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RESEARCH PAPER

Fine prediction of reef boundary based on slope attributes: A case study of Permian Changxing Formation in Luodingzhai area, Sichuan Basin, SW China

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Abstract: Based on the slope theory in geomorphology, a method, which can identify the boundary of platform reef by high precision slope attribute calculation based on the horizon data of fine seismic interpretation, combining the ancient geomorphic analysis method, was established. The conventional seismic prediction methods, drilling results and the thickness data of Changxing Formation were used to verify and supplement this method. Then, this method was used to identify the boundary of uplifted reef on the planar image in the Permian Changxing Formation in Luodingzhai area of Sichuan Basin. The results show that the reef boundary imaged by this method is consistent with the reef distribution revealed by the drilling, and is clearer in local details. Compared with conventional seismic prediction methods, the reef boundary identified based on the same fine seismic horizon interpretation results by this method has no multiple solution on the planar image.

Key words: Sichuan Basin; Permian Changxing Formation; reef; seismic interpretation; slope; boundary identification

Introduction

Reefs are a kind of carbonate rock body formed by organisms and biotic processes, usually in mound shape [1–3]. The reef-type reservoirs, mainly developed in the reefs of the carbonate platform margin and platform, are difficult to predict by seismic data [3–4]. Liu et al. described the exploration and development of the reef-type reservoirs in the Permian Changxing Formation of the Sichuan Basin as "miss what you expect to hit, and hit what you do not expect", that is a demonstration of the difficult prediction of reef-type reservoir by seismic data [5]. He et al. concluded that the special lithological characteristics of the reef reservoirs, the strong heterogeneity of the reservoir, the large difference between the reservoir and the surrounding rock, the great burial depth and the low quality of the seismic data are the main reasons behind difficult seismic identification and fluid detection of reef reservoir [6]. Researchers in China and abroad have tried a large number of seismic prediction methods to predict qualitatively and semi-quantitatively the development and spatial distribution of reef by analyzing the seismic reflection structure and energy difference of the reefs on the seismic data[7–14]. These seismic prediction methods have improved the coincidence of the reef-type reservoir prediction under certain conditions. However, as the scale of reef is controlled by deposition [4, 15–17], predicting the boundary of the reefs on the plane is difficult and ambiguous.

The growth and development of the platform reef and its special geological environment are the important factors causing the local variation of sedimentary landforms at the bottom of the overlying formation [1–2, 4, 15]. Zhou et al. thought the mutation of terrain slope was an important factor of the slope break belt to control the accommodation space and deposition, and realized the quantitative prediction of planar distribution of slope break belt by using the slope change in above and below the slope break belt. The platform margin reef terrain can cause change in terrain slope, especially on both sides of the reef, some abrupt variation of terrain slope could occur [15, 17]. Slope is an important geological parameter describing the abrupt change and undulating shape of terrain, which mainly reflects the inclination of the ground [18–19].

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Based on the quantitative study of slope, we used the three-dimensional seismic horizon interpretation data to calculate the slope of the top of reef formation, according to the change characteristics of the slope, and predict the reef boundary of the Changxing Formation in the Luodingzhai area, Sichuan Basin. Combining the conventional seismic prediction methods of reef, a precise prediction method of reef boundary based on stratum slope analysis was established. This method reduces the effect of fault on the identification of reef boundary and improves the reliability of reef boundary identification.

1. Seismic response characteristics of platform margin reefs

In the Permian Changxing Formation sedimentary period, the sedimentary environment of Northeast Sichuan in Sichuan Basin evolved from carbonate ramp to open platform of relatively deep-water shelf. The reef and shoal combination of Late Permian and Early Triassic occurring on the platform margin of Kaijiang Liang Ping deep-water shelf facies, is an important target for oil and gas exploration[3–4, 15]. The Luodingzhai area is located in the northern edge of the high-steep structure zone in eastern Sichuan, north of Huanglongchang structure, south of Wubaiti and Datianchi structures (Fig. 1). The Permian Changxing Formation reefs in the study area are part of the platform margin reefs of Kaijiang Liang Ping shelf[3–4,15].

