International Journal of Geosciences, 2022, 13, 985-995
https://www.scirp.org/journal/ijg
ISSN Online: 2156-8367
ISSN Print: 2156-8359

Application of Seismic Bedding Slice in Short to Medium Term Sequence Stratigraphy Division: A Case Study of the Sartu-Putaohua Oil Reservoir in Songliao Basin, China

Wanbai Dong[1], Xiangguo Zhang[1], Jianhua Zhong[2,3]*

[1]Exploration Division of Daqing Oilfield Co., Ltd., Daqing, China
[2]School of Resources and Material, Northeastern University at Qinhuangdao, Qinghuangdao, China
[3]School of Geosciences, China University of Petroleum (Eastern China), Qingdao, China
Email: *957576033@qq.com

How to cite this paper: Dong, W.B., Zhang, X.G. and Zhong, J.H. (2022) Application of Seismic Bedding Slice in Short to Medium Term Sequence Stratigraphy Division: A Case Study of the Sartu-Putaohua Oil Reservoir in Songliao Basin, China. *International Journal of Geosciences*, **13**, 985-995.
https://doi.org/10.4236/ijg.2022.1310050

Received: September 16, 2022
Accepted: October 28, 2022
Published: October 31, 2022

Abstract

Previously, stratigraphic evolution and sequence overlapping were represented by "substituting point for surface or multi-point for surface, line for surface or multi-line for surface", making it difficult to accurately reflect the stratigraphic evolution law across a larger area. We investigate the application of the seismic horizontal slice method for medium-short term stratigraphic sequence (four level), divided into reservoir group received, based on a 450 km^2 study area of three-dimensional (3D) seismic fine of the Sa-Pu formations west of the Daqing placanticline using a 50-millisecond horizontal slice. Sa-Pu oil layers can be divided into seven four-level sequences. We believe that a four-level sequence is more accurate in this application than in logging and data logging.

Keywords

Sequence Stratigraphy, Horizontal Slice, Longhu Pool, Songliao Basin

1. Introduction

In the 1970s, stratigraphic stratigraphy was developed based on seismic stratigraphy [1], which outlined the basic concepts and techniques of seismic stratigraphy while also incorporating the latest results of biostratigraphy, isotope stratigraphy, magnetostratigraphy, sedimentology, geochemistry, and tectonic geology [2]. The underlying principle is that the impacts of tectonic control construction, global absolute sea level changes, and sediment supply rates create stratigraphic records, also known as stratigraphic signals. These records indicate the magnitude, strength, duration, and extent of the effects of the aforementioned activities. Among them, the combination of tectonic action and sea level change, which causes global relative sea level change, controls the potential space for sediment formation. There are several basic theories or approaches to stratigraphic stratigraphy [3] [4] [5] [6]. However, it is challenging to use these methods to delineate low-sequence (less than tertiary) stratigraphic sequences in the immediate vicinity of the lake through cores, log curves, and seismic profiles, and can be influenced by the location and resolution of single wells and seismic profiles, etc. to reach different conclusions. Nevertheless, the seismic (sectioning) method of stratigraphy remains a key approach for oilfield exploration and development at present, and it has become a popular area of study in earth science in recent years [7]-[15]. This study aims to explore the issue of delineating the local low-sequence (class 3 - 4) stratigraphy of the lake from the surface using seismic parallelogram sectioning.

2. Geological Setting

The study area was the slope of Longhubo to the west of the northern part of the Daqing Changyuan-Longhubo Daan terrane, referred to as "Longhubo West", with an area of approximately 450 km^2 (**Figure 1**). The target of the study was the Yaojia Formation of the Lower Cretaceous and the Saertu (S) and Putaohua (P) Formations of the lower Nenjiang Formation (**Figure 2**). This set of strata consists of sandy mudstone-dominated clastic rocks with multiple mesomorphic layers, and more extensive liquefied sandstone veins are seen; no doubt, these veins interfere with to the delineation of the stratigraphy. Previous stratigraphic divisions for this set of strata have been performed, and the results are shown in **Figure 2**. The Yaojia Formation and the Neng 1 section were classified into four incomplete periodic rotations and 14 incomplete short-term rotations by the Daqing Petroleum Exploration Institute (**Figure 2**). Cheng, *et al.* (2008) split the Yaojia Formation and the Neng 1 section into 17 periodic spins (based on the Songke 1 well) [16]. We also separated the study area into spinners from a single well perspective, and the findings were inconsistent, indicating that both long- and short-term spinners may vary from well to well. Since local factors have a substantial influence on spiral delineation, it is necessary to investigate a method for delineating the sedimentary spiral or sequence that can eliminate the influence of local factors and have higher stability on the same tectonic depositional unit. Therefore, we studied the stratigraphic delineation of the Saertu and Putaohua Formations using 3D seismic along-stratigraphic slices, which is briefly described below.

