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Full Length Article

Pressure field characteristics of petroliferous sags in Bohai Bay Basin: Implication for hydrocarbon enrichment

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ABSTRACT

Pressure fields of different sags in a petroliferous basin were significantly different, and it was related to hydrocarbon enrichment. Based on pressure data of different sags in Bohai Bay Basin, types of pressure field and its distribution characteristics were well discussed, and relationships between overpressure and hydrocarbon generation, pressure field and hydrocarbon enrichment were also investigated. Results showed that the Paleogene pressure fields of different sags in Bohai Bay Basin could be divided into three types: normal pressure type, single overpressure type and double overpressure type. These three types of pressure fields had the zoned features in their distributions. The normal pressure fields were mostly distributed in peripheral sags of the basin, while the single overpressure fields were widespread in the basin, and the double overpressure fields were concentrated in the areas around the Bohai Sea. Hydrocarbon generation had a significant effect on overpressure formation, thus overpressure horizons generally were corresponded to major source rock horizons, and differences of filling evolution history and main hydrocarbon-generation strata of different sags might be important factors for the formation of these three types of pressure fields. Overpressure in source rock horizons was closely related to hydrocarbon enrichment. Horizontally, hydrocarbons were mainly distributed around the overpressure center, and the secondary migration distance of hydrocarbons was affected by the degree of overpressure. Vertically, hydrocarbon distribution was controlled by the type of pressure fields. Hydrocarbons in the normal pressure sags were mainly enriched in the major hydrocarbon-generation horizons and their adjacent horizons, hydrocarbons in the single overpressure sags were mainly distributed in the hydrocarbon-generation horizons and its upper and lower horizons, while in the double overpressure sags, the hydrocarbon enrichment degree in Neogene was high. Hydrocarbon enrichment in sags was controlled by the degree of overpressure in hydrocarbon-generation horizons, and these oil-rich sags had relatively large overpressure degree.

1. Introduction

Pressure fields, and especially overpressure in petroliferous sags, had significant impacts on hydrocarbon generation, evolution, migration, accumulation and preservation of organic matters. According to statistics, over 180 sedimentary basins in the world were of overpressures, and hydrocarbon distributions in about 160 basins were related to the development of overpressure (Hunt, 1990; Du et al., 1995; Ma et al., 2000). Formation mechanisms of overpressure included undercompaction, hydrocarbon generation, tectonic compression, clay minerals dehydration and hydrothermal pressurization. Generally, it was widely believed that the undercompaction and the hydrocarbon generation were the most important contributors to large-scale overpressure in the basins (Bradley, 1975; Spencer, 1987; Osborne and Swarbrick, 1997; Wang and Ye, 2001; Hao, 2005; Wang et al., 2007; Fan et al., 2015).

As an important petroliferous basin in East China, the Bohai Bay Basin had over 50 sags, and each a sag had relatively independent hydrocarbon generation and accumulation units (Lu and Qi, 1997; Zhao and Chi, 2000; Jiang et al., 2014, 2015a). Most petroliferous sags in the basin were of overpressure, predominantly caused by undercompaction and hydrocarbon generation. Vertically, pressure fields in these sags could be classified into normal pressure zone and overpressure zone (Li et al., 1997; Sui, 2004; Zhang et al., 2009;

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Guo et al., 2011; Liu et al., 2013), but there were significant differences in overpressure horizon, overpressure degree and vertical structures of overpressure zones in different sags, and the effect of the pressure field on hydrocarbon enrichment and distribution was different. Previous studies of pressure fields in Bohai Bay Basin mainly focused on the single sag or area, but few on structural characteristics of pressure fields in different petroliferous sags and their relationships with hydrocarbon distributions. Based on previous researches, pressure field characteristics of different petroliferous sags were well compared in accordance with measured formation pressures in Cenozoic strata, and standard for classification of pressure fields was established. In addition, relationships between overpressure and hydrocarbon generation, pressure field and hydrocarbon enrichment were also well discussed in this study.

2. Characteristics of pressure field

2.1. Distribution characteristics of pressure field

Major generation and preservation formations in Bohai Bay Basin were predominantly in the Paleogene. Most of the large-scale overpressure sections were distributed in the Member 4, Member 3 and Member 1 of Shahejie Formation and Member 3 of Dongying Formation. Since the Paleogene sedimentary center migrated from the basin periphery to the basin center (the area around the central Bohai Bay), spatial and time distribution of Paleogene source rocks gradually became new and more from the basin periphery to the basin center (Zhao and Chi, 2000), so did overpressure horizons.

The overpressure in Member 4 of Shahejie Formation was mainly distributed in Dongpu, Dongying, Liaohe West and other peripheral petroliferous sags (Tao et al., 1986; Zhang et al., 2009; Guo et al., 2011; He et al., 2012; Sun et al., 2013). Among them, the Dongying sag was characterized by the most extensive distribution of overpressure and the highest amplitude of overpressure, and pressure coefficient of the Lijin subsag and the Niuzhuang subsag was over 1.6 and the maximal pressure coefficient was 1.92 (He et al., 2012). In Dongpu sag and the Liaohe West sag, the pressure coefficient was over 1.5 and the area of overpressure distribution was relatively small.

