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Reservoir Prediction Restricted by Sequence Stratigraphy

—A Case Study of Bioclastic Shoal Reservoir in Changxing Formation of Jiannan Area

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Abstract

Bioclastic shoal reservoir in Changxing Formation of Jiannan area is characterized by small thickness and strong heterogeneity. The uncertainty of the reservoir distribution pattern has confined the effective development of this area, so the accurate bioclastic shoal reservoir prediction would be the key to achieve development breakthroughs. Based on drilling, well-log, seismic and core analysis data, this article conducted exquisite sequence stratigraphic classification and established isochronal regional stratigraphic framework of Changxing Formation in Jiannan area. The reservoir seismic corresponding features were determined by exquisite calibrating bioclastic shoal reservoir in Changxing Formation. Therefore, seismic processing methods, such as multiple attribute analysis and amplitude inversion, were applied to attain more reliable reservoir prediction results, which indicated the distribution of vertical reservoir in SSQ2, the IV sequence order and the distribution of horizontal reservoir around Well J43 and JZ1 in the platform margin of the study area.

Keywords

Bioclastic Shoal, Sequence Stratigraphic Classification, Reservoir Prediction, Changxing Formation, Jiannan Area

1. Introduction

Jiannan area is located in Lichuan of Hubei and Shizhu county of Chongqing, in the middle of Shizhu synclinorium in the east margin of Sichuan Basin structurally. The extension of strata is NNE and NE in the area. Jiannan and the adjacent area include sub-structural units like Qiyueshan anticlinorium, Shizhu synclinorium, Fangdoushan anticlinorium from east to west [1] (**Figure 1**). Changxing Formation of the Upper Permian is the primary gas production layer in this area. Recently, a series of geological and seismic studies have been carried out on the bioclastic shoal reservoirs of Changxing Formation to draw an elementary understanding [2] [3] [4]. However, the exquisite development of gas reservoir requires higher reservoir evaluation degree. This article is based on sequence stratigraphic classification, combined with multiple seismic reservoir prediction methods to characterize the vertical and horizontal extension of Changxing Formation reservoir, which provides favorable drilling suggestions for gas reservoir development [5] [6] [7] [8] [9] [10].

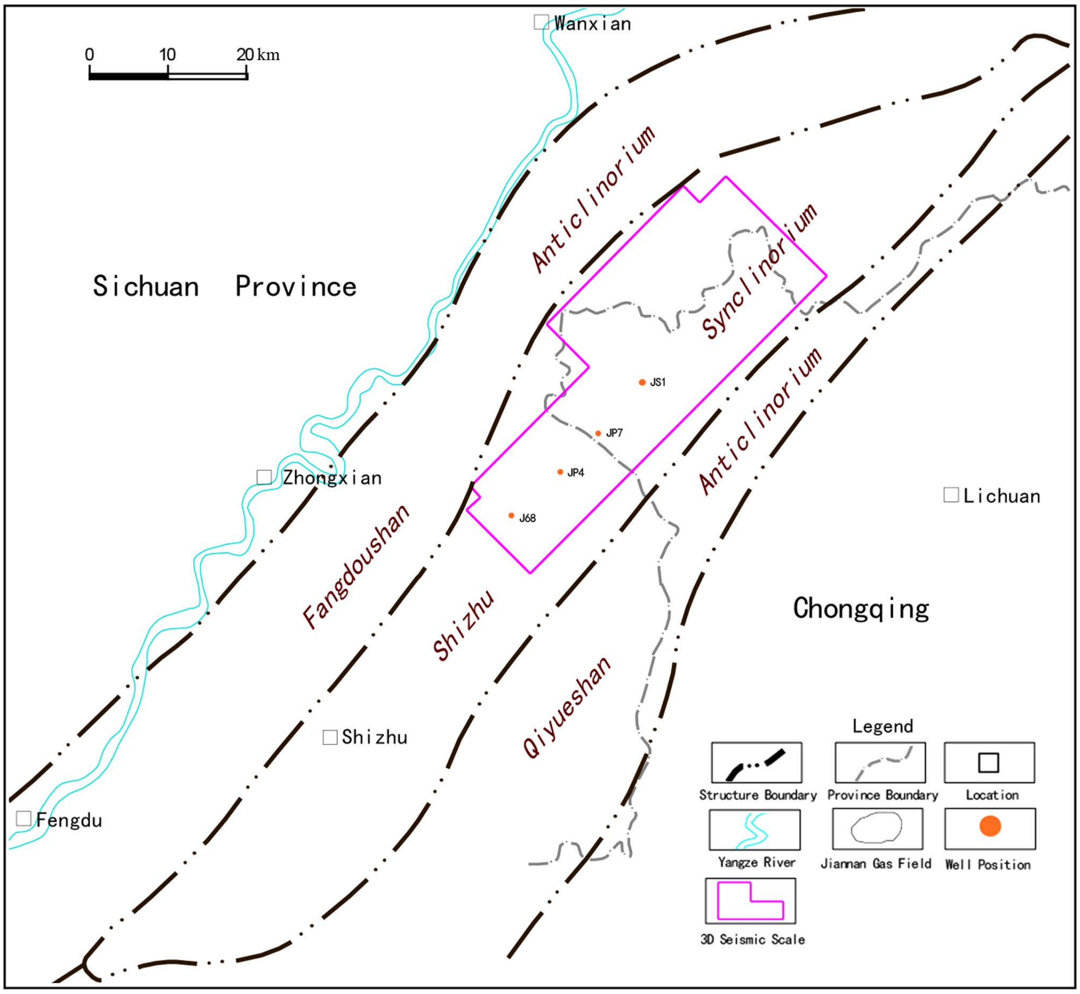


Figure 1. Regional structural map of Jiannan area.

