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Lower Limits and Grading Evaluation Criteria of Source Rocks and Reservoirs of Tight Oil and Gas

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1 Introduction

The importance of the unconventional petroleum is increasingly prominent, with the rising demand of oil and gas in the economic and social development and the gradual consumption and depletion of conventional oil and gas resources. Compared with the shale and coal-bed gas reservoir, tight reservoir has better fracturing capability. So it is the most realistic exploration targets (Zou et al., 2009; 2012; 2013; Jia et al., 2012a) and rich in unconventional petroleum resources as well (Jia et al., 2012b; Dai et al., 2012).

From hydrocarbon accumulation mechanism, the essential difference between the tight oil and gas reservoir and the conventional petroleum reservoir lies in that the former accumulate without relying on buoyancy action (Zou et al., 2012b). This characteristics determines that the six hydrocarbon accumulation factors, that is, source rocks, reservoir, caprock, migration, trap and the preservation conditions, are no longer indispensable to the unconventional petroleum accumulation. However, The accumulation, enrichment degree, distribution of the unconventional oil and gas are mainly dependent on the conditions of the source rocks and reservoirs. Thus, in which conditions of the source rocks and reservoirs, can tight oil and gas accumulate (lower limits)? And what are the beneficial conditions for hydrocarbon accumulation (grading evaluation critera)? The above questions are important problems concerned by many Explorationists and oil companies. Thus, understanding the lower limits and grading evaluation criteria of source rocks and reservoirs of tight oil and gas is conductive to prediction for favorable area and taking the targeted exploration. The existing standards, mostly based on experience, are lack of theoretical foundation and scientific significance and are mainly subjective and arbitrary with many classification boundaries hard for lateral comparison (Wang et al., 2005; Cao et al., 2009; Zhang et al., 2012; Hou and Liu, 2012; Jiang, 2012).

2 Lower Limits and Grading Evaluation Criteria of Source Rocks of Tight Oil and Gas

Grading evaluation criteria of source rocks of conventional oil and gas exist industrial standard which are widely used. Because tight reservoirs developed micro-scaled and nano-scaled pores and throats. Oil, gas and water existing within micro-scaled and nano-scaled pore throat are difficult to flow or separate, and the vast capillary pressure limits buoyancy, the key role of conventional hydrocarbon accumulation, affecting tight oil and gas enrichment. In this case, the main motive power of unconventional hydrocarbon migration and accumulation is pressure difference between source rocks and reservoirs. Therefore, the grading evaluation criteria of source rocks of conventional oil and gas have not adapted to the evaluation of source rocks of tight oil and gas.

Due to the general motive power of unconventional hydrocarbon accumulation is no longer buoyancy, but pressure difference between source rock and reservoir, depending on the overpressure of source rocks. Generally speaking, the overpressure of source rocks is related to hydrocarbon-generating pressurization, undercompaction, hydrothermal pressurization, dehydration of clay mineral, tectonic stress, etc. Among these factors, tectonic stress