3. Methods Introduction

Seismic sectioning techniques are becoming more popular in oil and gas exploration and development [7]. Seismic sectioning may be performed using three methods: stratigraphic sectioning [11], along-stratigraphic sectioning, and along-stratigraphic sectioning. We used the latter method because it simple and easy to use. With the continuous development and improvement of seismic technology, various novel processing and interpretation methods have emerged. Amplitude is one of the most essential properties of seismic waves, and its variation can be used to understand the physical properties (elastic modulus and wave impedance) of the subsurface strata and their variation. Because the elastic modulus and wave impedance of sandstone are greater than those of mudstone, the horizontal and vertical variations of sandstone may be determined based on the variation of amplitude. We produced seismic synthetic logs of certain wells using the software developed by Zhonghenglihua and limited the seismic with logs, and we discovered a strong correlation between the magnitude of the amplitude and the sandy mudstone (**Figure 3**).

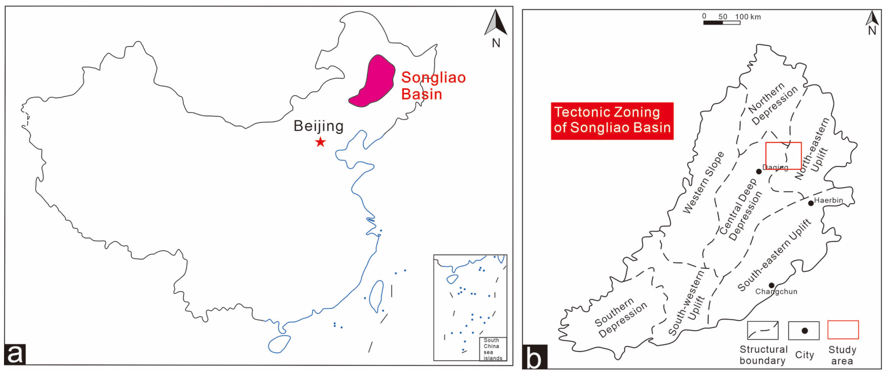


Figure 1. Location and geological structure of the study area.

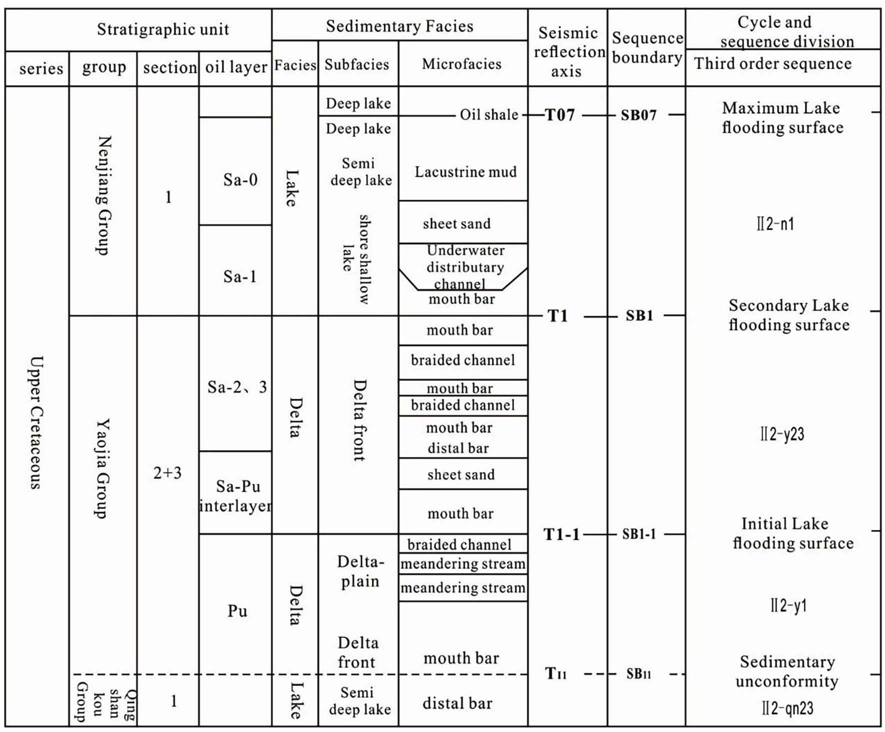


Figure 2. Stratigraphic column, logging and sequences of the study area (according to Daqing Exploration and Development Research Institute, 2016).