2. Formation Characteristics

Changxing Formation of Jiannan area is predominantly composed of carbonate platform deposits, with a thickness of 260 ~ 320 m, which is divided into two members [3]. Chang 1 Member was deposited in the transitional environment of continental shelf-slope and platform margin, leading to obvious distinction in lithology. The lower part was developed into medium-thin-layered grey, dark grey biomicrite, grey, dark grey siliceous argillaceous limestone containing chert nodule with low biodetritus content, mainly sponge spicules. The upper part was developed in organic reef and shoal environment, which is the elementary productive layer of this area. The lithology is grey bioclast limestone and dolomite in majority and grey, dark grey limestone, limestone with siliceous agglomerate and limestone with biodetritus. The biodetritus content increases, while chert content decreases from bottom to top. Chang 2 Member is mainly composed of dark grey, grey bioclast limestone, interlayering with several thin-layered dark clay and calcareous clay.

3. Sequence Stratigraphy Classification

According to drilling, well-log and seismic data analysis, combined with sequence boundary composition, identification symbols and genetic mechanism, the sequence stratigraphy classification was done in a single well and cross-well section at first [11] [12] (**Figure 2**, **Figure 3**). After well-seismic calibration, the sequence boundaries were interpreted continuously on seismic sections (**Figure 4**). Consequently, the sequence stratigraphic framework of the study area was established through horizontal sequence stratigraphy classification [13] [14]. In this research, Changxing Formation is divided into two III order sequences, SQ1 and SQ2. SQ1 is consisted of Chang 1 Member. SQ2 is consisted of Chang 2 Member. Furthermore, four IV order sequences are identified. Among them, SSQ1 and SSQ2 correspond to SQ1, while SSQ3 and SSQ4 correspond to SQ2.

SSQ1: Transgressional system tract (TST) developed micrite, siliceous limestone and siliceous shale, with a small amount of biodebritus, which were deposited in slope and shallow continental shelf facies. This set of strata is thick and stable in the study area. It followed the transgression of Wujiaping Formation, reached the maximum flooding surface, and deposited a set of siliceous marlstone (1 ~ 2 m), GR and the electrical resistivity of which are in peak form, making it an excellent correlation marker layer in this area. Highstand system tract (HST) has few changes in GR. Biodetritus and dolomite content increased while the mud content decreased. Sedimentary facies were mainly platform margin reef flat facies [9], followed by open platform and slope-shallow continental shelf facies. SSQ1 is a set of high-amplitude seismic reflection. The bottom boundary is a trough reflection formed by the base of Chang 1 Member and the top of Wujiaping Formation (**Figure 5**).

SSQ2: Transgressional system tract (TST) is transient, during which the sedimentary thickness is generally less than 10 m, so the deposit environment is quite stable. HST is the period when reef and shoal developed in Changxing Period and the sedimentary environment is in succession with the HST in SSQ1. SSQ2 is a set of medium-weak-amplitude, lower half wave crest on seismic sections. The top sequence boundary is the wave crest between the bottom of Chang 2 Member and the top of Chang 1 Member, and the bottom boundary is the wave trough at the top of Chang 1 Member (**Figure 5**).

SSQ3: Lithology of TST is dark grey limestone with low content of biodebritus and little dolomite, which was deposited in the open platform sedimentary environment. HST has lower GR while biodebritus and dolomite content rises, but it is also open platform sedimentary facies. SSQ3 is a set of medium-weak-amplitude, upper half wave crest on seismic sections. The top sequence boundary is the wave trough at the top of Chang 2 Member (**Figure 5**).