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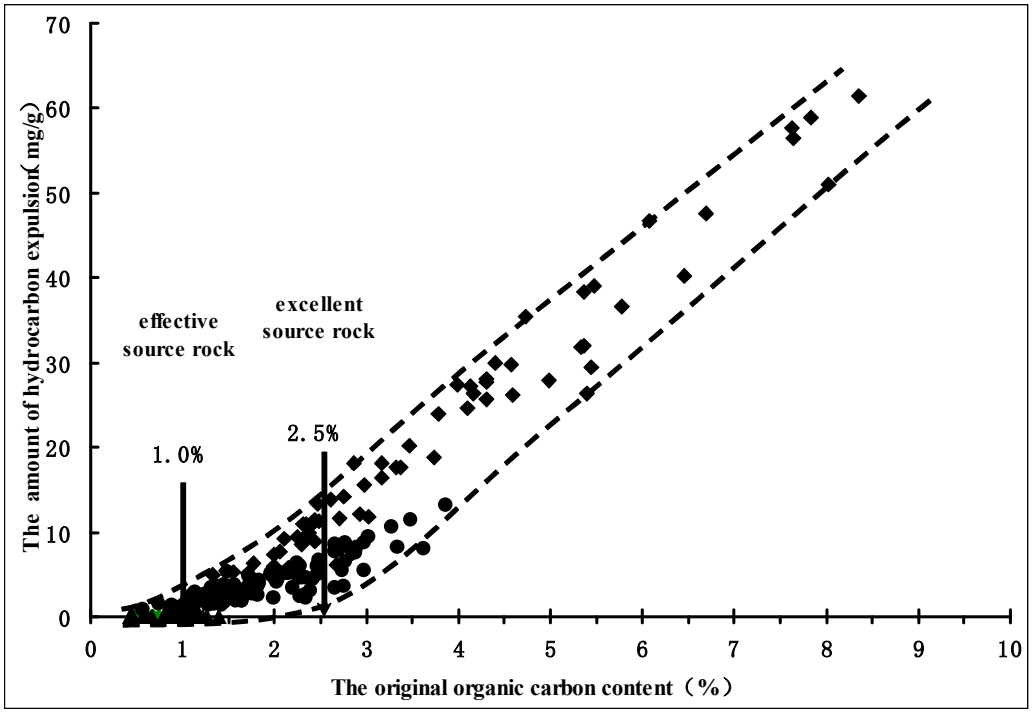

Fig.1 The relationship between the amount of hydrocarbon expulsion and original organic carbon content

acts on the source rocks and reservoirs at the same time, and can be partially offset each other. Further studies by some scholars show that hydrocarbon-generating pressurization and undercompaction are the most general and important factors, and undercompaction, hydrothermal pressurization and dehydration of clay mineral often have the same space with the hydrocarbon generation in the direction and time (Hunt et al., 1994; Hao, 2005). Therefore, the hydrocarbon-generating pressurization evaluation is the most crucial, while the presence of hydrocarbon-generating pressurization and hydrocarbon expulsion quantity of source rocks or not is the most visual indicator. The high quantity of hydrocarbon expulsion not only shows great motive power of hydrocarbon migration and accumulation, but also is the material basis of tight oil and gas enrichment. Thus, discussing and establishing lower limits and grading evaluation criteria of source rocks of tight oil should be based on the inflection points of relationship curve between the presence and the size of hydrocarbon-generating pressurization and hydrocarbon expulsion quantity of source rocks and geochemical indicators.

In accordance with the above ideas, source rock heterogeneity and distribution characteristics in plane and profile can be recognized through the analysis of the data in the target area, by combining with logging technology and geochemical technology. Moreover, hydrocarbon generation quantity, hydrocarbon expulsion quantity and residual hydrocarbon quantity can be evaluated by the hydrocarbon potential method, the thermal simulation experiment of immature source rock samples and the chemical kinetics model (Pang et al., 2004; Lu et al., 2008). Overpressure module in Petrol simulation software can be used to quantitatively evaluate the hydrocarbon generation and to estimate overpressure (history) caused by hydrothermal pressurization, clay dehydration, under-compaction and tectonic stress.

Based on the above quantitative evaluation, the relationship between hydrocarbon expulsion quantity, overpressure and geochemical parameters of source rocks (TOC, HI, R_O, etc.) can be acquired. Therefore, according to the hydrocarbon expulsion quantity and the existence and size of overpressure, the lower limits and grading evaluation criteria of source rocks of tight oil and gas can be obtained (Fig. 1).

From Fig. 1 it can be seen that the point (TOC_0=1.0%) of hydrocarbon expulsion quantity from scratch corresponding to the lower limits of source rocks, the inflection points indicated that the amount of hydrocarbon expulsion increased with the increase of TOC (TOC_0=2.5%), corresponding to the boundary of high quality source rocks of tight oil and gas. In practical application, the original organic carbon should be converted into the measured TOC. Using the principle of material balance, it is not difficult to achieve this (the 2 boundary points of measured TOC are 0.8% and 2% respectively). The size of overpressure is closely related to hydrocarbon expulsion quantity. Due to space limitations,