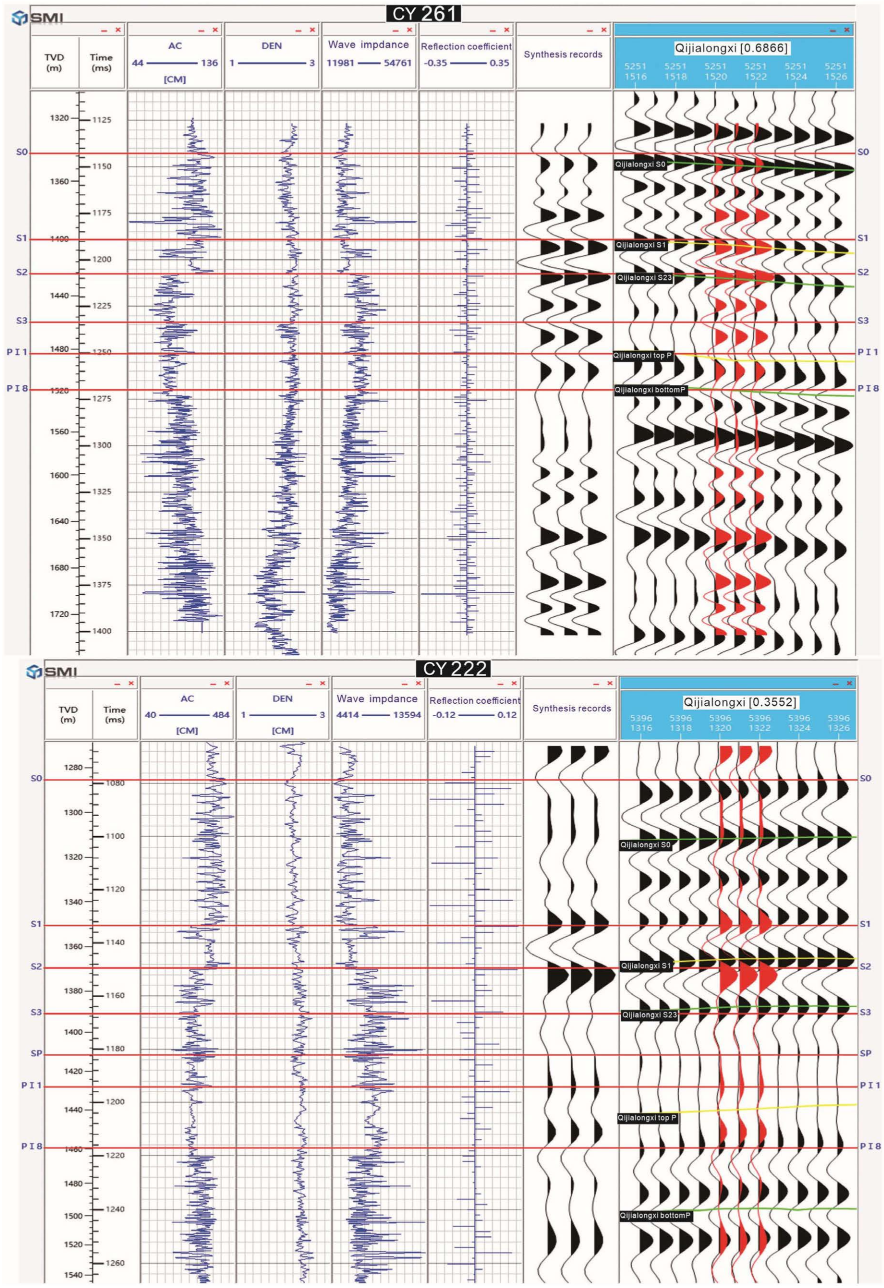


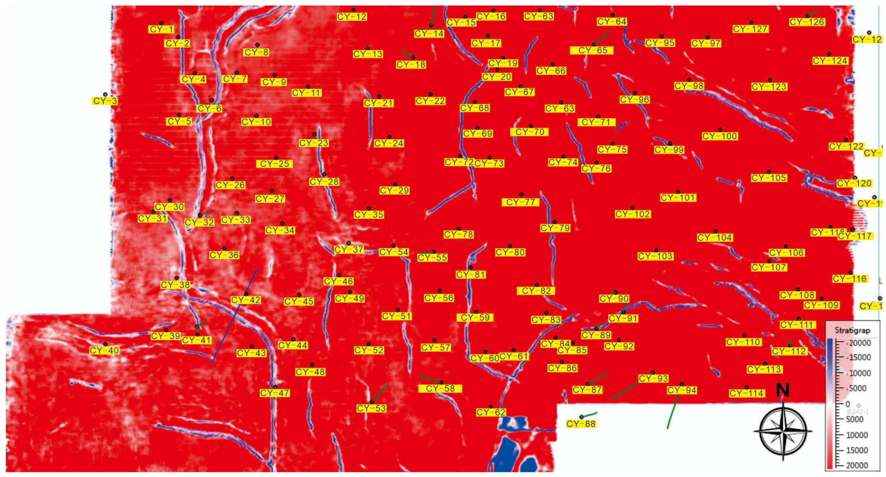
Figure 3. Seismic synthesis records for both well CY 261 and well CY 222.