SSQ4: It is a relatively shallow water open platform, when bioclastic shoal is

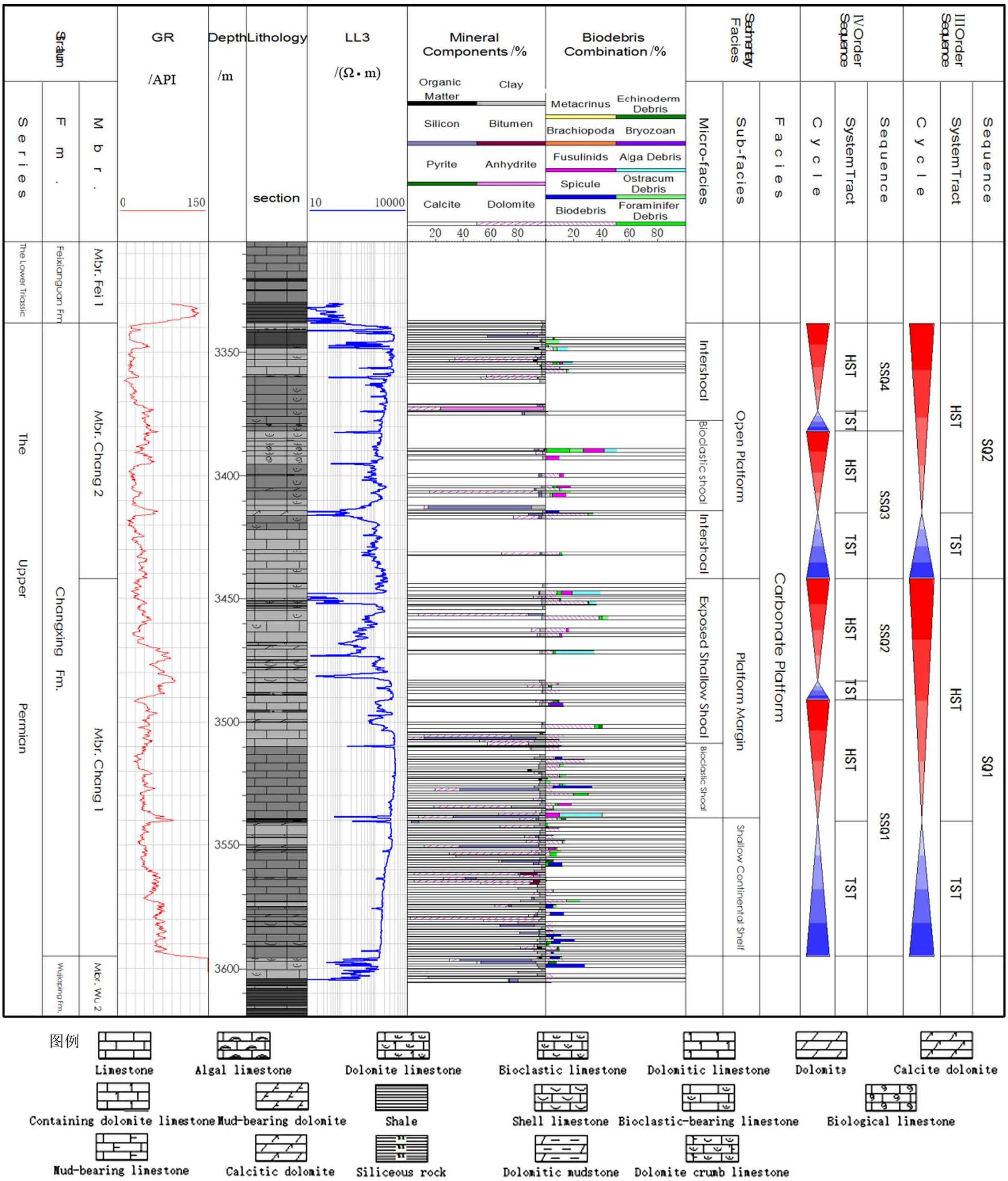


Figure 2. Sequence and sedimentary facies classification map of Changxing Formation, Upper Permian in Well J43.

