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Paleosalinity and water body type of Eocene Pinghu Formation, Xihu Depression, East China Sea Basin

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A R T I C L E I N F O

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A B S T R A C T

Xihu Depression is a relatively new petroleum exploration area in East China Sea Basin. Pinghu Formation is one of the most important oil-bearing formations in the depression. Due to the low exploration level of the depression, paleosalinity and deposition environment of the depression in Pinghu stage is not clear. Element geochemical analysis of samples from different structural units is used to study ancient water salinity and reveal the depositional environment. B/Ga ratio, which is sensitive to paleosalinity in study area, is 0.9–4.0 and indicates characteristics of mixed water of fresh and salt water. There is a threshold for Sr/Ba in water salinity study in the study area. When Sr/Ba ratio is lower than 0.15, it cannot be used as an indicator for salinity and ancient water body type. Equivalent boron content calculated by Walker's method is lower than 150 ppm. Paleo salinity from boron content calculated by Couch's method is 2.97‰–9.61‰ and the average is 4.8‰. Based on the above mentioned results, ancient water body of Xihu Depression in Pinghu stage has typical characteristics of brackish water and it belongs to oligohaline and mesohaline water. Combining paleogeomorphology and sedimentary facies distribution in the study area, paleowater body in Xihu Depression during Pinghu stage is transitional mixed water influenced by terrigenous diluted water. Paleosalinity contour lines extend on plane from north to the south and are parallel to paleo-coastline. Paleosalinity increases from the west to the east. Influenced by freshwater of deltas at western part of the depression, high abnormal salinity values occur around the wells M1 and L1 where salinity contour lines curve westward.

1. Introduction

Paleosalinity is an important index for ancient water type analysis, ancient coastline recognition and ancient sedimentary environment reconstruction (Degens et al., 1957; Frederickson and Reynold, 1960; Harder, 1970; Liu et al., 1986; Deng and Qian, 1993; Tuo et al., 1994; Liu, 2008). Common methods for paleosalinity reconstruction include; 1) qualitative analysis with fossils, petrological and mineralogical examination and organic geochemical data, 2) quantitative calculation based on geochemistry test and 3) measurement and test of pore fluid and liquid inclusions (Walker and Price, 1963; Couch, 1971; Qian and Shi, 1982; Lan et al., 1987; Zheng and Liu, 1999; Jiang et al., 2011). Geochemistry analysis is commonly-used method in paleosalinity study. Diverse parameters and methods are used such as B content, Na content, Ba/Ca ratio, B/Ga ratio, authigenic iron sulfides, carbon and oxygen isotopes, stable oxygen isotope ratios ($\delta^{18}O$), stable hydrogen isotope ratios ($\delta^{2}H$ or δD), and so on (Frederickson and Reynold, 1960; Curtis, 1964; Lerman, 1966; Couch, 1971; Veizer et al., 1977; Seward, 1978; Berner et al., 1979; Rohling, 2007; Weldeab et al., 2007). Any parameter has its use condition and limitation. For example, a variety of calibrations of $\delta^{18}O$ have been fashionable, but they are found to have unreasonably large uncertainties in the processed values (Rohling and Bigg, 1998; Schmidt, 1999; Rohling, 2000).

Boron content is a very common parameter in paleosalinity and sedimentary environment study. It has been recognized that boron content in marine sediments is higher than their fresh-water counterparts (Degens et al., 1957; Landergren, 1958; Harder, 1970). The relationship between boron content of sediments and their sedimentary environments has been studied and an agreement between chemical-analytical results and depositional environment is commonly accepted as an indication of applicability of the boron analyses to a given suite of sediments (Frederickson and Reynold, 1960; Walker and Price, 1963; Potter et al., 1963;

