Marine and Petroleum Geology 97 (2018) 277–287

Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

Research paper

Characteristics of the impedance variation in clastic rock reservoirs and lithology interpretation method for the threshold volume

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ARTICLE INFO

Keywords:
Petrophysics
Sedimentation
Diagenesis
Impedance
Threshold volume
Lithology interpretation

ABSTRACT

An analysis of the petrophysical characteristics of a reservoir demonstrated that the variations in wave velocity were controlled by sedimentary and diagenetic differences, resulting in regular variations in the acoustic impedance. The sedimentary differences are mainly associated with the grain size, sorting and shale content and lead to a slow horizontal change in the wave impedance of the reservoir; the diagenetic differences are associated with compaction, pressure dissolution and cementation and lead to a rapid vertical change in the wave impedance of the reservoir. The classic single threshold method only resolved the vertical variation in the acoustic impedance. As a result, the threshold volume method is proposed. The results of a case study demonstrate that the proposed method yields a more accurate and reliable interpretation of lithology using acoustic impedance than the single threshold method. In particular, the method effectively solves the uncertainty in the sand interpretation using the plane variation of impedance caused by the deposit.

1. Preface

Wave impedance inversion has become a critical technology in seismic reservoir lateral prediction. At present, seismic inversion techniques are developing rapidly, and various forms of inversion software are frequently being produced (Liu et al., 2013; Fang et al., 2017; Gu et al., 2016; Li et al., 2017; Wang Zhiqiang et al., 2017; Wang Kaiyan et al., 2017; Zheng et al., 2017). However, in practical application, there are still many examples of reservoir prediction failures. These failures may be due to issues with the inversion process itself or, in many cases, with the interpretation of the inversion results. Achieving a high-quality seismic impedance data body inversion is important; however, interpreting the inversion results rationally is also important. For example, when the characteristics of the reservoir wave impedance have not been carefully analyzed, the accuracy of the interpretation results can be reduced by using a single threshold value for reservoir interpretation; this method has been adopted by many recent seismic reservoir prediction studies (Liu et al., 2013; Ye et al., 2014; Qi et al., 2017; Liao et al., 2017).

In the course of deposition, the reservoir is influenced by sedimentation and diagenesis; thus, its geophysical characteristics differ over space. As a result, in areas with a relatively stable sedimentary environment, the wave impedance distribution intervals of sand and mudstone overlap less, and the wave impedance variation trend of sand and mudstone in different sedimentary facies is also reduced. Under this condition, sand bodies can be filtered out by a single threshold value. However, in areas with larger variations in sedimentary facies, such as delta sedimentary environments, from the delta plain to the delta front, the particle size and composition of the rock have changed considerably. Under this condition, the wave impedance difference of sand and mudstone will also vary considerably, and the sand and mud impedances may even overlap (Chen et al., 2011); therefore, the inversion results have multiplicity in the identification of lithology, and the conventional interpretation of sand bodies using a single threshold cannot yield high-accuracy reservoir prediction, which is a major problem in seismic inversion interpretation.

In this paper, an oil field in the Xihu Depression in the East China Sea Basin is taken as an example to solve the problem of using a single threshold in reservoir prediction and to analyze the distribution characteristics of the sedimentary system and the geophysical response characteristics of the reservoir. Moreover, the distributions and differences of the wave impedances of different sedimentary facies are clarified, and a threshold volume method is proposed for reservoir interpretation; specifically, different wave impedance threshold values are applied in different regions according to the sedimentary characteristics to accurately interpret the reservoir.

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https://doi.org/10.1016/j.marpetgeo.2018.07.001
Received 24 April 2018; Received in revised form 25 June 2018; Accepted 3 July 2018

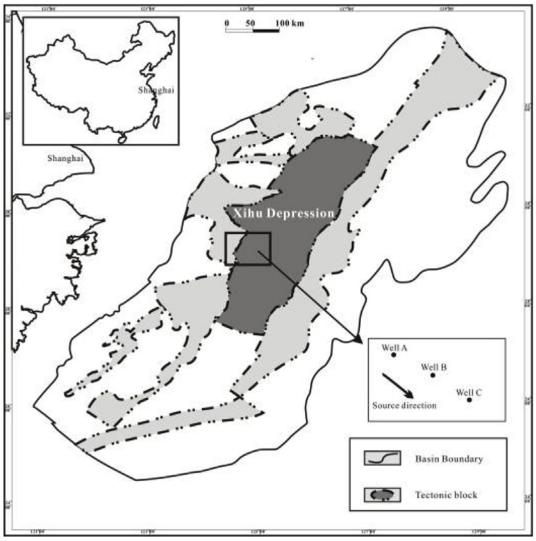

Fig. 1. Study area.

2. Survey of the research area

The study area is located in the Xihu Sag of the East China Sea Shelf Basin. The structural series of the East China Sea Shelf Basin are distributed along the NE-SW direction and are characterized by a north-south block and east-west zonation (Fig. 1). The Xihu Depression is a faulted basin with faulting in the east and overlying in the west; similar to the entire East China Sea Shelf Basin, it has the typical features of a north-south block and east-west zoning. The depression extends along the NNE direction, and the interior of the depression can be divided into five secondary structural units from west to east: the western slope belt, west subsidence belt, central inversion structural belt, east subsidence belt and eastern fault belt. The study area is located in the western slope zone, and the target layer is the Oligocene Huagang Formation.