Table 1 The lower limits and grading evaluation criteria of tight reservoir in the Southern Songliao Basin

reservoir levels		lithologic features	pore throat structure	mercury injection characteristics: maximum pore radius/μm	mercury injection characteristics: average pore radius/μm	mercury injection characteristics: peak of pore throat radius/μm	mercury injection characteristics: distribution of main flow throat radius/μm	physical properties: permeability/mD	physical properties: porosity/%	NMR: movable fluid saturation/%
conventional reservoir		medium sandstone	mesopore, middle throat	> 5	> 0.8	0.63～2.5	> 1.0	> 1.0	12	
tight reservoir	A	medium or fine sandstone	finepore, fine throat	2～5	0.4～0.8	0.16～0.63	0.2～1.0	0.1～1.0	9～12	47
	B	medium or fine sandstone	micropore, fine throat	1～2	0.3～0.4	0.025～0.16	0.1～0.2	0.05～0.1	6～9	27～47
	C	fine sandstone	micropore, microthroat	0.02～1	0.01～0.3	0.001～0.025	0.05～0.1	0.01～0.05	4～6	27
non-reservoir		siltstone	micropore, microthroat	＜0.02	＜0.01	＜0.001	0.05	＜0.01	4	

there is no further explanation.

3 Lower Limits and Grading Criteria Evaluation of Tight Reservoir

The mineral composition of tight reservoir, the composition and properties of fluids (oil, gas, water) and 3D distribution of pore-throat system of tight reservoir can be understood by making full use of various technologies (Loucks et al., 2009; Lau et al., 2012; Curtis et al., 2012. Through the analysis of the mud logging data, logging information and oil production testing data, lower limits and grading evaluation criteria of tight reservoir can be determined using the six methods mentioned below.

(1) The relationship of oil-bearing properties (productivity) and porosity (pore throat radius) of tight reservoir can be built and the lower limits and grading evaluation criteria of tight reservoir can be determined empirically by using the accumulated data and understanding the pore-throat structure of tight reservoir.

(2) Based on the idea that pore throat size should no less than the value of thickness of water film and oil (gas) molecular size, lower limits of tight reservoir can be determined. Among them, the thickness of water film can be accurately calculated by molecular dynamics simulation.

(3) The Upper limits of tight reservoir can be determined in theory taking use of the equilibrium between buoyancy (flotation) and capillary force. Buoyancy is controlled by oil (gas) density, while capillary force is controlled by the pore throat radius of tight reservoir. However, it may not be the real lower limits of tight reservoir, which may actually be a boundary of grading evaluation of tight reservoir. Under the background of the overall density, the reservoir above this boundary should be precisely dessert of tight oil and gas.

(4) The lower limits and grading evaluation criteria of tight reservoir can be determined using the inflection point of curves between pore structure and the parameter of stored energy and porosity.

(5) The relationship between movability of tight oil and gas and the pore throat size, distribution, rock composition, oil or gas composition, temperature and pressure can be determined using molecular dynamics simulations (Wu, 2002) and numerical simulation of lattice Boltzmann, so the lower limits of pore size and grading evaluation criteria of tight reservoir can be determined. Then by the relationship between porosity and pore size of tight rock, the lower limits and grading evaluation criteria of tight reservoir can be obtained.

(6) The relationship between the movability of tight oil and gas and pore throat size, distribution, composition of tight reservoir can be determined using NMR technology. And then, the lower limits of pore size and grading evaluation criteria of tight reservoir can be acquired. Based on the relationship between porosity and pore size of tight reservoir, the lower limits and grading evaluation criteria of tight reservoir can be obtained.

The grading evaluation criteria obtained by the above methods can be calibrated and verified each other, and it can deepen the understanding on its connotation and mechanism of lower limits and grading evaluation criteria of tight reservoir. Furthermore, the grading evaluation criteria are objective and reliable, which can be widely used in the petroleum industry.

Due to space limitations, there are no figures for explanation. The lower limits and grading evaluation criteria are listed in Table 1 using several methods by taking the southern Songliao Basin as an example.

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