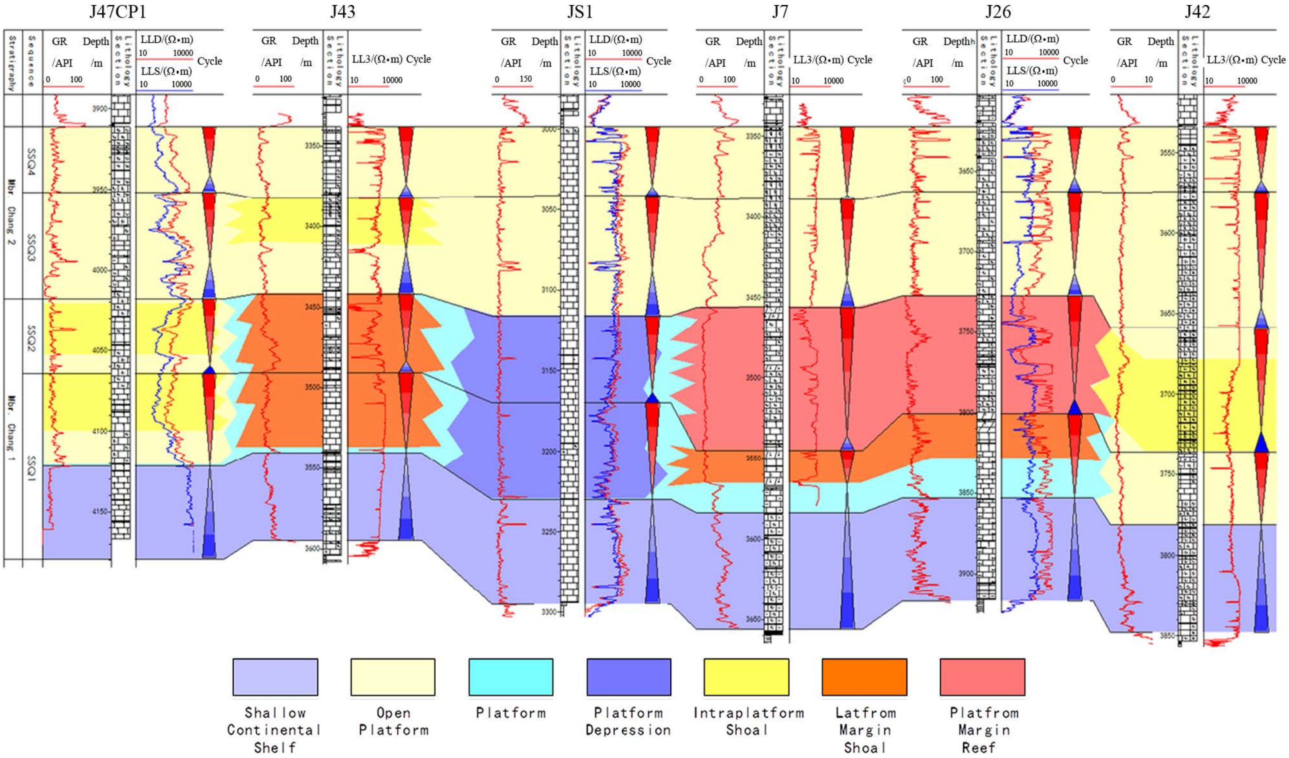


Figure 3. Sequence and sedimentary facies correlation cross-well section of Changxing Formation, Upper Permian in Jiannan area.

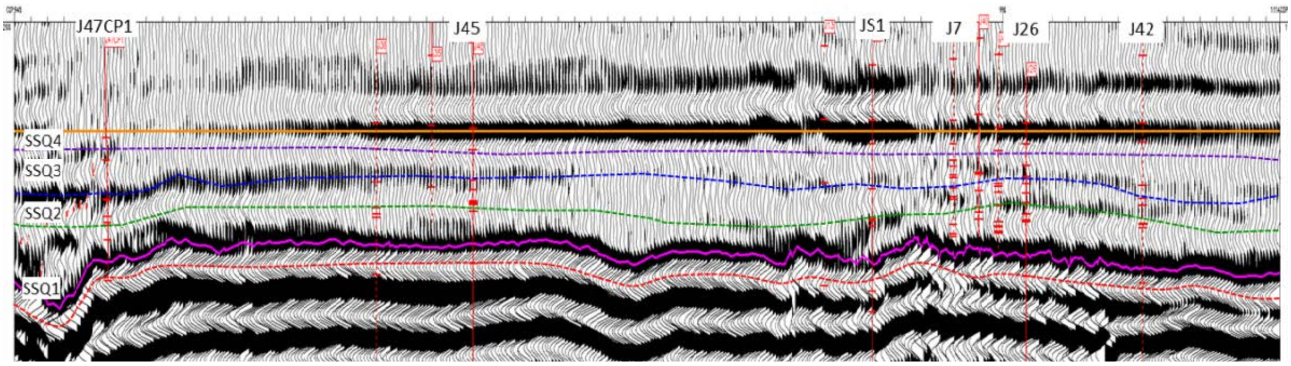


Figure 4. Seismic section from J47CP1 to J42 of sequence classification in Jiannan area.

rarely developed. SSQ4 is a set of high-amplitude seismic reflection. And the top boundary is wave crest formed by the bottom of Fei 1 Member and the top of Chang 1 Member (Figure 5).

4. Seismic Reservoir Prediction Restricted by Sequence Stratigraphy

4.1. Reservoir Elaborate Calibration

On the basis of sequence stratigraphy classification, the reservoir was elaborately calibrated and its seismic responding features were determined to provide the gist for reservoir prediction [15].

On the synthetic seismic record of Well J45 (Figure 5), the whole Changxing Formation corresponds to three seismic events. Phase 1 (TT_1f^1) represents the top of Changxing Formation, which is a strong peak reflection boundary formed with low-velocity shale at the bottom of Fei 1 Member and high-velocity limestone on the top of Chang 2 Member. Phase 2 (TP_2ch^2) represents the bottom of Chang 2 Member, which is the reflection boundary, parting relatively low-velocity bioclastic shoal reservoir and high-velocity wall rock. Phase 3 (TP_2ch^1) is another strong peak reflection boundary between low-velocity slit limestone at the bottom of Chang 1Member and underlying high-velocity limestone. Reservoir calibration reveals that bioclastic shoal reservoir mainly develops in the mid-upper parts of Chang 1 Member, between SSQ1-HST and SSQ2, which is the lower half crest of Phase 2 and the underlying trough.

