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Research article

Preservation conditions for marine shale gas at the southeastern margin of the Sichuan Basin and their controlling factors

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Abstract

Complex tectonic movements and high thermal maturity of marine shale dominate South China, where preservation conditions are critical for shale gas enrichment and productivity. Based on the exploration practices of the Silurian shale gas at the southeastern margin of the Sichuan Basin in recent years, conventional gas and shale gas were compared in terms of their preservation conditions. The results revealed that superior roof and floor conditions are indispensable to shale gas preservation. Moreover, the self-sealing ability and the huge gap of up to 2–8 times between vertical and lateral permeability of shale gas reservoirs determine the lateral diffusion as the basic pattern of shale gas migration. The unconformity at the bottom of Lower Cambrian leads to worse preservation conditions in the system, and cutting by faults may accelerate the diffusion of shale gas. Major controlling factors for shale gas preservation and their criteria of discrimination were also investigated. It is suggested that: (1) the strength of tectonic modification is the major factor controlling shale gas preservation. Broad and gentle structures with continuous seals and an anticlinal setting are more favorable for the enrichment of shale gas, and a closed evolutionary environment with late uplifting is more favorable for the preservation of shale gas; (2) shale gas can be preserved well in downdip areas without faults or effectively closed or shielded by faults and areas far away from outcrops or zones with stratigraphic hiatus; (3) pressure coefficient is a comprehensive indicator for discriminating preservation conditions. In the study area, the pressure coefficient is in positive correlation with shale gas production and the high or super-high pressure of reservoir is a signal of good preservation condition for shale gas; and (4) in the areas within the southeastern Sichuan Basin, other than those close to erosion zones or hiatus, the Wufeng Fm. of Upper Ordovician and the Longmaxi Fm. of Lower Silurian present high pressure coefficient (up to 2.25) generally, demonstrating good preservation conditions for shale gas, while the pressure coefficient reduces progressively toward or outside the margin of the basin, corresponding to downgrading preservation conditions.

Keywords: Sichuan Basin; Southeastern margin; Ordovician; Silurian; Marine shale gas; Conventional gas; Difference; Roof and floor conditions; Preservation conditions; Structural style; Pressure coefficient

1. Introduction

Compared with shale gas in the U.S., marine shale gas in South China has its unique characteristics. It has experienced complex tectonic movements like Caledonian, Hercynian, Indosinian and Himalayan, and the Lower Paleozoic marine shale series of strata was highly evolved. The exploration practices of Lower Paleozoic marine shale gas in the Sichuan Basin and its periphery show that marine mud shale has a favorable material basis, and has demonstrated universal gas show in drilling but obtained diverse results in gas production testing. More and more attention has been paid to the preservation conditions, which are generally believed as a key factor for the enrichment and high yield of shale gas.

Based on the exploration of Silurian shale gas at the southeastern margin of the Sichuan Basin, this paper discusses the main controlling factors for preservation conditions of shale gas, and presents the difference of preservation conditions between shale gas and conventional gas.

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2. Difference of preservation conditions between shale gas and conventional gas

Preservation conditions are also important in the conventional hydrocarbon exploration in South China. Numerous scholars have conducted thorough study [1–10], especially on the destruction of reservoirs in the following 6 aspects [1]: faulting-fragmentation, denudation, meteorological water infiltration, deeply buried thermal metamorphism, caprock effectiveness and natural gas leakage, and magmatic intrusion thermal metamorphism. Main parameters [2] for evaluating preservation conditions include caprock, tectonic movement, gasfield (reservoir) formation time, magmation, source-reservoir-caprock assemblage in time and space, source rock quality and reservoir pressure.

The preservation conditions of shale gas are somewhat similar to those of conventional hydrocarbons, but due to the characteristics of shale gas itself, the study on its preservation conditions is somewhat different from that on the conventional hydrocarbons.