The seismic amplitude parallel sectioning method can elucidate the general distribution and variation pattern of sandy mudstone across the study region. In the absence of turbidite sand development, we observed the sandstone as relatively shallow-water deposition and the (dark) mudstone as relatively deep-water deposition. We could then delineate the spinning and stratigraphic stratigraphy using seismic amplitude slices. The west slope of the Longhubu backslope study area is approximately 450 km^2 (**Figure 4**). A 3D seismic survey of the region was recently completed, and we collected a wealth of information on the stratigraphic cis-layer by slicing the Saertu-Putaohua oil reservoir in this area at intervals of

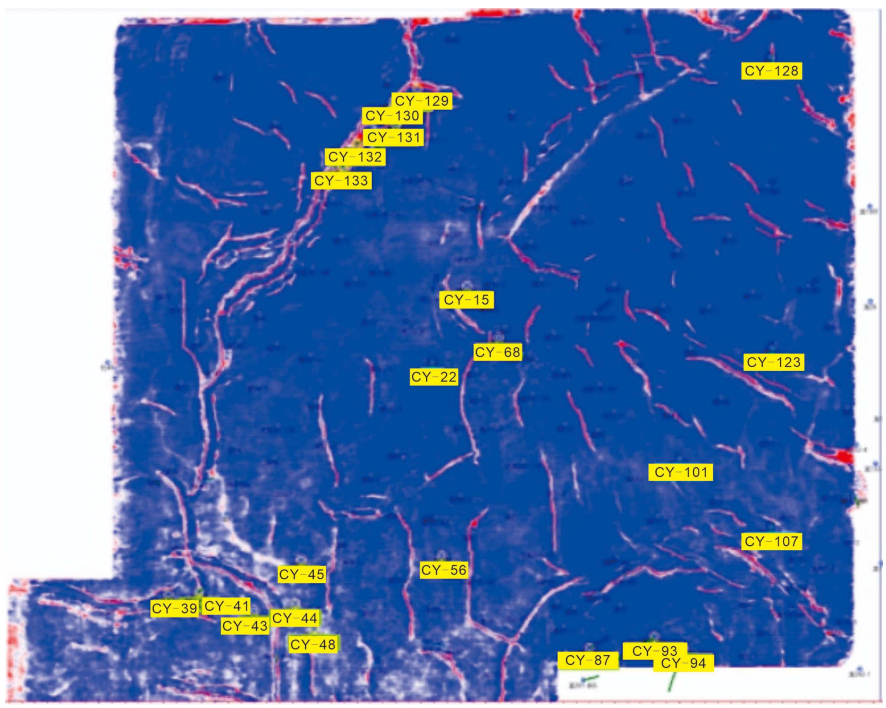
0.50 ms. High wave impedance represents sandstone and is represented in red (Figure 4(a)), indicating water retreat, while low wave impedance represents mudstone and is represented in blue, indicating water entry (Figure 4(b)).

4. Results and Discussion

Through abundance of 3D seismic slicing information, we can acquire the following results. Figures 5-8 show the vertical patterns in the cis-layer slices as follows:



(a)



(b)

Figure 4. The region of seismic bedding section and its two typical sections. (a) Low stand system tract section, mainly sandstone; (b) High stand system tract section, mainly mudstone.