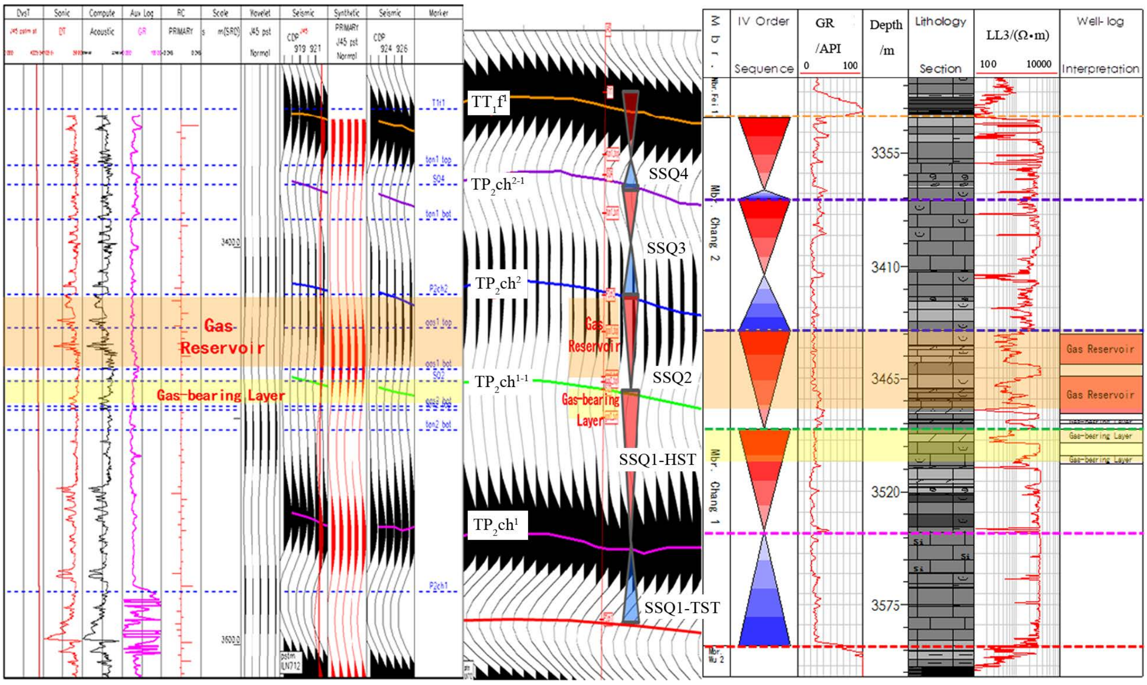


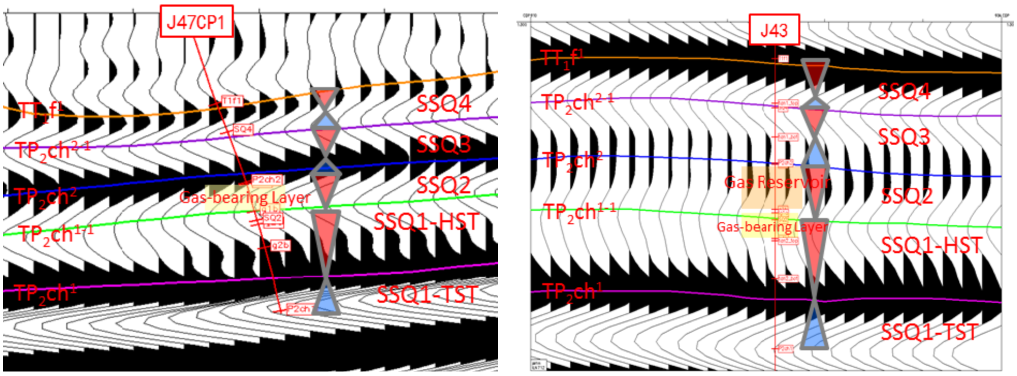
Figure 5. Synthetic seismic record of Changxing Formation in Well J45.

4.2. Reservoir Seismic Responding Features

According to well-log statistics, the bioclastic shoal reservoir of Changxing Formation is characterized by low-velocity (5500 ~ 6350 m/s), low-density (2.6 ~ 2.75 g/cm^3) and low-natural gamma value (0 ~ 40 API). Since different sedimentary environments present different seismic responding features, several wells are chosen to calibrate reservoir. From the results, intraplatform shoal reservoir represented by Well J47CP1 shows medium-high amplitude and continuous parallel reflection (**Figure 6(a)**). However, platform margin shoal reservoir represented by Well J43 shows medium-weak amplitude, complex wave and hypocontinuous parallel reflection (**Figure 6(b)**).

4.3. Attributes Analyses

According to sequence stratigraphy classification and reservoir calibration results of Changxing Formation, most of the bioclastic shoal reservoir distributes in



(a) (b)

Figure 6. Seismic responding features of Bioclastic shoal in Changxing Formation, Jiannan area (Well J47CP1 and Well J43).

SSQ1-HST and SSQ2, therefore, this research conducted seismic attributes analyses on bioclastic shoal reservoir of different sequences in Changxing Formation, Jiannan area to predict reservoir horizontal variations.