2.1. Roof and floor conditions and shale gas preservation

Roof and floor conditions are the most different preservation conditions between shale gas and conventional gas. Roof and floor refer to the overlying and underlying strata directly contacting the gas shale interval. They play an important role in the storage of shale gas, and also affect the performance of shale fracturing. The roof and floor can be any rock like mudstone, shale, tight sandstone and carbonate, and their quality depends on physical properties and closeness. Such quality is critical to the preservation of shale gas – good roof and floor can form fluid compartment [11] together with the gas shale interval, effectively slackening the outward migration of shale gas and thus allowing the shale gas to be effectively preserved; whereas poor roof and floor has poor closeness to the fluid, in which case the petroleum is apt to be dissipated outward and thus the shale gas reservoirs are destroyed.

Two shale gas series of strata (Silurian and Cambrian) were explored at the southeastern margin of the Sichuan Basin, but success has been obtained only in Silurian. We believe that the difference in preservation conditions resulted from diverse roof and floor properties is one of the key factors influencing the shale gas exploration effect. According to the Silurian exploration, the roof of Upper Ordovician Wufeng Fm. – Lower Silurian Longmaxi Fm. Member I shale gas reservoir is a large set of gray – dark gray argillite intercalated by thin silty mudstone and siltstone developed in Longmaxi Fm. Member II and strata above it, with a thickness of about 170 m, and the floor is the gray knotty rock limestone, marlstone and limestone successively deposited in Upper Ordovician Jiancaogou Fm. and Middle Ordovician Baota Fm., with a total thickness ranging 30–40 m. The roof and floor of Wufeng Fm. – Longmaxi Fm. shale gas reservoir, regardless of mudstone, siltstone or limestone, are very tight and have a good sealing ability. For instance, the siltstone developed in the Longmaxi Fm. Member II in Well JY2 has an average porosity of 2.4%, average permeability of 0.001 6 mD, and formation breakthrough pressure of 69.8–71.2 MPa at 80 °C; whereas the rocks like gray knotty rock limestone successively deposited in Jiancaogou Fm. and Baota Fm. have an average porosity of 1.58%, average permeability of 0.001 7 mD, and formation breakthrough pressure of 64.5–70.4 MPa at 80 °C, which reflects that the roof and floor provide good seal for the Wufeng Fm. – Longmaxi Fm. Member I shale gas reservoir. As for Lower Cambrian shale gas interval, the roof is the upper Niutitang Fm. tight mudstone that has a good sealing ability, but the floor is the Sinian Dengying Fm. paleo-weathering crust. Tongwan movement resulted in the development of Dengying Fm. palaeokarsts and fractures in geologic history. Lower Cambrian shale gas ceaselessly migrated out through the Dengying Fm. unconformity oil and gas migration “speedway”, and resulted in the destruction of shale gas reservoirs. For instance, Lower Cambrian high-quality mud shale is developed in Well TX1, but the floor is the Sinian Dengying Fm. paleo-weathering crust, and the post-frac effect is unsatisfactory.

2.2. Self-sealing ability of shale gas

Mud shale is a kind of tight pulveryte that often acts as the caprock of conventional hydrocarbons. Owing to the special occurrence mechanism of shale gas and the low porosity and low permeability of mud shale, shale gas accumulation doesn't require the same harsh preservation conditions as conventional oil and gas reservoirs. Mud shale has a sealing ability itself, and can act as the caprock of shale gas reservoirs. Especially for thicker mud shale, when the thickness exceeds the maximum range of hydrocarbon discharge at both top and bottom in the hydrocarbon generation peak stage of mud shale, gas will be effectively sealed in the mud shale itself.

Therefore, if mud shale has certain thickness itself, it can self-seal to trap some shale gases (which, however, do not always have industrial values). For instance, the Silurian is buried below 500 m in Well JY1, which achieved good oil and gas shows in drilling. Preservation conditions are seldom considered when shale gas plays are evaluated in North America, since the gas shale structure is stable and the shale gas can be trapped due to the shale's self-sealing ability.

Two mud shale samples were used to simulate and measure the permeability of Wufeng Fm. – Longmaxi Fm. mud shale in Well JY2 under confining pressure. As the buried depth increases, the pressure rises, and the permeability of the samples drops from 2.675 4 mD and 0.707 8 mD to 0.071 3 mD and 0.004 1 mD respectively (Fig. 1), by two orders of magnitude, indicating a sharp reducing process of permeability of mud shale during sedimentation. Under deep-buried circumstances, according to microanalysis data, Lower Paleozoic marine mudstone has very low permeability and thus has self-sealing ability.