1.1. Seismic facies of Changxing Formation reefs in single wells

The reefs of Permian Changxing Formation in the Luodingzhai area have obvious superimposed feature of the upper, middle and lower three members in the vertical direction. The upper member is mainly composed of dolomitic limestone, dolomite with dissolved pores and dolomite. Compared with argillaceous limestone of the upper Triassic Feixianguan Formation, this member has the characteristics of low acoustic (high acoustic velocity) and high density. Seismic forward modeling shows that the member is a peak reflection with strong amplitude, and the gas-bearing layer is weaker in seismic amplitude (Fig. 2). The middle member is mainly limestone, with several dolomite interbeds, and is relatively larger in thickness. It has the characteristics of high acoustic (low velocity) and low density, and its seismic reflection characteristics are weak amplitude reflection or large section blank reflection. The characteristics of low velocity and low resistivity are obvious in the gas bearing section, resulting in peak reflection of stronger amplitude (Fig. 2). The lower member is rich in organic matter; lithology is dominated by limestone, with high gamma ray, high acoustic and high resistivity. Moreover, it is the reef base deposits on platform margin facies. Its seismic reflection features trough reflection of weak amplitude (Fig. 2).

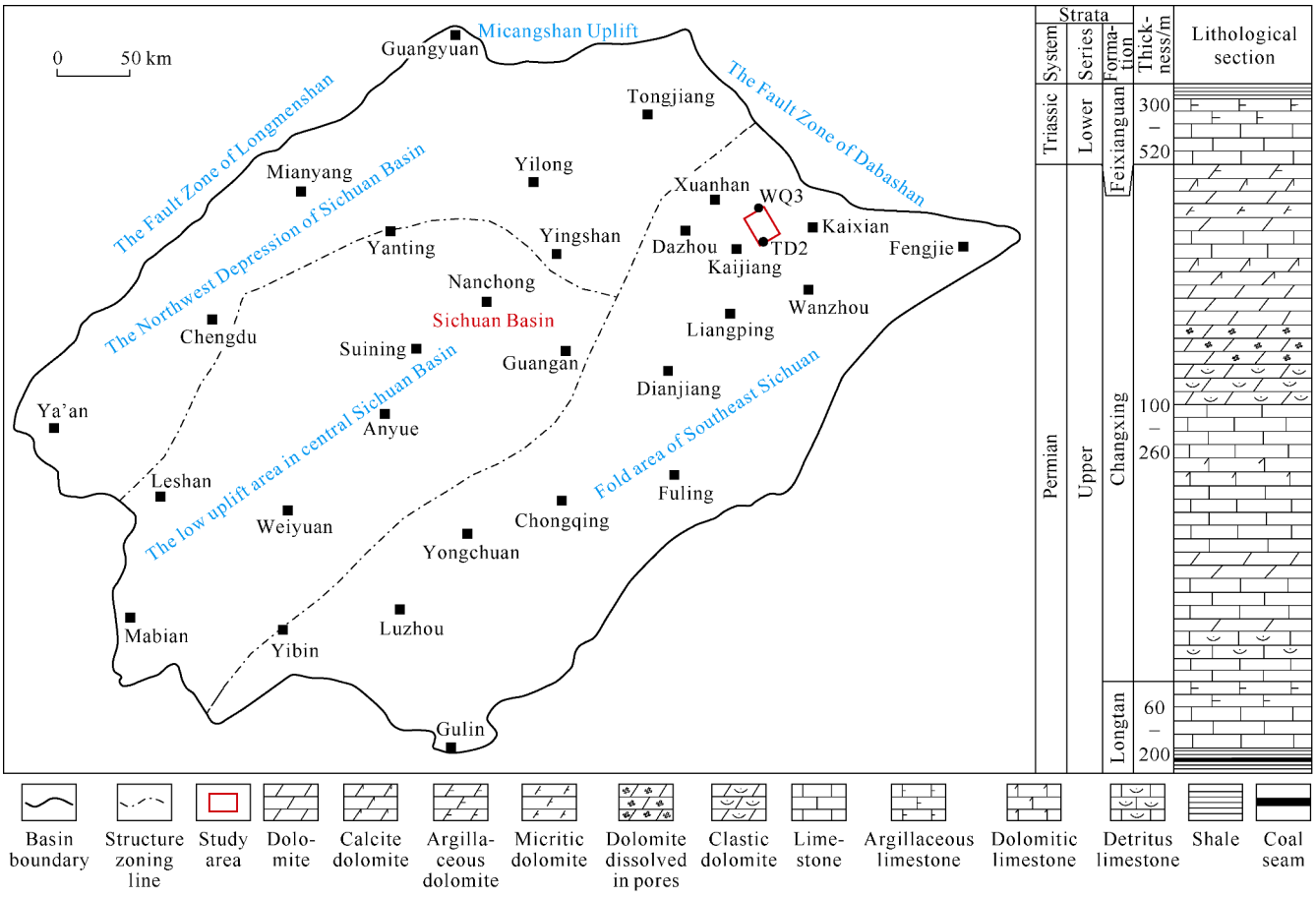

Fig. 1. The geographical location and geology of the study area.