Petroleum Research xxx (2017) 1–24

Contents lists available at ScienceDirect

Petroleum Research

journal homepage: http://www.keaipublishing.com/en/journals/petroleum-research/

Full Length Article

Research advances in the formation poredynamics of sedimentary basins

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ARTICLE INFO

Article history:
Received 6 January 2017
Received in revised form
21 April 2017
Accepted 26 April 2017
Available online xxx

Keywords:
Formation Poredynamics
Geotemperature
Geopressure
Porosity
Critical property of sandstone reservoir
Hydrocarbons charging
Sedimentary basin

ABSTRACT

In the 21st century, the geodynamics is developing towards quantitative researches. However, due to the irreversible geological processes, it was very difficult to recover the geological process. In particular, the restoration of geological parameter evolution process at the microscopic scale has become a major scientific problem in geology presently. Thereby, a concept of the formation poredynamics is revised and proposed, and the formation poredynamics is a fundamental discipline which focus on the mechanical characteristic of porous media, the pore evolution law, the dynamic genesis and the seepage property of pore fluid during the burial process of clastic rocks. Moreover, it is a new interdiscipline of underground diagenetic dynamics and pore fluid dynamics, and also is as an important part of sedimentary basin dynamics. Research advances were made in both basic theory and applied research. The advances in the basic theory include: (1) the static equilibrium principle of the formation pore, (2) the porosity evolution mechanism and quantitative model of sandstone during the burial diagenetic process, (3) the compaction characteristic and the porosity evolution quantitative model of mudstone, (4) the theoretical relationship between the underground pore fluid temperature and the pore fluid pressure, (5) the influence of the tectonism-induced additional geostress on the pore fluid pressure, and (6) the relationship between the mudstone compaction and the vitrinite reflectance (R_o) of organic matter. The advances in the applied research include: (1) the geotemperature-geopressure system division of the sedimentary basin and the interpretation of the hydrocarbon distribution dynamic, (2) the modification of the strata pressure prediction model, (3) the construction of the reservoir critical properties and the reservoir dynamics evaluation system, (4) the simulation of the evolution process of the formation fluid pressure, (5) the numerical simulation and physical experimental simulation on the sandstone hydrocarbon charging dynamics, and (6) the dynamic process analysis of the hydrocarbon accumulation in tight sandstone. Through the integration between the pore genesis evolution and the pore fluid dynamic evolution, the formation poredynamics is one of the representative discipline branches that the geological dynamics research had developed toward the underground microscopic scale in recently 20 years, and it also is an inevitable result from the quantitative development of the formation and distribution mechanisms of sedimentary mineral deposits. Based on the formation poredynamics research, eight important research achievements are summarized, and the geological researches are extended from the macroscopic scale to the microscopic scale, to find out the pore parameter evolution law under control of the formation pore evolution during the burial process, and update and improve exploration and production application technologies.

1. Introduction

In the 21st century, the geodynamics is developing towards quantitative research (Scheidegger, 1982; Fu and Huang, 2001; Teng et al., 2010). The basin simulation technique that began in

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Peer review under responsibility of Petroleum Research.

http://dx.doi.org/10.1016/j.ptlrs.2017.04.001

1970s and 1980s, provided the scientific theoretical basis and the practical computer model for quantitative researches on geological process, and a commercial software system had been built. Over more than three decades of application practice, it was found that there were quite a few problems about basic concepts and basic models of the basin dynamics research, which should be further studied and explored (Liu, 2008; Xie et al., 2012; Li, 2015). On the other hand, as development of the geology, the geological process research was equal to the geological function research. Researchers no longer studied only the geological function unilaterally, but also the influence of geological process on the geological phenomenon. However, due to the irreversible geological process, it was very difficult to recover the geological process. In particular, the recovery and estimation of the geological parameter evolution process at the microscopic scale was a major scientific problem in the geology (Bao, 1994; Sun and Chen, 1995).

The concept of the formation poredynamics was promoted by the authors based on two major demands. Firstly, the classical rock mechanics supposed that the formation was the uniform and continuous media, but it was not in accord with the actual formation situation of the discontinuous and heterogeneous characteristic, and thus it could not reflect the formation stress-strain law reasonably. Secondly, the diagenetic dynamics focused on studies of the diagenetic environment, diagenesis and pore space variation (Davies and Smith Jr, 2006; Li et al., 2006a; Li and Liu, 2009), and ignored the varied laws of other pore-related parameters such as the pore fluid pressure, the geotemperature and R_o; moreover, the basin fluid dynamics based on classical hydrogeology mainly emphasized studies of the seepage property of groundwater or fluid in porous or fractured media (Wang, 2002; Xie and Wang, 2003), and could not consider the geological genesis of the seepage. Because there was a gap between both the diagenetic dynamics and the basin fluid dynamics, then the formation poredynamics could be a new bridge to combine the porosity genesis evolution and the pore fluid dynamics evolution, thereby promoting the development of the microscopic formation dynamics.