The breakthrough pressure of Longmaxi Fm. Member I gray black mudstone in Well JY4 is measured as 41.6 MPa,

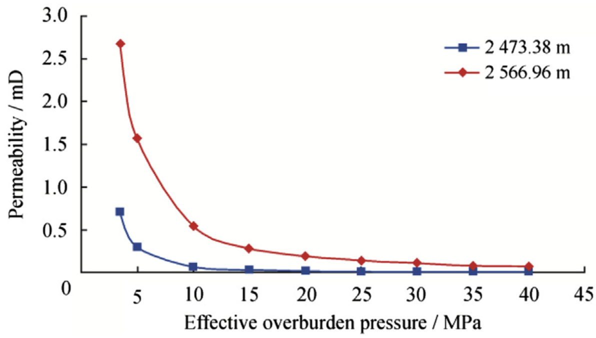

Fig. 1. Permeability vs. confining pressure of Longmaxi Fm. mud shale samples taken from Well JY2.

showing that highly-evolved marine mud shale has high breakthrough pressure and also a good self-sealing ability.

2.3. Directional percolation of shale gas

Percolation and diffusion are two basic modes for oil and gas migration, and they exit in the whole process of generation and evolution of shale gas, like conventional hydrocarbons. However, what is different from conventional hydrocarbons is that, as a reservoir, the mud shale itself contains nano-level pores, with low porosity and ultra low permeability, and it is also featured by lamellation, which decides its directionality of percolation.

With the mud shale compaction, the flaky clay mineral therein tends to be lineation parallel to the rock bedding plane, and experiences repeated superimposition and plastic deformation, so excellent lamellation plane is formed, which results in stress weakening in bedding direction and percolation rate increase. The vertical and lateral permeability analyses of Wufeng Fm. − Longmaxi Fm. full diameter core samples taken from Well JY4 (Fig. 2) show that the permeability in bedding direction is far larger than that in the direction perpendicular to it, and the lateral permeability is basically 2−8 times that of vertical permeability. This implies that the pore connectivity and microfissure development in the direction parallel to the bedding plane is far larger than that in the direction perpendicular to it. Observation on cores taken from Wufeng Fm. − Longmaxi Fm. in Jiaoshiba area confirms that the lamellation is better developed in top quality organic rich shale interval than in organic lean mudstone; moreover, interlaminar fissure is more easily developed in organic rich shale, and its existence increases the permeability of shale in lateral direction. The difference between lateral permeability and vertical permeability of shale results in larger percolation and diffusion rate of shale gas in lateral direction than that in vertical direction. The lateral percolation and diffusion of shale gas in the position suffered from tectonic faulting or near the outcrop of Longmaxi Fm. mud shale would bring forth unfavorable effect on the preservation of shale gas.

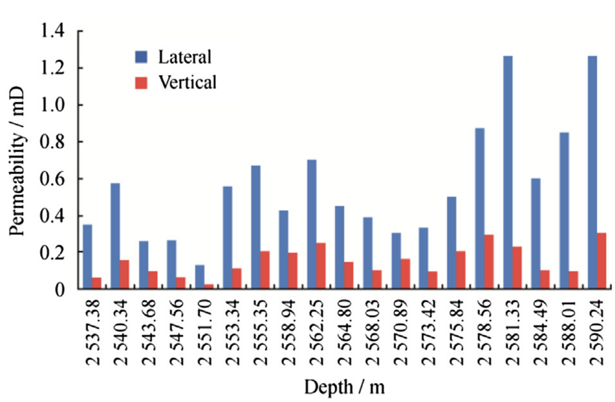

Fig. 2. Vertical permeability vs. lateral permeability of Wufeng Fm. − Longmaxi Fm. cores taken from Well JY4.

The characteristics of shale gas like self-sealing ability and directional permeability make it different in view of preservation conditions from conventional hydrocarbons, namely, shale gas preservation requires lower hydrological and caprock conditions than conventional hydrocarbons. What's more, the time of tectonic movement, the degree of tectonic deformation, the denudation, and fault become the most important factors influencing the preservation conditions of shale gas.