Four sensitive attributes were chosen to process exquisite reservoir description. On the seismic attribute map of SSQ1-HST (**Figure 7**), the Yellow-Red zone

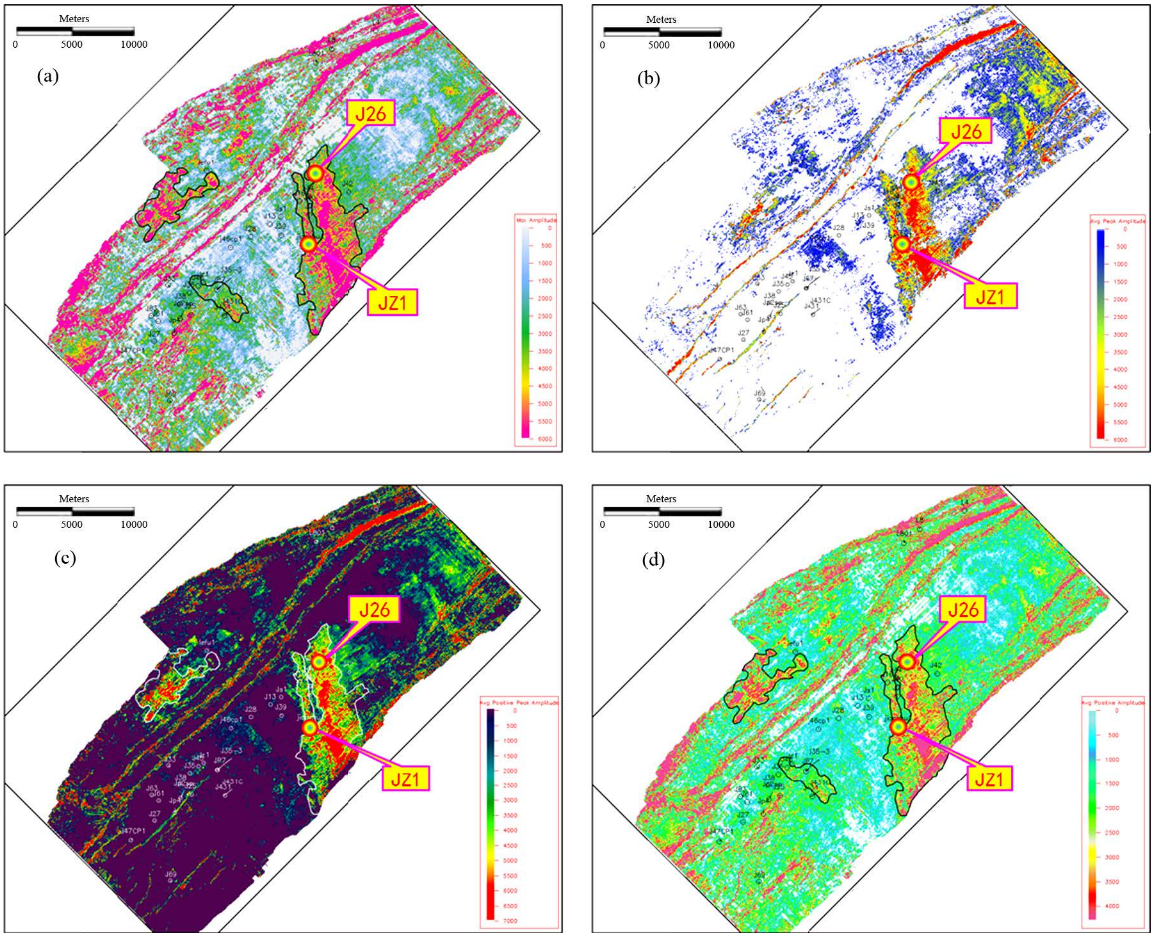


Figure 7. Seismic attribute map of SSQ1-HST, Changxing Formation, Jiannan area. ((a) Maximum amplitude; (b) Average peak amplitude; (c) Average peak value; (d) Average positive amplitude).

represents early platform margin shoal reservoir distribution in the north high point of Jiannan area, namely Zone J26-JZ1. Blue-Green zone represents the shallow water shelf facies with no bioclastic shoal reservoir. On the seismic attribute map of SSQ2 (**Figure 8**), the Yellow and Red zone of low amplitude represents middle stage platform margin shoal reservoir distribution in the south high point of Jiannan area, namely Zone J43-J431 and north high point, which locates in the west of Well L8 and Zone J26-JZ1. Red zone of high amplitude represents the distribution of intraplatform shoal, in the south of Jiannan area, mainly Zone J47CP1-J61, Nangaotai and Fenghuangsi direction to the southwest of Taipingzhen Fault. Blue-Green zone represents the shallow water shelf facies with no bioclastic shoal reservoir.

