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Original research paper

Seepage system of oil-gas and its exploration in Yinggehai Basin located at northwest of South China Sea

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Abstract

Seepage systems of oil-gas in Yinggehai Basin are divided into two types, namely: “micro-seepage”, which is presented by gas chimneys and pockmarks; and “macro-seepage”, which is also called oil-gas outflow; and, in addition, the combination of the two basic types. Among the oil seepage systems, the combined seepage system at Yingdong Slope of Yinggehai Basin is the most eye-catching, and gas chimneys and pockmarks micro-leakage systems in mud diapir zones in the central part of the basin are very common. Both the indications of large-scale oil-gas outflow at Yingdong Slope, which have been booming for a hundred years; and the occurrence of pockmarks at the central mud diapir belt, along with the chaotic seismic reflection of widely-distributed shallow gas chimneys—have shown that hydrocarbon in this area is sufficient and oil-gas is now in dynamic equilibrium of the processes of accumulation, migration, gathering and dispersing. It builds up good conditions for the accumulation, migration, gathering and reserving of oil and gas. However, it must be noted that the results of oil-gas exploration at Yingdong Slope didn't turn out to be satisfactory, despite the presence of oil-gas outflow and gas chimney combined seepage systems. So, strengthen synthesized analysis and study on oil-gas seepage systems and on the conditions for accumulation, migration, gathering and dispersing; the forecasting and evaluation to the advantageous conditions for enriched oil and gas zones; and trap preservation in accordance with the dynamic balance theories; are of significant importance for purposes of exploration.

Keywords: Oil-gas seepage system; Outflow of oil-gas/gas chimney; Macro-seepage/micro-seepage; Trap conditions; Yinggehai Basin; South China Sea

1. Introduction

Widely distributed in the marine environment, especially on shelf seabed offshore, seepage systems have been researched throughout the offshore areas of continental margins around the world by many energy companies, universities and research institutions [1−7]. Seepage on the seabed is the process in which shallow (mainly biogenic) or deep (mainly thermogenic) gas sources overflow from the seabed in the buoyancy along the channels (such as deposition layer gap, the fault plane, mud volcanoes) [5,6]. Seepage can exist in the range of 10−3000 m in ocean depth in a variety of geological environments, such as passive continental margins in the Gulf of Mexico [8], Monterey Bay transition zone in the USA [9], the Australia's offshore [10], the Sea Ridge of the Mediterranean [11,12], the Black Sea [13], and the Barbados Ridge in the Atlantic [14]. The presence of seepage on the seabed indicates that it may be rich in oil and gas resources in seafloor sediments [5]. The study of seepage can help us know the progress of generation, migration, accumulation and dispersal

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of oil-gas, and to predict the oil and gas prospects quickly, economically and effectively [5−7].

Internationally, the early studies of oil and gas seepage systems are based on geochemical analysis of bitumen, water geochemistry "sniffing" sampling, synthetic aperture radar, and so on [10,15]. In recent years, the comprehensive application of modern acoustic detection methods has improved the reliability of investigation and interpretation of oil and gas seepage. For example, in the Yampi shelf area of northwestern Australia [10], using side-scan sonar and 120 kHz single-beam bathymetric reveal, a large number of active oil-gas seepage systems have been discovered, corresponding to the true seepage position.

China has begun to focus on research in this area in recent years. Chen et al. [16], and Li [17] summarized the geophysical characteristics and identification methods of seepage on the seabed. Li et al. [18] pointed out the existence of gas seepage system in the central sag zone of Yinggehai Basin, based on analyzing the date of high-resolution seismic profiles, 3.5 kHz shallow stratigraphic section, side-scan sonar image interpretation. Zhao et al. [19] used the full-covered Side-Scan Sonar and high-resolution seismic survey method to research hydrocarbon seepage in the north depression of South Yellow Sea Basin. However, systematic and targeted exploration work remains to be further research.