3. Effect of tectonic movement on the preservation of shale gas

Compared with carbonate rock and sandstone, mud shale usually has stronger plasticity, and certain survivability for its low porosity and low permeability. However, when violent tectonic movement results in intensive uplifting, denudation, folding, deformation and faulting of strata, as well as surface water infiltration and pressure system destruction, or the caprock losses plasticity due to tectonic force and stress, the sealing and preservation conditions of mud shale become worse. Therefore, the transformation intensity of late tectonic movement is the primary cause of destruction and dissipation of oil and gas reservoirs [12−14], and the preservation conditions of petroleum are changed mainly by faulting and denudation.

3.1. Uplifting denudation and shale gas preservation

Uplifting denudation results in the thinning of formation above the shale gas interval, which even crops out. The original balance is broken by the reduction of overburden pressure; under the action of tectonic stress and pore fluid pressure, the closed fracture is opened again, and shale gas percolates and dissipates. Triaxial physical testing simulation of Longmaxi Fm. mud shale samples taken from Pengshui area reveals that, when the confining pressure drops to a certain level (16.6 MPa), rock suffers from shear breakage, and microfracture is thus generated. It is speculated that in the course of sustained uplifting denudation, when the overburden pressure of Longmaxi Fm. dropped to 16.6 MPa, microfracture started to open on a large scale, and shale gas dissipated rapidly in a percolation mode. In addition, denudation results in the reduction of shale pore loads and thus the increase of porosity; also, the natural gas diffusion rate increases. Krooss et al.

found that the diffusion coefficient of methane in rock increases with the increase of porosity [15]; Schloemer et al. [16] used time lag method to measure the diffusion coefficient of methane in rock at different pressures, and discovered that with the increase of pressure, the diffusion coefficient of methane exhibits a logarithmic decrease. Therefore, uplifting denudation can also result in the acceleration of shale gas diffusion, and is unfavorable for the preservation of shale gas.

In the course of multicycle tectonic reworking at the southeastern margin of the Sichuan Basin, the whole marine structural layer experienced serious deformation and significant denudation by basically 4500 m plus; the marine shale gas exploration targets cropped out in many places, and even the core of anticline was substantially denuded. Uplifting denudation destroyed the continuity of shale gas interval, roof or overlying caprock, allowed the shale gas to dissipate laterally along the lamellation plane or interlaminar fissure, and the preservation conditions suffered from destruction. For instance, the targets in Wells YY1 and QY1 are shallowly buried, and the gas occurrence in shale interval is not good.

However, there are remnant Triassic − Jurassic strata in local syncline regions, where the overlying caprocks are relatively complete. The shale gas intervals are buried until cropping out only after having passed some distances, as a result, the preservation conditions would relatively get better with the increase of these distances and become the best in the cores of synclines. For instance, in the overburden Triassic of Sangtuoping syncline, the exposed point of Longmaxi Fm. mud shale is at least 8 km away from the core of the syncline, and the productivity of Well PY3HF located in the synclinal core is higher than of Well PY1HF located in the synclinal limb.

3.2. Faults and shale gas preservation

Faults are the cracking of formation due to the release of stress accumulated in tectonic movement, and faults often go with fractures, that is, fractures are also developed in the vicinity of faults. The fractures developed in shale gas interval increase the shale permeability, allows the shale gas to migrate rapidly towards the faults in a percolation mode; if faults are opened, they are unfavorable for the preservation of shale gas. The destructive effect of faults on shale gas is most directly manifested in the following aspects: the “exceedingly high” faults can break up and pass through the upper regional seal, and become the channel of shale gas dissipation, and result in the destruction of shale gas reservoir; in contrast, when the open faults breaking up and passing through the shale gas reservoir connect the high permeability zone, they can also allow the shale gas to migrate outward and thus result in the reduction of gas content. For instance, an exceedingly high fault was encountered in Lower Cambrian in Well Z101; diplog interpretation showed that a faulted broken belt was encountered in Lower Cambrian Niutitang Fm. (or Qiongzhusi Fm.); the TOC of reservoir in this well is higher, showing that it has good material basis, but the gas content of Niutitang Fm. mud shale is only 0.17−0.51 m^3/t, and gas component is dominantly nitrogen (>90%), confirming that the exceedingly high fault has destroyed the shale gas reservoir. Well HY1 is close to a fault at the bottom of Lower Silurian, and gas show of Longmaxi Fm. in this well is poor, with gas content of only about 0.74 m^3/t; after fracturing, shale gas was not withdrawn, and only fresh water was produced. It was believed through analysis that the fault nearby connected the lower high permeability zone, to which the shale gas was migrated through the fault, and the preservation conditions were destroyed.