The Member 3 of the Shahejie Formation had the widest range of distribution of overpressure, and the overpressures were developed in every petroliferous sag. The overpressure range and amplitude of Member 3 of Shahejie Formation in Dongying, Dongpu, Zhanhua, Liaohe West and other sags were higher than that in the Member 4 of Shahejie Formation (Tao et al., 1986; Zeng et al., 2009; Zhang et al., 2009; Guo et al., 2011; He et al., 2012; Liu et al., 2013; Sun et al., 2013). The overpressure amplitudes were generally high, the pressure coefficient in most of the sags was from 1.6 to 1.8, and the pressure coefficient in oil-rich sags was all high, for example, the pressure coefficient was up to 1.99 in Dongying sag (He et al., 2012), 1.9–2.0 in Bozhong sag (Liu et al., 2008).

Overpressures in the Member 1 of Shahejie Formation and the Dongying Formation were mainly distributed in every sags around the Bohai Sea, the overpressure center migrated to sea areas around the Bohai Sea. The pressure coefficient in Bozhong sag was over 1.6, and over 1.4 in Nanpu, Qikou and some other sags (Liu and Wang, 2001; Li et al., 2004, 2006; Liu et al., 2008; Sun et al., 2010). Overpressure in the Dongying Formation was distributed in a relatively small range, mostly around the Bohai Sea, the strong overpressure was developed in Bozhong sag with the pressure coefficient up to 1.8 (Liu et al., 2008).

With the available statistics of the measured formation pressure varying with depth in petroliferous sags, except for Weibei, Damintun and a few other sags of the normal pressure type, the formation pressure in most of the hydrocarbon-bearing sags had the vertical zonation, in other words, the hydrostatic pressure zone occurred in the upper strata, and with increase of buried depth, the overpressure zones was developed in the lower strata (Fig. 1). Top depths of overpressure zones in different sags were quite different, but mostly varied from 2000 to 3000 m, for example, in Dongying sag and Zhanhua sag, top depths of overpressure zones were 2200 m and 2300 m, respectively (He et al., 2012), while in Huimin sag, it was up to 3000 m. Overpressure in Member 3-Member 4 of the Shahejie Formation was developed in Dongpu, Dongying, Huimin and other sags, accordingly, these sags just had one overpressure zone vertically. While in Bozhong sag and Zhanhua sag, overpressure was not only developed in Member 3-Member 4 of the Shahejie Formation, but also in Member 1 of the Shahejie Formation-the Dongying Formation, therefore, these sags were characterized by two overpressure zones vertically (Fig. 2).

2.2. Structural characteristics of pressure field

The study of the vertical pressure field in Bohai Bay Basin showed that the regional overpressure zones (excluding regional overpressure induced by fluid properties and other causes) were predominantly developed in Member 4, Member 3, Member 1 of the Shahejie Formation and the Dongying Formation (Tao et al., 1986; Liu and Wang, 2001; Li et al., 2004, 2006; Liu et al., 2008; Zeng et al., 2009; Zhang et al., 2009; Sun et al., 2010, 2013; He et al., 2012). Occurrence horizon of overpressure zones in different sags might be somewhat different, but development horizon of overpressure was consistent with occurrence horizon of hydrocarbon generation. Based on development horizons and vertical superposition relation of overpressure, the pressure field of major hydrocarbon-bearing sags in Bohai Bay Basin could be classified into three types: normal pressure type, single overpressure type and double overpressure type (Fig. 2).

In normal pressure type sags, formation pressure was consistent with hydrostatic pressure varying with depth. Vertically, no obvious overpressure zones were developed in such the sag. Major hydrocarbon-generation horizon was characterized by normal pressure, such as Weibei sag with the normal pressure system.

Single overpressure type sag had one overpressure zone in the vertical direction, and the overpressure was developed in one or two neighboring hydrocarbon-generation horizons; vertically, continuous distribution of overpressure could be formed. A sealing layer of sedimentary rocks with low permeability on the top of the overpressure zone was developed to prevent the release of overpressure effectively (Hao, 2005). In Dongying sag, the formation pressure of the Upper Submember of Member 3 of the Shahejie Formation and overlying strata was normal, a set of overpressure zone was continuously developed in the Upper Submember of Member 4 and the Middle & Lower Submembers of Member 3 of the Shahejie Formation, and the normal pressure zone was developed in the Lower Submember of Member 4 of Shahejie Formation and underlying strata; generally, a lithologic transitional zone with gain sizes from coarse to fine was developed from the normal pressure zone to the overpressure zone.

Vertically, the double overpressure type sag had two clearly independent overpressure zones. In Zhanhua sag, an overpressure zone was developed in the Middle & Lower Submembers of Member 3 and the Upper Submember of Member 4 of Shahejie Formation, the other overpressure zone was developed in Member 1 of Shahejie Formation. Between these two overpressure zones, the normal pressure zone was developed in the Upper Submember of Member 3 and Member 2 with the relatively developed sandstone; moreover, the formation pressure of strata above Member 1 of Shahejie Formation and below the Upper Submember of Member 4 of Shahejie Formation was also normal (Fig. 2).

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