Seepage systems of oil-gas at Yinggehai Basin located northwest of South China Sea develop tremendously, mainly in forms of outflow of oil-gas (described as "macro-seepage"), gas chimneys and pockmarks (described as "micro-seepage"), and the combined type of the two seepages. Oil-gas outflows are widely distributed in shallow water in adjacent areas of the Yingdong Slope surrounding the southwest margin of Hainan Island [20−23]. It's been over a hundred years since the macro-seepage of oil-gas outflow has shown a strong abnormality and a great amount and large distribution of oil-gas rarely found domestically and abroad. While indications of micro-seepage, such as gas chimneys and pockmarks in the seabed, are mainly found in the shallow layer of the central diapir belt along the concave area at the central part of the basin, the Yingdong Slope—especially the margin part of the basin where it's near the central diapir zone—together with indications of oil and gas outflow, form the combined seepage system of oil and gas [23−25].

The existence and boom of oil-gas seepages, oil-gas outflows, gas chimneys, and seabed pockmarks; as well as other indications of macro-seepage and micro-seepage; have shown that there are oil and gas reserves and active oil-gas generation systems and hydrocarbon sources in its deep underground, as well as in the adjacent areas [21,23]. However, the traditional theories and methods on oil and gas exploration all take these as signs, important grounds, and clues for exploring and searching for oil, gas reserves, and oil fields—which means that research is done on the basis of seepages in exploring and tracing the major direction of oil and gas accumulation, as well as advantageous locations for their reserves; so as to deploy and implement exploration to locate advantageous areas with rich reserves. So, the existence of seepages and the outflow of oil-gas and gas chimneys are signs of the generation, gathering and dispersal of oil-gas; and are direct instructions and traces of oil-gas exploration—which fully suggests that it is a very active area with oil-gas storage, accumulation and dispersal; thus, it is of great significance to oil geology and oil gas exploration [5−7,21,23]. This paper aims to study the distribution characteristics of macro-seepage system of oil-gas and outflows in Yinggehai Basin, as well as the micro-seepage system of oil-gas and gas chimneys. Moreover, the paper will focus on their genesis as well as the characteristics of its hydrocarbon source. It will analyze and discuss the geological significance and prospects in oil exploration, in order that the study would help promote oil and gas exploration in areas with active oil-gas outflow and gas chimneys.

2. Geological background

Yinggehai Basin is a young pull-apart basin, characterized by high temperature and overpressure, which develops on basis of the Red River strike-slip fault zone [26−29]. Huge Neocene neritic sediments (over 10 km) deposited in the basin center, provide material for mud diapir and oil-gas generation [25]. However, the slope areas have thin sediments. The long axis of the basin is oriented along the north-west direction, and there are three primary structural units: the Yingdong Slope, the Yinggehai concave area (central concave) and the Yingxi slope from northeast to southwest (Figs. 1 and 2). The tectonic evolution of the basin can be divided into two stages: a Paleogene extensional rifting event and a Neogene post-rift thermal subsidence [27,30,31]. Basically two mega sequence, and thick deposits of Cenozoic clastics on Paleozoic and Mesozoic basement rocks, filled the basin (Fig. 1); abnormal high temperature and a super pressure system existing under 3200 m [26,32,33] formed an uplift tectonic zone at the central diapir zone at the scale of 20,000 km^2 (Fig. 1). At present, a number of middle-large gas reservoir groups and gas bearing structures have been found in this shallow layer [34−36]. There is a great amount of gas chimneys and pockmarks in the shallow layer of gas fields and gas bearing structures, and even the seabed [23−25], which is an obviously common signal of a natural gas seepage system in the gas field and the gas bearing structure. Gas chimneys and pockmarks are valid and very common in regular 2D seismic-profile and shallow layer seismic profile obtained by seafloor engineering and geological survey of exploration wells.

The slope of areas, such as the Yingdong Slope (Fig. 2), has a thinner accumulation compared with the central diapir zone; geothermal field is low with the existence of discordogenic fault released by flow of No. 1 faultage and Yingdong faultage. So there is no possibility of a stratigraphic system of abnormal high-temperature and super-pressure, and there is no diapir zone development. We can say that there are no hydrocarbon conditions [21−37]. However, the transforming system of lateral migration made by No. 1 faultage, Yingdong faultage, multi-regional unconformities and sand bodies are originated here; it further forms a high speed channel for oil gas

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