The exterior margin of the Sichuan Basin is mainly in the trough-like deformation zone and trough-step transition zone. Fault distribution patterns show that there are numerous large faults that extend for a wide range, especially “exceedingly high” faults. For the whole marine structural layer, the deformation is stronger, the fault cutting is apparent, the vertical and lateral continuity of strata is poor, and the impact of fault on the preservation of shale gas is relatively universal (Fig. 3).

3.3. Tectonic styles and shale gas preservation

Different episode and intensity of tectonic movements result in different levels of stratigraphic folding deformation, cracking and denudation, and thus result in the formation of different tectonic styles, which further result in the different preservation conditions due to the differences of lateral percolation and diffusion. The tectonic style with weak tectonic reworking is the most effective to the preservation of shale gas, whereas that with strong tectonic reworking is unfavorable for the preservation of shale gas. The lateral percolation and diffusion of shale gas in the interval suffered from tectonic faulting or near the outcrop area would bring forth unfavorable effect on the preservation of shale gas. Generally, the following tectonic styles are relatively effective to the preservation of shale gas: broad tectonic style with an anticlinal setting; downdip areas without faults, or effectively closed or shielded by faults; and areas far away from outcrops or zones with stratigraphic hiatus. The tectonic styles like shallow buried depth and in the faulted zones (faults are exceedingly high and most probably opened) are unfavorable for the preservation of shale gas.

Broad tectonic style with an anticlinal setting and downdip areas without faults or effectively sealed or shielded by faults are effective for the preservation of shale gas. Taking the Jiaoshiba area where commercial shale gas discovery has been obtained as an example (Fig. 4), the major part of Jiaoshiba structure is a box-like anticlinal shape [17], i.e., the top is broad and both flanks are steep; there is a gentle faulted nose structure of thrust fault footwall in the south-north direction, where NE and near SN trend faults are developed, but both are apparent reverse faults and have good sealing abilities. This indicates that there are two favorable tectonic styles simultaneously formed in the Jiaoshiba area; furthermore, there are good roof and floor conditions and proper buried depth (>2000 m). Although having experienced multiphase tectonic reworking, Wufeng Fm. − Longmaxi Fm. shale gas reservoir

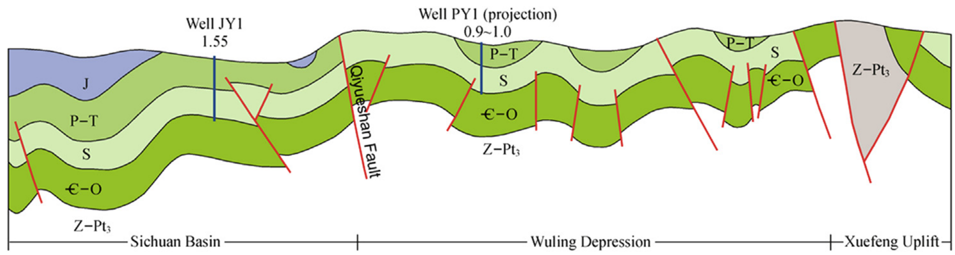

Fig. 3. Stratigraphic development and fault distribution pattern in Jiaoshiba and Pengshui areas in the southeastern Sichuan Basin.

still keeps high pressure coefficient (1.55) nowadays, and exhibits favorable preservation conditions. Well Y201 is located in an anticlinal structure where faults are not developed, 43×10^4 m^3/d gas flow was obtained from Wufeng Fm. – Longmaxi Fm. in well test, confirming that such a tectonic style with an anticlinal setting is effective in the preservation of shale gas.