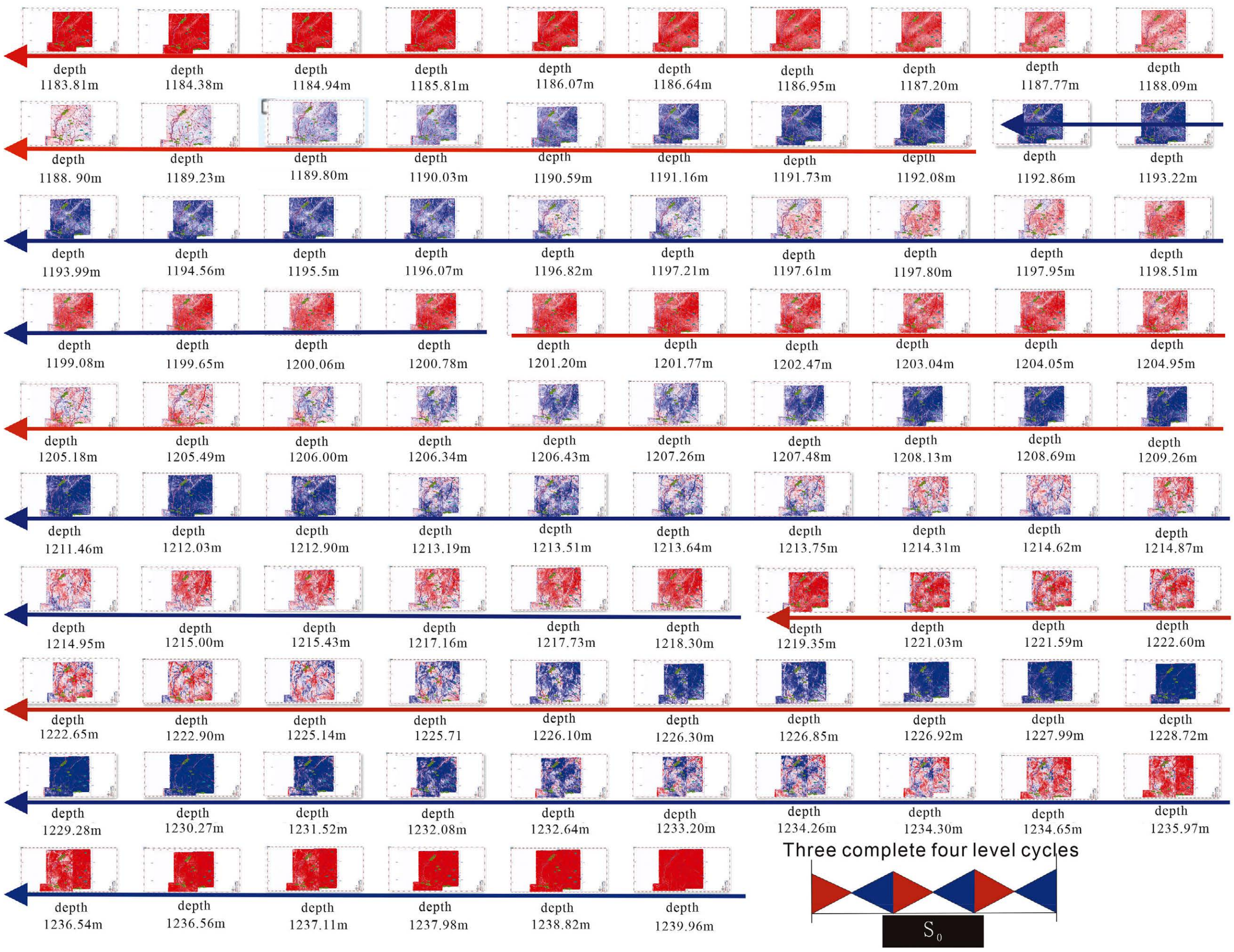


Figure 5. S_0 horizontal section and sequence division—divided into three complete four level circles.

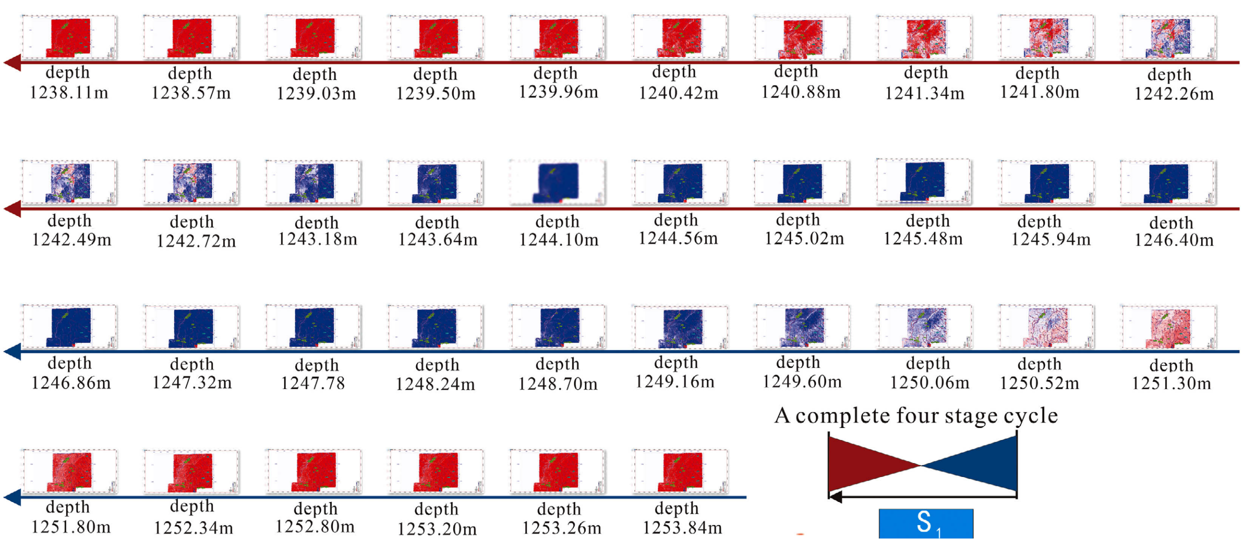


Figure 6. Sa_1 horizontal slice with stratigraphic division—divided into a complete four level cycle.

1) S_0 underwent three cycles of change from large to small and from small to large from bottom to top amplitude. This property can be considered as three

