On the geobiological evaluation of hydrocarbon source rocks

XIE Shucheng (✉)1,2, YIN Hongfu1,2, XIE Xinong2,3, QIN Jianzhong4, HU Chaoyong1, YAN Jiaxin1, HUANG Junhua2, ZHOU Lian2, YANG Xianghua3, WANG Yongbiao1, XU Sihuang3

1 Key Laboratory of Biogeology and Environmental Geology of Ministry of Education, China University of Geosciences, Wuhan 430074, China
2 State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences, Wuhan 430074, China
3 Faculty of Earth Resources, China University of Geosciences, Wuhan 430074, China
4 Wuxi Research Institute of Petroleum Geology, RIPED, SINOPEC, Wuxi 214151, China

© Higher Education Press and Springer-Verlag 2007

Abstract  Hydrocarbon source rocks are characterized by the hydrocarbon discharge, and the alteration and variation in organic compositions and organic content due to the enhanced thermal maturation. These variations throw constraints on the application of the conventional inversion evaluation of hydrocarbon potential by assessing the residual organic matter left in source rocks. Geobiology, probing the interaction between the life system and the earth system, provides new principles in deciphering the whole dynamic processes related to the organic evolution history from living biomass to organic burial. Geobiological subdisciplines, including molecular geobiology, geomicrobiology, geoeconomy and biogeochemistry, offer new methodology and techniques to estimate the paleoproduction, depositional organics and organic burial capacity and their components. Geobiofacies, newly proposed herein, is terminologized to define the geobiological dynamic processes through the combination of biofacies with organic facies and sedimentary facies, and expressed by the biohabitat types, paleoproduction, depositional and preserved organics. Geobiofacies is identified as a useful means to create the geobiological evaluation system, which in turn rectifies the conventional evaluation system for the marine source rocks.

Keywords  marine source rock, geobiology, evaluation system, geobiofacies, productivity, organic burial capacity

1 Introduction

The theories and the principles related to petroleum generation, derived from the investigation on hydrocarbons of terrestrial environments, exerted an extensive influence in guiding our national petroleum exploration in the past decades. These theories and principles also contributed a lot to the international energy resources. However, the majority of the oil and gas reservoirs were internationally found in marine carbonate rocks rather than terrestrial strata. In particular, most large oil and gas fields found globally are hosted in marine carbonate rocks spanning a variety of geological ages, including Paleozoic, Mesozoic and Paleoproterozoic (Dutkiewicz et al., 2003; Rasmussen, 2005). Marine carbonate rocks have thus been targeted as an important lithology for international petroleum exploration.

In contrast, the known reserves in domestic marine carbonate rocks account for only 5% of the total proved reserves in China. The recent discoveries of both the Tahe large oil field and the Puguang large gas field hosted in marine carbonate rocks throw a promising prospect on the marine source rocks in China. Consequently, the marine source rocks are potentially important for the national petroleum exploration, giving rise to the fascinating shift of the national oil and gas exploration from terrestrial to marine source rocks.

2 Challenge of the conventional evaluation methodology applied in the high-post mature marine source rocks

2.1 Impact of the hydrocarbon discharge on the inversion assessment of the reserves

The source rocks are the basis of the oil and gas systems and were paid a great deal of attention by the international petroleum geologists. For the last ten years, a variety of studies were conducted in marine source rocks, in particular the carbonate rocks, covering the sedimentary environmental condition, organic occurrence, mechanisms of generation and
discharge of hydrocarbons, thermal simulation of hydrocarbon generation, geophysical characteristics of the source rocks, the logging response and so on (Clegg et al., 1997; Glikson, 2001; Younes, 2001; Sharaf, 2003; Younes, 2003; Riediger et al., 2004; Wilde et al., 2004; Fildani et al., 2005; Younes and Philp, 2005; Rabbani and Kamali, 2005; Lash and Engelder, 2005; Ercegovac and Kostić, 2006). The great achievement of these studies has resulted in the recognition of the importance to understand the mechanisms related to the source rock formation, in addition to the description of the source rock characteristics.