In addition, the areas far away from the outcrops or zones with stratigraphic hiatus are also relatively effective in the preservation of shale gas. It is proved in the foregoing paragraphs that under a stable state, shale gas mainly migrates in the form of diffusion and percolation in a bedding direction; if a shale gas interval crops out or is absent, the shale gas is apt to suffer from parallel migration and dissipation; the buried depth becomes shallow towards the direction of outcropped or absent areas, and the shale permeability increases gradually, and the shale gas diffusion and percolation are enhanced; on the contrary, the preservation of shale gas gradually gets better towards the opposite direction of outcrop or absent areas. For instance, there is a broad SN syncline in the Changning area, and Wufeng Fm. – Longmaxi Fm. crops out in the north; Well N201 drilled far away from the outcrop (19.5 km) produces gas at a rate of 15×10^4 m^3/d, whereas Well N203 drilled closer to the outcrop (9.5 km) produces gas only at a rate of 1.29×10^4 m^3/d. For Well W201 drilled on the Caledonian palaeohigh slope in the Leshan-Longnüsi area is close to Silurian absent area, Wufeng Fm. – Longmaxi Fm. produces gas only at a rate of 0.28×10^4 m^3/d, whereas Well W202 was drilled far away from the absent area, and its shale gas production is increased to 2.75×10^4 m^3/d.

The preservation conditions for shale gas are unfavorable in the area with shallow buried depth or in the faulted zones. It is proved in the foregoing paragraphs that uplifting denudation results in the thinning of overlying formation, the shallowing of buried depth and the acceleration of shale gas diffusion; when the overlying formation is thinned to a certain level, the fractures are opened again, and the shale gas percolation also speeds up. In the faulted zones, especially in the places where exceedingly high faults are developed, the shale gas percolation speeds up; moreover, when the fault connects the high permeability zone or the ground surface, the shale gas dissipation also speeds up; therefore, gas dissipation is fast in the area with shallow buried depth or in the faulted zones, which are unfavorable for the preservation of shale gas. For instance, the buried depth of Wufeng Fm. – Longmaxi Fm. shale gas interval in Well YY1 is 325 m, and the gas content in a field test is only 0.1 m^3/t; a faulted zone was encountered in Lower Cambrian Niutitang Fm. shale gas interval in Well Z101, and a fault connects the Dengying Fm. unconformity and the ground surface. Although the buried depth is as deep as 1767 m, the gas content in a field test is only 0.57 m^3/t.

3.4. Tectonic reworking time and shale gas preservation

After strata having been uplifted and denuded, the hydrocarbon generation of source rock stopped. Shale gas could not be supplemented effectively in the late preservation. But the shale gas kept on dissipating. Therefore, the uplifting time decided the dissipation volume – the later the uplifting, the more favorable it is for the preservation of shale gas. So far as Silurian is concerned, the reworking time of Yanshan – Himalayan tectonic activities in different areas has a great impact on the preservation of shale gas. The earlier the Yanshan – Himalayan uplifting denudation started, the more unfavorable it is for the late preservation conditions of shale gas.

Affected by the orogeny of Xuefeng Mountain, the tectonic uplifting starts late from the orogenic belt at the margin of the Sichuan Basin (about 95 Ma ago) towards the Basin (80 Ma ago), and is featured by progressively younger. This is similar to the research conducted by Mei Lianfu [18] indicating that the tectonic deformation becomes late from western Hu'nan and Hubei (165 Ma ago) towards the Huaying Mountain in eastern Sichuan Basin (95 Ma ago). The Lower Triassic Xujiahe Fm. samples taken on the surface in the Shizhu area in western Hubei – eastern Chongqing show three stages of uplifting, and the initial uplifting started 120 Ma ago. The initial Yanshan – Himalayan denudation was about 85 Ma ago in Well JY1 drilled in the Jiaoshiba area, whereas the Yanshan – Himalayan tectonic reworking time was about 125 Ma ago in Well PY1 drilled in the Pengshui area. Therefore, the tectonic uplifting became late from the western Hu'nan and Hubei, Pengshui area, Shizhu area and Jiaoshiba area in turn; expected lower Paleozoic shale gas was not obtained from western Hu'nan and Hubei, whereas commercial shale gas discovery was obtained in the Jiaoshiba area, indicating the relation between shale gas preservation and tectonic uplifting time.