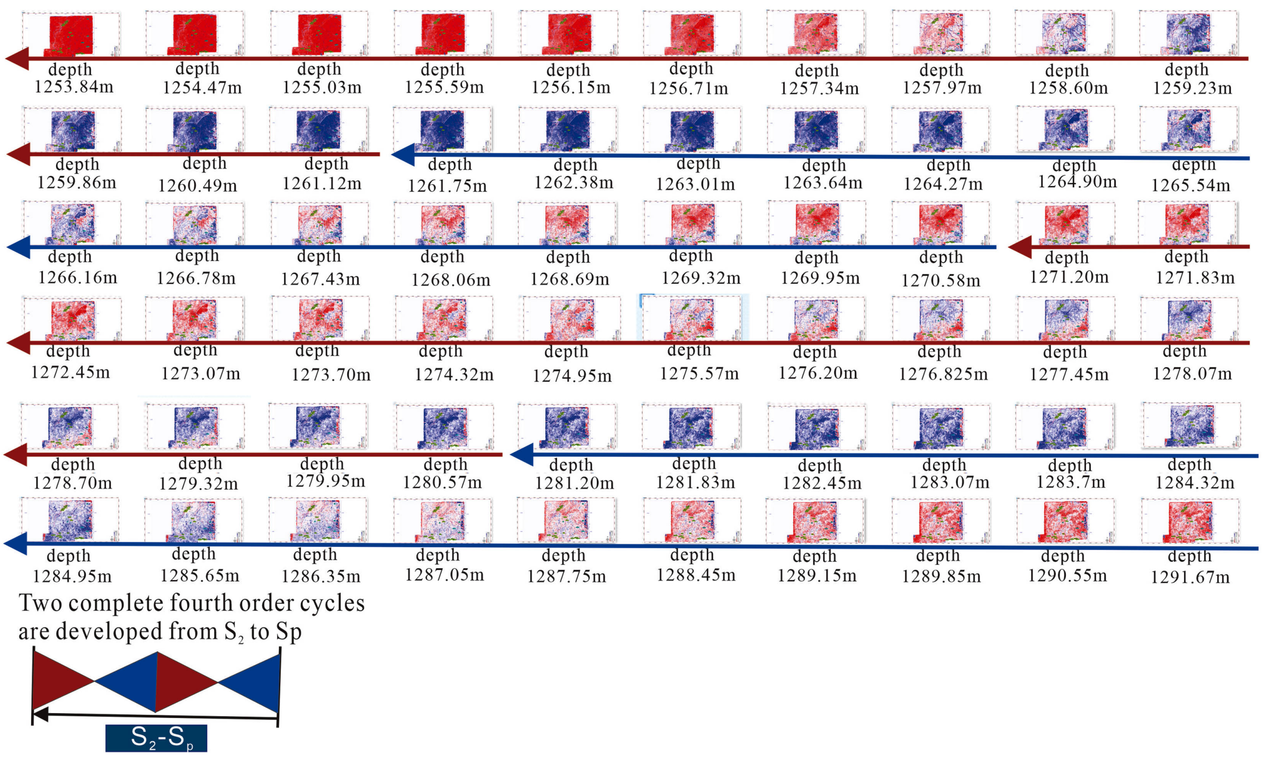


Figure 7. S_{23} horizontal slice and sequence division—divided into two complete four level cycles.

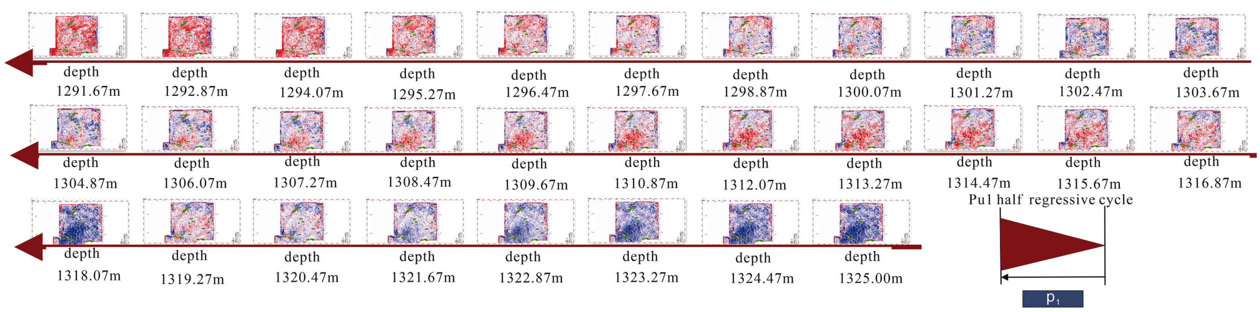


Figure 8. P_1 horizontal section and stratigraphic division—divided into a semicircle.

cycles of lithological change from sandstone to mudstone then mudstone to sandstone, or as three cycles of change from deep water to shallow water and from shallow water to deep water. Sandstone (red, higher wave impedance) and mudstone (blue, lower wave impedance) are regarded as shallow as deeper waters. Thus, S_0 exhibits three deep—to-shallow water transitions, corresponding to water inflow and outflow as well as in-accumulation and recession of stratigraphic stratigraphy, respectively. Thus, the cis-laminated part of S_0 reacts to three water-in and water-out or in-accumulation and out-accumulation signals (**Figure 5**), corresponding to three complete four-level stratigraphic sequences (**Figure 5**).

2) S_1 comprises a cyclotron that fluctuates in amplitude from large to small and small to large from bottom to top, representing a complete water-in-water-out or water in-accumulation-out accumulation, corresponding to a four-level

layer sequence (**Figure 6**).

3) From S_{23} to the top of the Portuguese, two variations of large to small and small to large rotations were observed, representing two complete water-in and water-out and water-in and water-out accumulations (**Figure 7**). S_{23} and the Sapsucker interval were difficult to distinguish in cores and logs, but two complete rotations from S_{23} to the top or bottom of the Sapsucker interval were observed in parallelogram sections, one of which can be attributed to S_{23} and the other to the Sapsucker interval, corresponding to two quasi-four-level sequences (**Figure 7**).