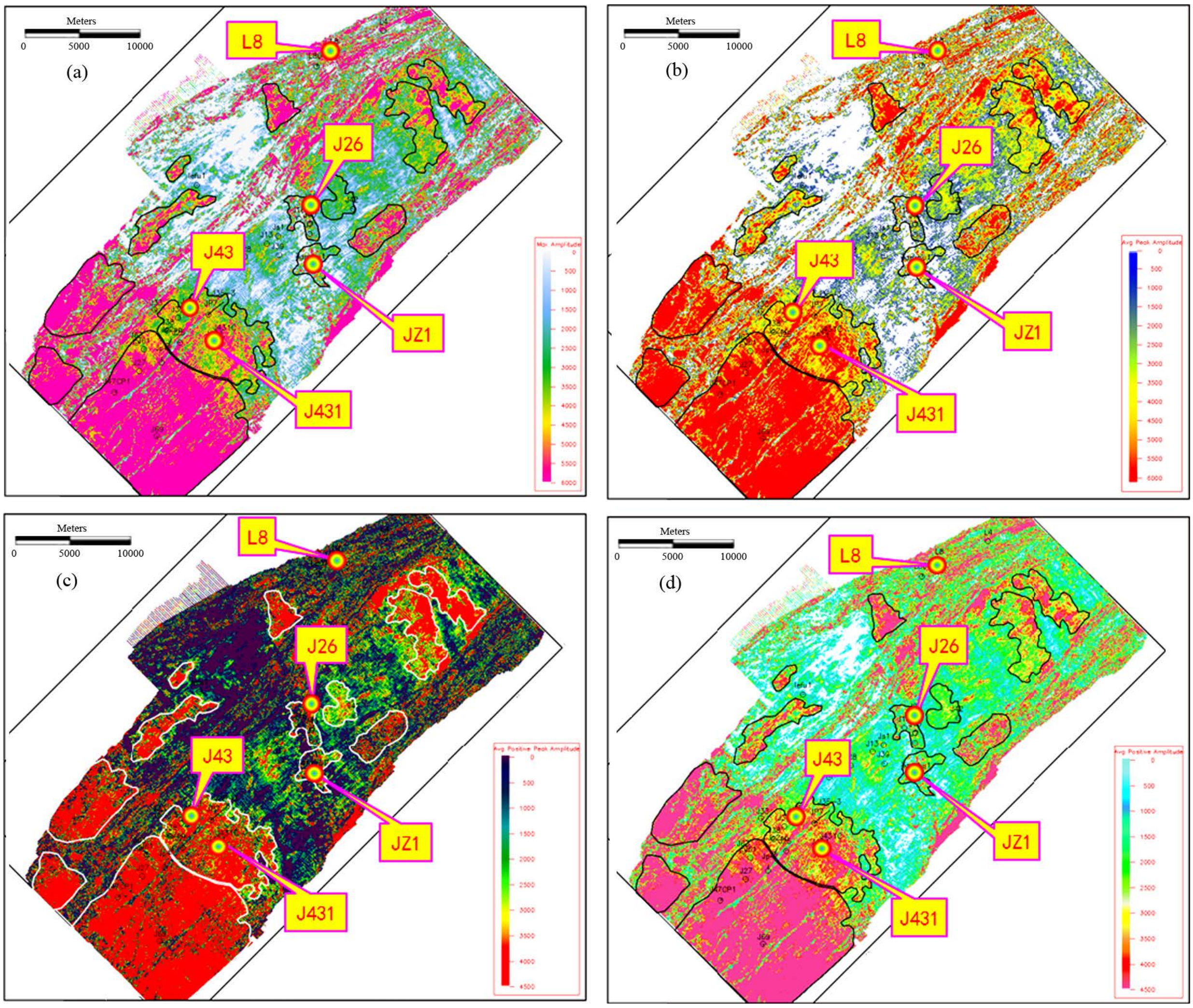


Figure 8. Seismic attribute map of SSQ2, Changxing Formation, Jiannan area. ((a) Maximum amplitude; (b) Average peak amplitude; (c) Average peak value; (d) Average positive amplitude).

4.4. Quantitative Prediction

Seismic wave impedance inversion is one of the most effective methods for reservoir prediction. Furthermore, wave impedance is highly corresponding with gas reservoir [16]. Post-stack restricted sparse pulse inversion was applied to realize quantitative reservoir prediction in the study area. Because the develop location and lithology of bioclastic shoal reservoir are different, different time windows and wave impedance thresholds were chosen accordingly to calculate reservoir thickness of different sequences.

SSQ1 was mainly developed at the early stage of platform margin shoal, where dolomite is the predominant reservoir type, whose wave impedance is 16,50000 ~ 17,30000 g·(s·cm^2)$^{-1}$. A time window is kept open for 5 ms downward from TP_2ch^{1-1} that is SSQ1-HST, then it is filtered with the reservoir threshold in this scale, the acquired sample rate is multiplied by the reservoir velocity (6250 m/s) and the time grid of single travel time, and the predicted reservoir thickness is calculated. On the reservoir prediction thickness map (**Figure 9(a)**), the reservoir distributes around the north high point, Zone J7-JZ1, with a thickness of 5 ~ 20 m, and the south high point, Zone JP7, with a thickness of 5 ~ 15 m.

