because the Changxing Formation is in a more favorable position closer to the Longtan Formation source rocks, the saturation (averaging 78%) of gas reservoirs is higher than for that of the

Triassic Feixianguan Formation (averaging 58.3%). Therefore, the possibility of hydrocarbon accumulation in a Changxing Formation reef body is higher than that in the Feixianguan Formation.

Summary

In addition to connecting source rocks and reservoirs, the faults can also play a constructive role in the formation of reservoirs. The formation of diagenetic pores in carbonate rocks often requires fluid flow to carry material needed to promote the occurrence of dolomitization and burial corrosion. The large-scale faults in the Luojiazhai-Puguang area can provide good pathways for the migration of diagenetic material; therefore, the quality of reef and oolitic reservoirs in this area is better than in the LG area.



composition	Raman Shift/cm^{-1}
CO_2	1285 、1387
CH_4	2917
N_2	2328
H_2S	2611

Figure 1. Raman spectra of reef and oolitic reservoir fluid inclusions.

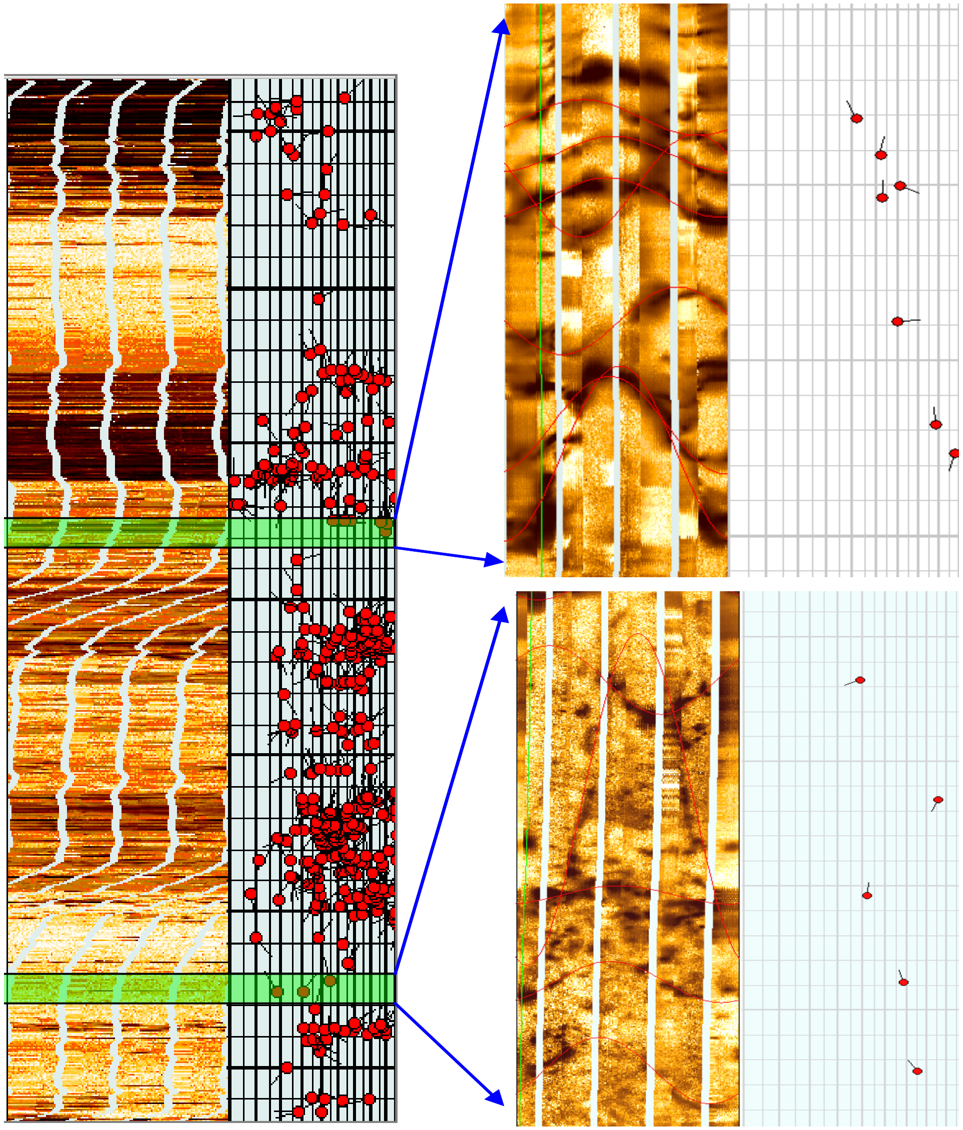


Figure 2. Fracture showing in FMI of one well in reef and oolitic reservoir.