4) The entire Portuguese 1 section can be divided into semi-rotations. Water receded from the semi-deep lake phase of the Qingshankou Formation into a fluvial-deltaic-shallow lake evolutionary system, corresponding to a semi-quadrangular sequence (**Figure 8**).

The Sapo Formation component from cores, logs, and logs is separated into four quaternary sequences, but seven quaternary sequences from parallelogram slices. However, we believe that the latter is more accurate and reliable since the former is a one-hole or multi-hole view, whereas the latter is a one-sided view covering an area of 450 km^2. This is perhaps the first time we advocate using parallelogram slices to delineate the stratigraphic sequence.

Furthermore, all four interfaces from S_{23} to the bottom of the pluvium display clear cut-off top super or channel on the seismic profile, with obvious in-accumulation, recession, and accretion characteristics, indicating that these four interfaces were sedimentologically significant depositional surfaces.

Figure 5 depicts the cis-layer slices of S_0 corresponding to three complete rotations, with each turning point reflecting the relatively deepest and shallowest phases of the lake, respectively. The shallowest water phase was an alluvial plain, where sand filling degraded the channel and even causes denudation; the deepest water period was a deltaic submerged divergent channel where sand filling is insufficient and is filled with mud but preserved channel morphology. The most significant feature throughout the S_0 phase was the development of river channels, with water always retreating into the river channels, revealing that the S_0 study area was a river-delta-shallow lake environment rather than a deep-water lake environment, despite the development of oil shale at the top and replacement by deep-water mudstone of Tender 1. Seismic paralleling sections demonstrate that S_0 was the most developed river channel throughout the Saertu-Putaohua period. S_0 was previously believed to be a set of deep-water mudstones with undeveloped sand bodies; however, recent exploration has revealed that there are multiple sand formations in S_0. Furthermore, 2942×10^4 t of oil were recently discovered in S_0, accounting for more than half of the newly discovered Saertu-Putaohua reserves. Previous authors defined S_0 plus S_1 as a three-level laminar sequence, whereas S_0 was classed as a four-level laminar sequence (**Figure 2**). This paper is considerably different.

We analyzed the rationality of dividing the S_0 into three- or four-level sequences in terms of time. The Sapsucker Formation lasted about 6 Ma. It was about 8 Ma in total (88.5 - 80.0 Ma), while the Sapsucker Formation was about 6 Ma due to the general absence of Lusitano 2, minus Lusitano 2, which is about 2 Ma. In Longxi, the entire Sapo formation is about 100 m thick and S_0 is approximately 50 m thick, which is the sum of the thicknesses of the other four to five oil formations. In addition, because mudstone dominates S_0, it was reasonable to assume that S_0 took longer to form than the total of the other parts. According to conservative estimates, S_0 took about 3 Ma to form, as did the other four sections.

The stratigraphic classification of the 450 km^2 study area was carried out by seismic paralleling method, and seven water-in and water-out stratigraphic sequences were identified, albeit it was not clear whether they correspond to tertiary or quaternary levels. The stratigraphic sequence is between the three and four levels. We believe that the findings obtained using the parallelogram slicing method are unquestionably superior to those obtained from single wells and from the delineation on the composite histogram over a 450 km^2 area. It is important to note that seismic slice data cannot simply correspond one-to-one with his corresponding stratigraphic lithology [11], but extreme amplitude values can indicate the amplitude of the wave impedance and hence the relative presence and water depth of the sandy mudstone.

5. Conclusions and Outlooks

The above briefly describes the stratigraphic delineation of the Sapu Oil Formation on the Longhubu backslope of the Changwon slope using the along-stratigraphic slicing method, and the following conclusions were obtained:

1) The Sapo Oil Formation can be divided into seven fourth-grade sequences, which is three sequences more than the third-grade sequences divided by the conventional method and seven sequences less than the fourth-grade sequences divided by the conventional method. Therefore, it is a layer sequence between three and four levels, and we believe it to be closer to the four-level sequence, which is a division scheme with the sand formation as the change unit.

2) The lower four quaternary sequence interfaces, which are characterized by truncated top super and depositional interruptions, are also suitable depositional interfaces.

3) The cis-layer section in section S_0 delineates three- and four-level sequences, but what was previously considered to be a four-level sequence with half a basal rise, representing a single transformation from a shallow lake to a deep lake, is now thought to be three complete four-level sequences with three distinct water-entry and water-exit midway, according to the cis-layer section.

4) Novel stratigraphic findings can provide fresh insights on the extreme evolution of the studied sedimentary environment, particularly for the analysis of the fine-layer evolution and distribution pattern of hydrocarbon source rocks and sand bodies. For example, the three rotations of the S_0 section correspond to three water retreats with considerable distribution on the plane and the sand

groups formed by such water retreats, and the slicing technique also reveals that these three water retreats and sand groups correspond to three river developments. Is the area for future oil and gas exploration, rather than the previous environment where only deep and semi-deep lakes were developed. This is very different from the conventional view.