SSQ2 developed middle stage platform margin shoal and intraplatform shoal, where lime-bearing dolomite and dolomitic limestone are the main reservoir rock types, whose wave impedance is 15,50000 ~ 16,25000 g·(s·cm^2)$^{-1}$. Open a time window from the top to the base of SSQ2, then filter seismic wave with that reservoir threshold, multiply the acquired sample rate by the reservoir velocity (6000 m/s) and the time grid of single travel time, and the predicted reservoir thickness is calculated. On the reservoir prediction thickness map (**Figure 9(b)**), the reservoir distributes around both the north and south high points, with a thickness of 10 ~ 30 m in the south, and 12.5 ~ 35 m in the north. Meanwhile, the principal part of shoal extended along both sides of the continental shelf.

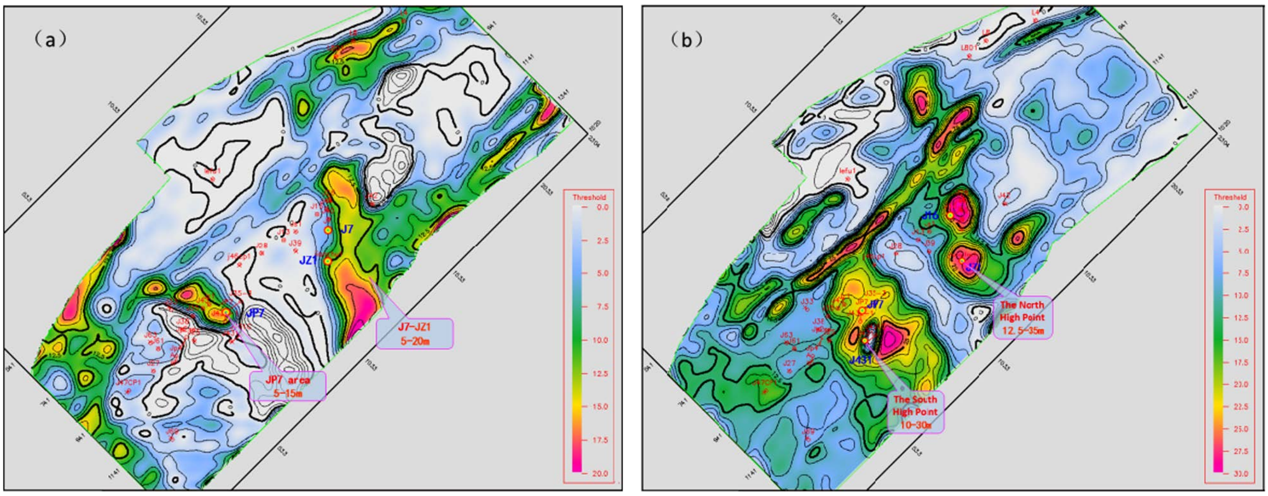


Figure 9. The reservoir thickness prediction map of Changxing Formation in Jiannan area. ((a) SSQ1 reservoir thickness,(b) SSQ2 reservoir thickness).

4.5. Prediction Result Analyses

When the results of qualitative attribute prediction are compared with quantitative wave impedance prediction, early stage platform margin shoal in SSQ1 distributes around the north high point, Zone J7-JZ1, however, the south high point has shown no reservoir on attribute analyses maps. The prediction results of middle stage platform margin shoal in SSQ2 are in accordance with each other, but the intraplatform shoal has no response in quantitative prediction. When the inversion predicted reservoir thickness is compared with actual drilled well-log interpretation thickness, the error is relatively small (Table 1), which means the inversion prediction method is effective for quantitative reservoir calculation.

Table 1. Comparison of predicted reservoir thickness and drilled thickness.

Sequence	Well	Well-log interpretation thickness/m	Inversion predicted thickness/m	Thickness error/m
SSQ1	JP7	18.6	15.0	−3.6
	J7	4.0	5.0	1.0
	JZ1	16.8	12.5	−4.3
SSQ2	J43	33.0	25.0	−8.0
	JP7	19.4	21.0	1.6
	J431	8.4	7.0	−1.4
	J16	29.4	27.5	−1.9

5. Conclusion

This article conducted an exquisite sequence stratigraphic classification and established isochronal regional stratigraphic framework. Changxing Formation was divided into four IV order sequences from well-seismic interpretation, which identified the bioclastic shoal reservoirs in this Formation. Under the restriction of stratigraphic framework, the seismic responding features of intraplatform shoal and platform margin shoal were concluded by exquisite reservoir calibration. Intraplatform shoal reservoir shows medium-high amplitude and continuous parallel reflection, while platform margin shoal reservoir shows medium-weak amplitude, complex wave and hypo continuous parallel reflection. On this basis, attribute analyses and wave impedance inversion were applied to realize the reservoir prediction. The results indicate that the favorable reservoir vertically distributes in SSQ2 and horizontally distributes around Well J43 and Well JZ1, which used to be the platform margin. This application of seismic reservoir prediction method restricted by sequence stratigraphy is proved to be effective in bioclastic shoal reservoir prediction of Changxing Formation in Jiannan area and provides useful information for future deployment of the development wells.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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