The target area is a delta depositional system with an area of 200 km^2. In recent years, drilling in this block has not achieved the expected effect, primarily because the distribution of the reservoir in this area is not well understood, and it is difficult to open up a new prospect. Because this area has few wells, the characteristics of the detailed sedimentary microfacies distribution cannot be easily obtained in this area. In addition, although there are post-stack seismic data in the work area, the previous analysis of the Huagang Formation reservoir impedance characteristics indicated the presence of a large overlap area of wave impedance under the sandstone and mudstone in the lower section of the Huagang Formation (Fig. 2). This characteristic makes it difficult to determine the effective threshold of wave impedance of sand shale, which is needed to perform a reasonable reservoir prediction. Therefore, a detailed analysis of the characteristics of the reservoir geophysical response to establish a set of feasible reservoir interpretation methods is particularly important for achieving a breakthrough in the West Lake Depression.

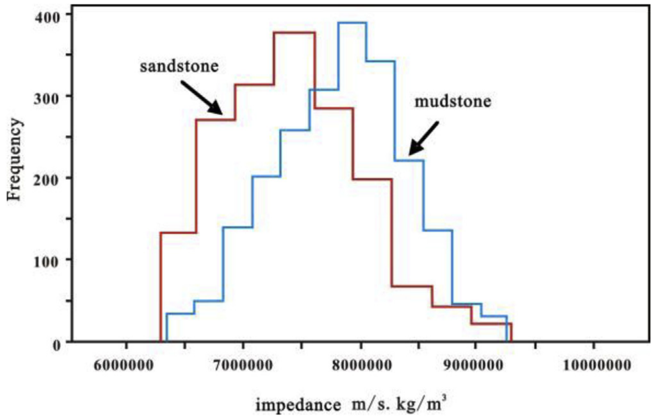

Fig. 2. Histogram of the wave impedance distribution in sand and mudstone.

3. Analysis of the change law of seismic velocity

The wave impedance of rock is the product of the wave velocity and the density of the rock. Thus, wave impedance reflects the resistance of rocks to the momentum transfer that occurs when a seismic wave propagates through a rock mass. The reservoir density is a relatively small range of variables; however, the velocity of sound waves is greatly influenced by the lithology, pore and fluid of the rock, particularly the development of pores, which directly affect the wave propagation velocity and the wave impedance of rock (Gassmann, 1951; Zimmerman, 1991; Song et al., 2004; Avseth et al., 2005; Mavko et al., 2009). In this paper, the spatial variation of the seismic P-wave velocity in the study area is analyzed in detail, thereby providing a theoretical basis for further reservoir prediction.

3.1. Diagenesis and longitudinal velocity variation trends

There are 3 wells in the study area, as shown in Fig. 1 (the black arrow in the map is the direction of the source). Fig. 3 shows a cross plot of the porosity and P-wave velocity in two wells, denoted A and B, where the depth range of the well A data is large (1700–2450 m) and the depth range of the well B data is small (1750–1817 m). The diagram shows that the slope of the sandstone velocity porosity in well A is large, exhibiting a steep change trend, while the trend line of well B is relatively gentle. A comparison of the features of the thin section under the different segments of well A (Fig. 4) illustrates that point contact is the main contact between particles at 1815 m (Fig. 4a) and line contact is the main contact between particles at 2320 m (Fig. 4b); with increasing depth, the compaction of the formation is enhanced and the contact between particles is closer, which leads to a steeper speed change trend. However, the depth span of well B is relatively short, and the microscopic characteristics show that the compaction is not serious. In Fig. 5, the formation of the short depth segment well is mainly related to the sedimentary environmental change factors, as confirmed by many studies (Han, 1986; Vernik and Nur, 1992; Vernik and Liu, 1997;

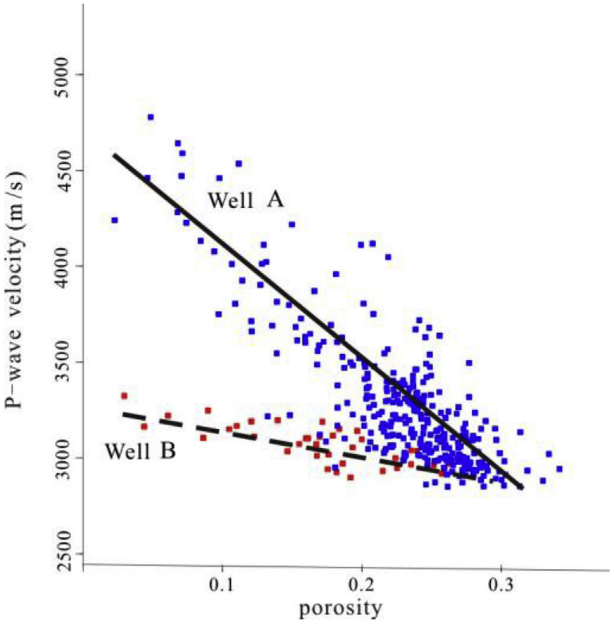

Fig. 3. Cross plot of porosity and P-wave velocity.