5) The 3D seismic cis-layer sections reveal not only the seven quaternary spins, but also the evolution of sand formations based on these spins; in particular, the three full spins in the S_0 section demonstrated the presence of three sand formations (excluding the bottom) in the study area, which will most likely be the direction of future oil and gas exploration.

3D seismic produces vital subsurface information, and the seismic slicing technique is widely used in the comprehensive interpretation of full 3D seismic. We provided a new method that based on seismic bedding slice to analysis short to medium term sequence stratigraphy division, this method can be used to the sedimentary stratigraphy research of the similar basin, and the method will be widely used to oil and gas exploration of sedimentary basin.

Acknowledgements

This work was supported by National Natural Science Foundation of China (Grant No. 42072138; 41572088). We also thank the Daqing Petroleum Exploration and Development Research Institute for providing the 3D seismic data body of the study area; and we thank Senior Engineer Caiyu Shen of the Physical Exploration Institute of Shengli Oilfield for his guidance.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Vail, P.R. (1977) Seismic Stratigraphy and Global Changes of Sea Level. *AAPG Bulletin*, **26**, 49-212.

[2] Sloss, L.L. (1988) Forty Years of Sequence Stratigraphy. *GSA Bulletin*, **100**, 1661-1665. https://doi.org/10.1130/0016-7606(1988)100%3C1661:FYOSS%3E2.3.CO;2

[3] Miall, A.D. and Miall, C.E. (2001) Sequence Stratigraphy as a Scientific Enterprise: The Evolution and Persistence of Conflicting Paradigms. *Earth-Science Reviews*, **54**, 321-348. https://doi.org/10.1016/S0012-8252(00)00041-6

[4] Catuneanu, O. (2002) Sequence Stratigraphy of Clastic Systems: Concepts, Merits, and Pitfalls. *Journal of African Earth Sciences*, **35**, 1-43. https://doi.org/10.1016/S0899-5362(02)00004-0

[5] Bhattacharya, J.P. (2011) Practical Problems in the Application of the Sequence Stratigraphic Method and Key Surfaces: Integrating Observations from Ancient Fluvial-Deltaic Wedges with Quaternary and Modelling Studies. *Sedimentology*, **58**, 120-169. https://doi.org/10.1111/j.1365-3091.2010.01205.x

[6] Burgess, P.M., Lammers, H., van Oosterhout, C. and Granjeon, D. (2006) Multivariate Sequence Stratigraphy: Tackling Complexity and Uncertainty with Stratigraphic

Forward Modeling, Multiple Scenarios, and Conditional Frequency Maps. *AAPG Bulletin*, **90**, 1883-1901. https://doi.org/10.1306/06260605081

[7] Qian, R. (1993) Concomitant and Secondary Phases on the Time Profile. *Petroleum Geophysical Exploration*, **28**, 282-291.

[8] Zeng, H., Henry, S.C. and Riola, J.P. (1998) Stratal Slicing, Part II: Real 3-D Seismic Data. *Geophysics*, **63**, 514-522. https://doi.org/10.1190/1.1444352

[9] Zeng, H., Backus, M.M., Barrow, K.T. and Tyler, N. (1998) Stratal Slicing, Part I: Realistic 3-D Seismic Model. *Geophysics*, **63**, 502-513. https://doi.org/10.1190/1.1444351

[10] Zeng, H., Hentz, T.F. and Wood, L.J. (2001) Stratal Slicing of Miocene-Pliocene Sediments in Vermilion Block 50-Tiger Shoal Area, Offshore Louisiana. *The Leading Edge*, **20**, 408-418. https://doi.org/10.1190/1.1438962

[11] Wang, Y.M., Ji, Y.X., Li, D.P., Shen, G.Q. and Chen, S.L. (2001) Application of Seismic Attribute Technique to Predict Reservoirs in Area A. *Petroleum Physical Exploration*, **40**, 69-76.

[12] Liu, W.L., Niu, Y.L., Li, G. and Guo, Y.R. (2002) Extraction and Validity Analysis Method of Seismic Attributes for Multi-Information Reservoir Prediction. *Petroleum Physical Exploration*, No. 1, 100-106.

[13] Lin, C.Y., Zhang, X.G. and Dong, C.M. (2007) Seismic Sedimentology and Its Preliminary Applications. *Journal of Petroleum*, No. 2, 73-76.

[14] Lin, C.Y. and Zhang, X.G. (2016) Exploration of Seismic Sedimentology. *Advances in Earth Sciences*, No. 11, 44-48.

[15] Wang. L.W., Liang, C.X., Zou, C.N., Li, M., Song, L.W. and He, H.Q. (2004) Application of Integrated Seismic Interpretation Technique in Predicting Lithologic Reservoirs in Southern Songliao Basin. *Oil and Gas Reservoir Evaluation and Development*, **27**, 58-62.

[16] Cheng, R.H., Wang, G.D. and Wang, P.J. (2008) Sedimentary Cyclogenesis and Milankovitch Cycle in the Cretaceous Quan-San-Nen-E Section of the Songliao Basin. *Journal of Geology*, **82**, 55-64.