In modern days, the pathways and the effects of the hydrocarbon discharge are believed to be the important properties of the source rocks to be investigated. Some conceptual terms including the good-quality source rocks and effective source rocks were proposed and defined, which shed light on the importance of hydrocarbon discharges (Leythaeuser, 1988; Banerjee et al., 2000). These terms lay great attention to the relationship between organic content, lithology, thickness and the geological processes the source rocks experienced with the hydrocarbon generation and discharge. However, the discharge of oil and gas from the effective source rocks means that both the organic content and the organic compositions might vary greatly at different stages. The occurrence of the hydrocarbon discharge would challenge the conventional inversion evaluation of the hydrocarbon potential which only assesses the residue organic matter left in the source rocks. It is thus necessary to evaluate the hydrocarbon potential on the basis of the systematical investigation of the whole dynamic process during the source rock formation, which enables to reconstruct the history of the organic variation in both the content and the composition.

2.2 Complexity of the high-post mature marine source rocks

The marine carbonate source rocks in China were formed in the cyclic superposition basins, with an experience of a long geological age, a deep burial history and an intensive tectonic movement in the Mesozoic and Cenozoic. This complexity leads to the occurrence of the multiple sources and multiple stages for the hydrocarbon generation (Jin et al., 2000; Ma, 2006), which causes the difficulty in the petroleum exploration. The identification of the effective source rocks among the multiple source rocks is currently a key scientific issue to be resolved, and the setup of the effective evaluation methodology is of great significance for the high-post mature source rocks (Liang and Chen, 2005).

In South China, a majority of molecular organic geochemistry parameters are believed to be unable to indicate the original geochemical processes in the marine strata due to the high-post maturity. There is weak or no correlation in the content of both the chloroform bitumen “A” and the total organic carbon, in particular in the Lower Paleozoic with the enhanced thermal maturity. The distributions of biomarkers appear to be unchanged, irrespective of the geological settings, and their maturation indicators approach the equivalent values. This prohibits the biomarkers from evaluating the sedimentary environmental conditions and the organic origins. The kerogen has been thermodynamically evolved to such a degree that the identification of their types was demonstrated to be impossible. The intensive carbonization invalidates the identification of the kerogen macerals.

The existence of the above-mentioned issues limits the understanding of the organic origins, preservation conditions and the mechanisms of the hydrocarbon generation in the high-post mature source rocks. Specifically, the highly thermal evolution history resulted in difficulties in the reconstruction of the hydrocarbon generation history. The novel methodologies, techniques and theories related to the basin formation, hydrocarbon generation and reservoir preservation need to be brought out and explored, to meet the specific conditions of marine environments in South China.

3 Geobiological concerns on the dynamic processes of the source rock formation

3.1 Geobiological probe of the interactions between the life system and the earth system

The guidance of the geological principles is proposed to be the prerequisite to the discovery of oil and gas fields, and the technical innovation is the key issue of the petroleum exploration (Kang, 2004). The advanced exploration of energy resources awaits the development of geosciences. The earth system science, the newly developing discipline in geosciences, considers the earth as a whole complex dynamic system. The reconstruction of the earth dynamic system necessitates the integration of all the disciplines to decipher any of the big scientific issues, such as the global changes, the coupling among the geosphere, the biosphere, the hydroosphere and the atmosphere, and their relationship with the resources and the environments.

The interaction between the earth system and the biosphere is one of the important issues in the earth system science. Physical, chemical and biological processes are the three roles during the evolution of the earth. Geophysics and geochemistry, the two most-developed disciplines in geosciences, deal respectively with the physical and chemical processes. The geophysical and geochemical principles are being widely used to understand these two processes during the formation of oil and gas reservoirs, with the corresponding techniques being employed to explore energy resources. In contrast, geobiology identifies the biological process as its own issue, with the emphasis on the interaction between the geosphere and the biosphere, or between the organics and inorganics (Knoll and Hayes, 1997, 2000; Amend et al., 2001; Pennisi, 2002; Yin et al., 2004; Xie et al., 2006). Geobiology places concerns on the co-evolution between the organisms and their environments (Knoll, 2003; Noffke, 2005; Riding and Liang, 2005), which spans most (80%, i.e. 3.8 Ga) of the earth