2. The concept of the poredynamics

In a sedimentary basin, the bedded infillings of clastic sediments under the action of geological agents was a dynamic geological process (Bao, 1994). After the depositional period, the bedded clastic particles underwent such as the mechanical compaction, cementation and dissolution during the burial process, resulting in formation of some new authigenic minerals; while the original particle pore spaces were changed constantly, and these changes could be outlined by the diagenetic dynamics (Li and Liu, 2009). On the other hand, with increase of the burial depth, the thermal evolution degree of organic matter in the fine-grained argillaceous pores rose, this process was called the chemical reaction dynamics process (Zhao, 1988). Meanwhile, fluid pressures in pores were changed, then led to the complex migration and accumulation of oil, gas and water in pores.

Obviously, the latter dynamic processes in the microscopic pores controlled formation, distribution and enrichment of the sedimentary mineral deposits (Liu, 2008). However, the basic dynamic characteristics that occurred in the microscopic pore spaces after the clastic sediments burial, were not studied deeply; in particular, the dynamics problems on pore variation and its influence were not yet systematically studied and discussed.

2.1. Research background and main scientific problems

In 1980s, the geological science was further developed towards studies on quantitative genetic mechanism. However, the basic disciplines that related to the formation poredynamics had some limitations. As a comprehensive discipline for exploring geological genesis of the Earth (Fu and Huang, 2001; Teng et al., 2010), and from the classical petroleum geology to the hydrocarbon accumulation dynamics, the geodynamics mainly focused the macroscopic researches at the basin or zone scales, and rarely considered the geological variation characteristics at the microscopic scale. As a specialized discipline on study of the rock deformation laws, although the rock mechanics has considered a fact that rocks were of elastic, plastic and viscous characteristics, the research object was still the uniform and continuous media rather than the porous media, so that the rock mechanics models were always quite different from the actual rock conditions (Chen, 1986; Li, 1989). The basin fluid dynamics or groundwater dynamics only focused on the seepage law of water or fluid in formation pores, and did not involve causes of the seepage in pore media and change laws of the temperature, pressure and related parameters induced by changes of pore media (Wang, 2002; Xie and Wang, 2003). As an interdiscipline involving testing techniques of sedimentary petrology, petroleum geology and metallogeny (Fan et al., 2009), the diagenetic dynamics focused on pore genesis and variation, but did not concern variation of pore fluid dynamics and related parameters. Obviously, a comprehensive discipline focusing on both pore variation law and change of pore fluid dynamics was required in the field of pore media.

The following problems occurred if the diagenetic dynamics and the basin fluid dynamics were combined.

(1) Basic researches on the stress-strain law of porous formation were less little. Terzaghi model (Terzaghi and Peck, 1966) (the total load of overlying strata was equal to sum of the effective stress and the pore fluid pressure) was not suitable to express the microscopic static equilibrium in porous rock. Compared with the effective stress, the particle stress was more capable to reflect the stressed state of the framwork, thus it was necessary to reintroduce the particle stress to investigate the static equilibrium equations of different rocks.
(2) Influence degree of pore evolution process on porosity was still unclear. The Athy model (the formation porosity and burial depth exhibited an exponential relationship) (Athy, 1930) was used by most of scholars, to describe and express quantitative relationship of porosity versus depth, but the Athy model was a statistical model, the reliability was still controversial. Due to complex pore structure and many types of diagenesis, the porosity evolution was influenced by many factors, it was difficult to quantitatively describe porosity evolution process. Untill now, there is no mature porosity evolution model.
(3) Models for fluid pressure and temperature parameters under the pore media condition were too obsolete to adapt to further development of basin dynamics and hydrocarbon accumulation dynamics. Many geologists believed that there must be a certain inevitable connection between the geotemperature and the geopressure, and some concepts such as hydrothermal pressurization, geothermal field, pressure field, and stress field were proposed (Barker, 1972; Hunt, 1990; Fu et al., 1999). However, there were few basic researches on the geotemperature–geopressure relationship and the geopressure-geostress relationship, and some corresponding theoretical models were absent.
(4) A relationship between mudstone porosity and thermal maturity was found through analysis of actual data, but this relationship still lacked the theoretical basis which should be further developed to better predict petroleum exploration.

Please cite this article in press as: Liu, Z., et al., Research advances in the formation poredynamics of sedimentary basins, Petroleum Research (2017), http://dx.doi.org/10.1016/j.ptlrs.2017.04.001