Fuel 232 (2018) 666–671

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Short communication

A new and more precise experiment method for characterizing the mineralogical heterogeneity of unconventional hydrocarbon reservoirs

Shuheng Du[a,b,c], Shan Pang[a,c], Yongmin Shi[c,*]

[a] School of Earth and Space Science, Peking University, Beijing 100871, China
[b] Institute of Mechanics, Chinese Academy of Sciences, Beijing 100190, China
[c] Oil and Gas Institute, Peking university, Beijing 100871, China

ARTICLE INFO

Keywords:
Unconventional hydrocarbon reservoirs
Mineralogical heterogeneity
Hydrocarbon exploitation

ABSTRACT

This study is aimed to introduce the new and more precise experiment method which could characterize the mineralogical heterogeneity of unconventional hydrocarbon reservoirs. As the 2D characterization methods and techniques still have a large amount of information to be excavated with quite strong vitality, the new method could be used to discover the minerals directly under the FE-SEM combining with the EDS method after considering both the resolution (10 nm) and representativeness (20 mm). The higher the ratio of the maximum to the minimum and the mean square deviation of each mineral parameter in thin sections from 8 different directions, the higher the microscopic heterogeneity of the reservoir. The new method would help to the study on enhancing the remaining unconventional hydrocarbon recovery.

1. Background

Unconventional reservoirs are usually characterised as quasi continuous or continuous accumulation, having a small pore-throat scale, strongly heterogeneous, and difficult to mine. The method to improve the characterisation of the heterogeneity of unconventional hydrocarbon reservoirs and their influence on exploitation has become an important scientific problem nowadays [1,2].

With the deepening of interdisciplinary research, high-resolution observation technology has been applied to the characterisation of unconventional reservoirs. Predecessors used micron computed tomography (CT), nano CT and focused ion bean-scanning electron microscopy (FIB-SEM) series technology to carry out much fruitful research work on unconventional reservoirs, and they obtained a series of important research conclusions [3–5]. However, with in-depth study and feedback from the practice, the technology has gradually exposed many core issues, such as a high cost, unreasonable CT threshold division and a poor representative sample size. In fact, resolution and representativeness are a pair of contradictions in reservoir characterisation that cannot be considered together nowadays [6,7]. Therefore, we should devise some innovative ideas to study the macroscopic and microcosmic characteristics of reservoir minerals and reservoir space on different scales, which could reduce the degree of the impact of the contradiction between resolution and representativeness to a certain extent [8–11].

The characterisation of mineralogical heterogeneity, especially of some brittle minerals, is significant in enhancing the recovery efficiency of unconventional hydrocarbon, because minerals influence the distribution characteristics of hydraulic fracturing. In addition, according to the principle of sedimentology, the formation of pore throats is essentially due to the accumulation, compaction and subsequent diagenesis of minerals, and this is achieved by the primary and secondary boundaries of minerals, where the boundaries of pore throats are the grain boundaries after denudation, transportation and reconstruction [12–14]. Pore-throat characteristics largely reflect the sorting and grinding properties of minerals, which is a true reflection of the deposition, compaction and modification processes. Hence, the formation of reservoir space and minerals during the deposition process has an obvious symbiotic relationship. In addition, the characteristics of minerals, especially brittle minerals, are rather important in reservoir stimulation and hydrocarbon exploitation [15–18].

Taking the unconventional sandstone reservoir for example, this paper introduces a new technique to characterise the mineralogical heterogeneity of reservoirs, quantitatively called ‘umbrella deconstruction’, which would also benefit further the innovation of other heterogeneity characterisations of unconventional reservoirs.