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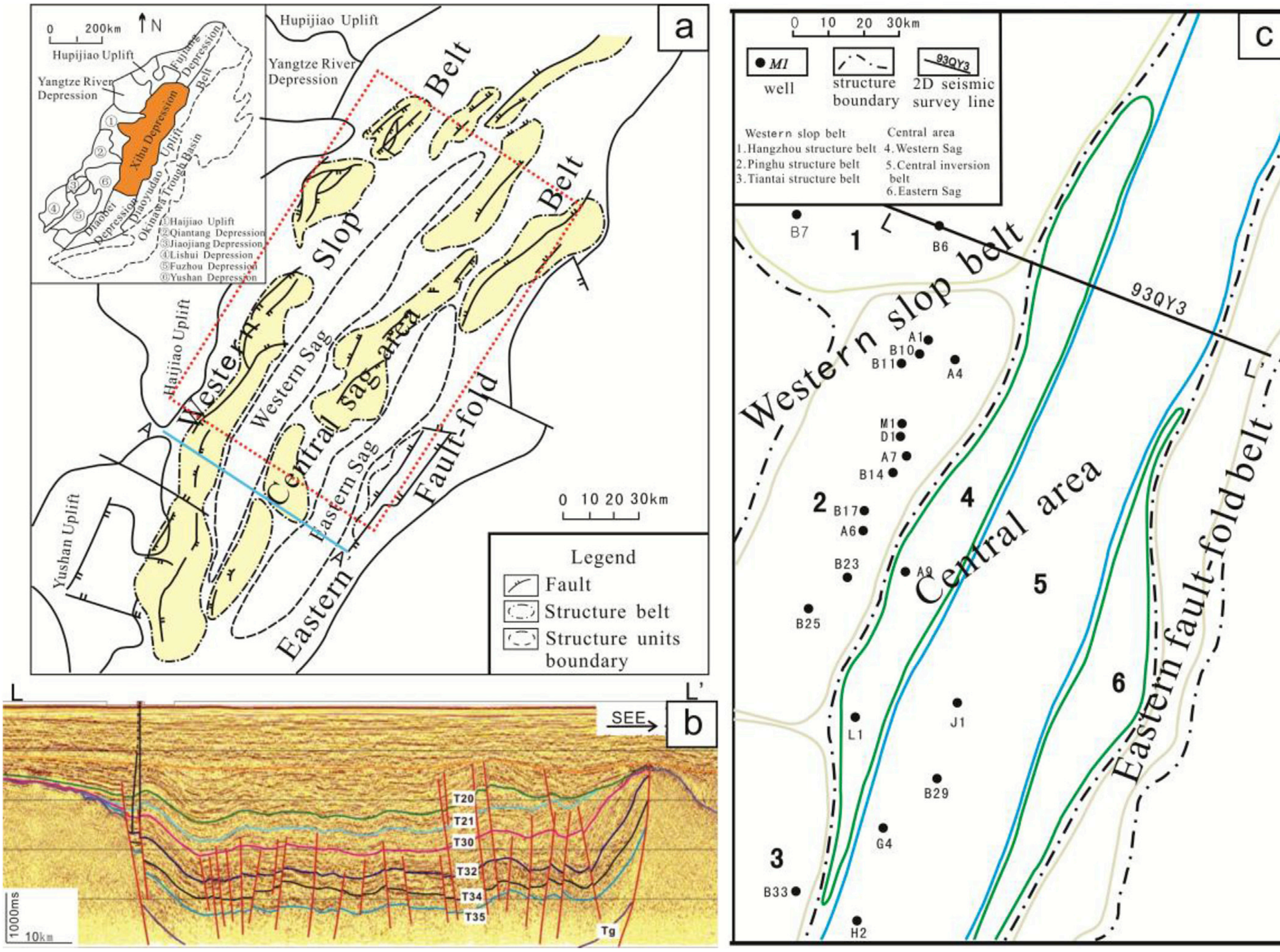

Fig. 1. Structure location and tectonic division of Xihu Depression. Map a: the location of Xihu Depression in Eastern China Sea Basin and its structural subunits. Map b: 2D seismic section at Line L-L'. Geological surfaces of the seismic reflection: T20-boundary between Longjing Formation and Huagang Formation (also surface between Miocene and Oligocene); T21-surface between upper and lower parts of Huagang Formation; T30-surface between Huagang Formation and Pinghu Formation (surface between Oligocene and Eocene); T32-surface between upper and middle parts of Pinghu Formation; T34-surface between middle and lower parts of Pinghu Formation; T35-surface between Pinghu Formation and Baoshi Formation. Map c is the main structure units of Xihu Depression.

Walker, 1964; Couch, 1971).

Xihu Depression is one of the major oil and gas-bearing depressions of East China Sea Basin. Pinghu Formation in Paleogene is an important petroleum exploration formation in the area (Jiang et al., 2011; Zhang et al., 2012; Wei et al., 2013a,b). Wells are mainly in the west and the middle of Xihu Depression, as study degree of Xihu Depression is low, depositional environment and ancient-water body type in Pinghu stage of the depression is still disputed (Liu et al., 2009; Jiang et al., 2011).

Xiong's study (2007) reported that the sedimentary environment is coastal wetland and lakes in Pinghu formation. His conclusion is based on the development of coal layers in Xihu Depression. Wu (2016) finds abundant of tidal sand ridges which indicate offshore environment with intense tidal action in study area. In Jiang's study of micro-fossils, the upper part of Pinghu formation is continental deposit and there develops lakes of fresh water to brackish water (Jiang et al., 2011). In many studies, it is thought to be offshore and shallow sea environment which has deeper water than Jiang's study (Li et al., 2014).

In this study, geochemical analysis of elements is used to study paleosalinity in Pinghu stage. The average Sr/Ba is less than 0.2. Correlation analysis shows that there is a threshold for Sr/Ba ratio in study of water salinity in this area. When Sr/Ba ratio is lower than 0.15, it does not have a good correlation with paleosalinity and therefore cannot be used as an indicator of salinity and ancient water body type. B/Ga ratio, which is sensitive to paleosalinity in the study area (0.9–4.0), covers parts of the B/Ga ranges of both fresh water and salt water. Values of Sr/Ba and B/Ga ratio indicate mixed water of fresh and salt water. Equivalent boron content obtained by Walker's method and paleosalinity by Couch's method is used as paleo-water analysis index in this study. Combining the above analysis, ancient water body in Pinghu stage is concluded as brackish water which is transition of terrestrial freshwater and salt water. With evidences from paleogeomorphology and sedimentary facies distribution of study area, the terrestrial freshwater is from the deltas in the western parts of the depression. Paleosalinity increases from the west to the east on plane. Salinity contours lines extend from the north to the south and curve westward locally around wells M1 and L1 where salinity is abnormally high.

2. Geological setting

Xihu Depression is a NE-trending depression which is located in the west of East Sea Basin. It evolved from part of a Paleogene continental margin megarift (Li et al., 2009). Xihu Depression, Diaobei Depression (also named as Jilong Depression. Kong, 1998 and Hsu et al., 2001) at the south, and Fujiang Depression at the north form a huge continental margin rifting system. The rifting system parallels to Diaoyudao Uplift (also named as Taiwan-Sinzi belt. Kong, 1998, and Hsu et al., 2001) and