4. Evaluation on preservation conditions

Formation pressure coefficient is an aggregative indicator for evaluating the preservation conditions of shale gas.

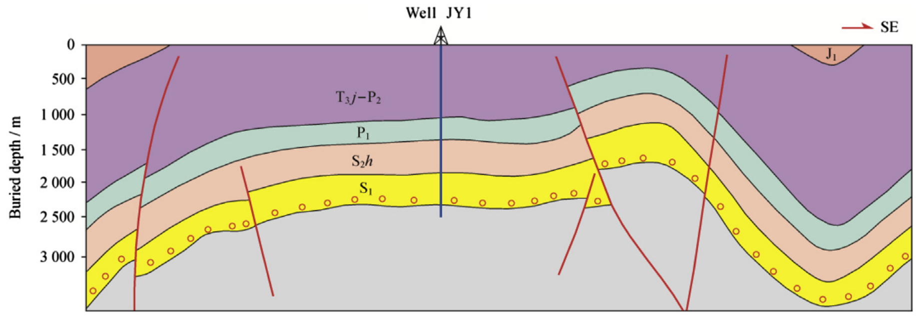

Fig. 4. Tectonic style in Jiaoshiba area.

Compared with conventional oil and gas reservoirs, shale gas reservoirs have their unique characteristics, i.e., it is a triune geologic body of sources, reservoirs and caprocks, which decides that the evaluation on their preservation conditions should be somewhat different from those of conventional reservoirs. Conventional oil and gas reservoirs have extraneous sources; if the preservation conditions are good, they possibly exhibit either overpressure or low pressure. Shale gas reservoirs have internal sources; the hydrocarbon generation of shale (source rock) results in the increase of pore pressure and thus the formation of surpressure; under the action of abnormal pressure and hydrocarbon concentration difference, the hydrocarbon migration always points to outside; if the gas reservoir sealing ability is not good, shale gas would be discharged rapidly and result in great reduction of formation pressure, or even form low pressure; on the contrary, higher formation pressure could be maintained. Therefore, formation pressure coefficient has a favorable indication on the preservation conditions of shale gas.

Among the wells drilled for Lower Paleozoic shale gas, high-yielding wells like JY1, N201-H1 and Y201-H2 all were drilled in surpressure shale gas reservoirs, whereas stripper wells and micro gas-containing wells like HY1, YQ1 and YY1 generally were drilled in normal pressure or subnormal pressure shale gas reservoirs. In addition, it is discovered through statistics that the Lower Paleozoic shale gas flow rate in the Sichuan Basin and its peripheral areas is in logarithmic positive correlation with the pressure coefficient (Fig. 5). The above phenomena and rules also reveal that higher pressure coefficient reflects good preservation conditions of Lower

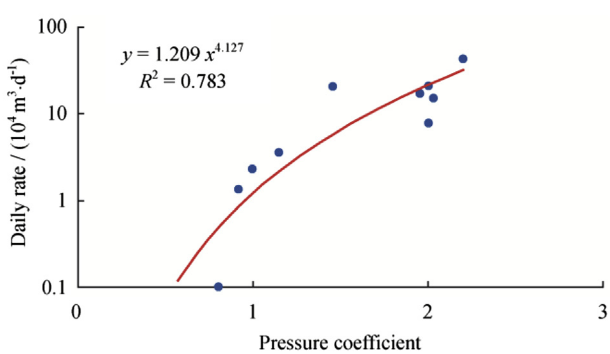

Fig. 5. Pressure coefficient vs. shale gas flow rate.

Paleozoic marine shale gas reservoirs, while lower pressure coefficient stands for poor preservation conditions.