Abbreviations: CT, computed tomography; FE-SEM, field-emission-scanning electron microscope; EDS, energy dispersive spectrometer; 2D, two dimension; 3D, three dimension

* Corresponding author at: No. 5 Yiheyuan Road, Haidian District, Beijing, China.
E-mail address: sym@pku.edu.cn (Y. Shi).

https://doi.org/10.1016/j.fuel.2018.06.012
Received 8 March 2018; Received in revised form 31 May 2018; Accepted 4 June 2018

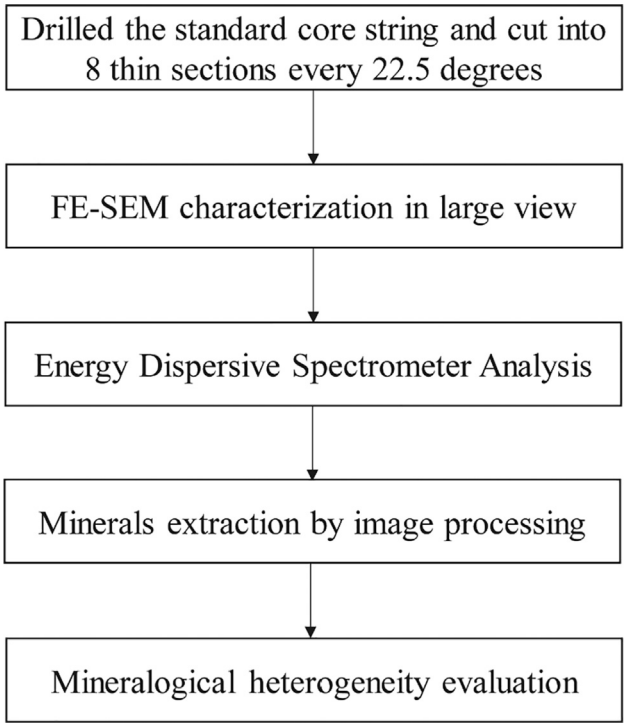

Fig. 1. Technical process of the new characterisation technique.

2. Technical process

According to the background analysis, the flowing chart of the technical process is shown in Fig. 1.

First, we drill the standard core sample with the diameter (25 mm) and length (50 mm), draw 8 lines every 22.5 degrees in the overlook surface of the sample and cut the thin sections along the 8 lines. Second, we carry out the FE-SEM characterization on the reservoir of 8 thin sections in large review. Third, the Energy Dispersive Spectrometer analysis should be carried out to identify the mineral type quantitatively. Fourth, we use the technology of image processing to extract the minerals respectively. Finally, we could carry out the parameter calculation of 8 thin sections to evaluate the mineralogical heterogeneity of the unconventional hydrocarbon reservoir.

The number of thin section could be adjusted according to our research purpose. But it is not the more sections, the better because we need to ensure that all the minerals in each thin section are independent of each other or it may cause paradox. When the number of slices is increasing, some mineral individuals will be destroyed for various reasons or even be divided into several parts. So the number of "eight" in this paper is based on the actual rock property and our research purpose which could meet the needs of the mineralogical heterogeneity characterization.

3. Innovation discussion

3.1. Advantages of the new method

Most of the research on the microscopic heterogeneity of reservoirs depends on the development of various testing techniques.

Micro or nano CT scanning has been widely used in the characterisation of unconventional reservoir space in recent years, and its importance and superiority are self-evident. Scholars proposed the maximum sphere method to carry out the segmentation of pore throats based on CT data [19,20]. Like other technologies, there are also some shortcomings in this technology. For example, resolution and representativeness cannot be taken into account at the same time, and the types of minerals cannot be judged carefully.

Field emission (FE)-SEM imaging could be effective in tight oil sandstone reservoirs based on the conductivity of minerals, and the accuracy could be up to 0.5 nm. It can identify pore-throat spaces effectively, and the accuracy is much higher than that of casting thin sections. It is non-destructive to the reservoir sample. At the same time, the observation range is larger than the sample size and the analysis scale of nano CT, and it is also a little better than nuclear magnetic resonance because of the ease of operation and the low cost. Therefore, to achieve the purpose of accurately identifying pore throats, this study will identify a pore throat and the related minerals beside the pore throat effectively by combining with an energy spectrum analysis. The umbrella deconstruction method was put forth based on the combination of the FE-SEM method and other technology with the above advantages. The imaging observation scale could reach approximately

Properties	Descriptions
Well	H191
Porosity/%	6.6
Permeability/$10^{-3}\mu m^2$	0.05
Phenomenon	Wedge-shaped cross bedding

Properties	Descriptions
Well	H198
Porosity/%	11.0
Permeability/$10^{-3}\mu m^2$	0.51
Phenomenon	Strip distribution of crude oil

Fig. 2. Typical rock samples observation and the basic information descriptions.