For the formation pressure coefficient is obtained on the basis of well drilling whose data are relatively limited, in the evaluation of the regional preservation conditions, preservative factors like formation denudation, faulting and uplifting time should be considered. The pressure coefficient contour map of Wufeng Fm. − Longmaxi Fm. in the southeastern Sichuan Basin (Fig. 6) is plotted based on the above method, and then the preservation conditions of the area are evaluated. In the areas within the southeastern Sichuan Basin, other than those close to denuded areas and stratigraphic hiatus, the formation pressure coefficient of Wufeng Fm − Longmaxi Fm is high as a whole (up to 2.25 maximally), and the preservation conditions are good; in contrast, the formation pressure coefficient reduces progressively toward southern and eastern margins of the Basin, generally less than 1.2 outside the Basin, and the preservation conditions for shale gas are poor on the whole.

5. Conclusions

1) The lateral permeability of mud shale is 2−8 times that of its vertical permeability, the lateral diffusion is the basic dissipation pattern of shale gas, and the cutting of faults can expedite shale gas dissipation.
2) Excellent roof and floor conditions are the basis for the shale gas reservoirs to have favorable preservation conditions. The roof and floor and shale gas reservoir of Longmaxi Fm. suffered from successive sedimentation, with large thickness, tight lithology, high breakthrough pressure and good sealing ability, and can prevent the hydrocarbons in the mud shale interval from dissipating. Tongwan movement resulted in the development of Dengying Fm. palaeokarst, with unconformity developed in local areas, and the floor conditions of Lower Cambrian shale gas reservoir being poor.
3) Tectonic reworking intensity is the main control factor for preservation conditions of shale gas reservoirs; the closed evolutionary setting with late uplifting and weak tectonic reworking intensity is favorable for the preservation of shale gas. A broad tectonic style with an anticlinal setting where faults are not developed, reservoirs are buried to a certain depth and shale intervals are successively deposited is most favorable for the preservation of shale gas; the

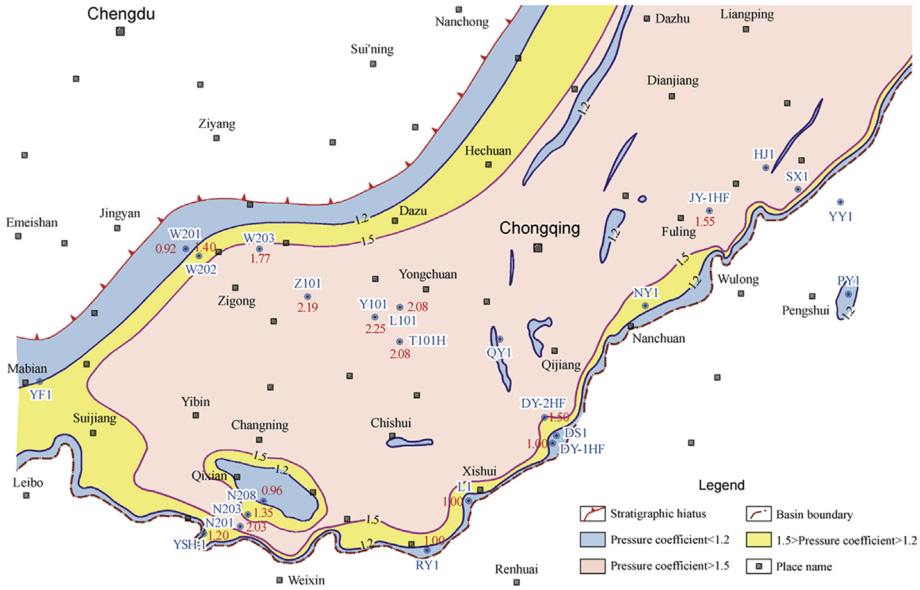

Fig. 6. Formation pressure coefficient contour map of Wufeng Fm. − Longmaxi Fm. in the southeastern Sichuan Basin.

downdip areas effectively sealed or shielded by faults, areas far away from outcrops and stratigraphic hiatus are relatively favorable for the preservation of shale gas; and the areas with shallow buried depth and in a faulted zone is unfavorable for the preservation of shale gas.

4) The pressure coefficient is an aggregative discrimination indicator for preservation conditions, and it is in logarithmic positive correlation with shale gas flow rate.

Fund project

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