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Original research paper

Comprehensive insight of the Cambrian carbonate platform types as well as margin segmentation characteristics' exploration in Tarim Basin, China☆

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Abstract

The carbonate platform types and features of the platform margin belt plays an important role in controlling the reservoir formation; it also affects the relationship between reservoirs and caps. The Cambrian carbonate platform in the Tarim Basin underwent three evolutionary processes, namely, the Early Cambrian ramp platform, the Middle Cambrian edging evaporative platform, and the Late Cambrian edging platform; the northern platform margin was the deposition type, whereas the eastern platform margin was for fault control, additionally, the Lungu-Gucheng had evident sectional differences. The line from Wushi-Kashi-Maigaiti-Hetian to Minfeng of the southwestern Tarim Basin was an ancient land in the Early Cambrian. Through evolution, the sea level raised the underwater lows in the Middle and Late Cambrian period that possibly developed it to platform edge deposits in the Late Cambrian. The carbonate platform margin of both steep slope and gentle slope formed different reservoir-seal assemblages. The Upper Cambrian aggradation-progradation platform margin reservoir in the steep slope of the eastern Lungu and Gucheng area was developed with good connectivity, its caprock had been always the key of the platform margin reservoir-seal assemblages. Therefore, the reef-beach located behind the platform margin belt near the seaside of the lagoon had favorable reservoirs; the reservoirs often overlaid carbonate caprock which formed good reservoir-seal assemblages. The platform margin belt in the gentle slope in the Well Yingmai 7-Well Yingmai 8, in west Tabei, was a dolomite reservoir for algal mound and reef-bank complex with caprock of middle-lower Cambrian dolomicrite, gypsum dolomite, and mud dolomite. Aforementioned dense layers' reservoir-seal assemblage was superior to that of the eastern Lungu and Gucheng that had better exploration prospects.

Keywords: Platform types; Platform margin belt; Sectional differences; Tarim Basin; Cambrian; Exploration enlightenment

1. Introduction

Several studies and exploration of carbonate rocks proved that carbonate platform types and its stacked relationships play an important role in the reservoir formation as well as configuration between reservoir and capping [1−6]. Carbonate platform was divided into five general genetic types, namely, the ramp, rimmed shelf, epeiric platform, isolated platform,

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and drowned platform [7]. A handful of research work on Tarim Basin's Cambrian lithofacies paleogeography was accomplished. While there were already few wells drilled in the Cambrian, fewer wells were drilled throughout the study in the Cambrian (39 wells were already drilled, and nine more wells were drilled throughout the study). This study primarily focused on analyzing the basin margin of the Cambrian outcrops and single well sedimentary facies. There were few achievements in the overall research of the Cambrian, but the type of Cambrian platform was controversial [4,8,9]. It lacked systematic study on characterization of the platform margin and the inner platform differentiation. The depth of the Carbonate oil and gas exploration in the Tarim Basin went deeper, especially in the Cambrian, which leads to an urgent and more sophisticated study on lithofacies paleogeography. The full use of the limited drilling data combined with outcrop data and a large number of seismic facies analysis the Tarim Basin Cambrian platform type and its platform margin segment difference feature that impacts reservoirs as well as exploration effects will be discussed in this paper.

2. Tectonic setting

The paleogeography-tectonic setting directly controlled the carbonate sedimentary record, that is to say, “structure control basins that control facies”. The thorough understanding of palaeotectonics became significant to the study of the Paleogeography. The Tarim Basin was formed in different plate tectonic movements and has gone through long-term development from Sinian to Neozoic. The superimposed basin was found by the superimposition of various types of large-scale prototype basins [10−15]. It was surrounded by small ocean basin on all sides from the early Paleozoic to the early Late Paleozoic; the Tianshan ocean was on its north side, Kunlun ocean was on its southwest, Altyn ocean was on its south side, and Kuluketage sea was on its east side. Paleogeographic evolution patterns showed that the basin experienced a complete transformation from mountain to the basin: clastic continental shelf in the early Sinian → carbonate ramp and shelf in the Late Sinian to Early Cambrian → latitudinally-trending carbonate platform ramp-deep water basin system in the middle Cambrian to the middle Ordovician → aborted foreland basin in the Late Ordovician to Middle Devonian. The basin was divided into two distinct development stages by tectonic-sedimentary conversion interface mark in the late Middle Ordovician [14,15]. Similar to the rifting stage, development of the cratonic basin, basin cracking, expansion, sea level rise, and carbonate platform accretion became the main characteristics of the Sinian-Early Ordovician and it also became the rising cycle of the first order of the eustatic sea level cycle change. On the compression stage of the basin uplift, the sea level dropped and numerous clastic material filling became the main characteristic of the late Ordovician-Middle Devonian. Likewise the compression stage of the craton basin development, the strata of the eustatic sea level change cycle declined.

3. Platform types and features of platform margin sectional differences

3.1. Types of platform

A much recent series of the Cambrian lithofacies paleogeography mapping used the comprehensive mapping method in analyzing multifactor singly. The difference from the past was that, using the logging lithology analysis, based on the rock composition and structure as well as the seismic facies analysis based on seismic parameters and waveform clustering, optimized techniques for sedimentary facies' analysis. Thus, this added new well data for Zhongshen 1, Zhongshen 5, Chengtan 1, and Gucheng 8 to further quantize the single factor maps through logging superiority, seismic facies, strata thickness figure, and more. This could aid to keep the lithofacies paleogeographic maps updated. As for the wells, this may possibly support in characterizing the difference between the gypsic saline lake and bank body within the platform. According to recent updates of the new series of lithofacies paleogeography mapping, the Cambrian carbonate platform in the Tarim Basin underwent the evolution process starting from the Early Cambrian ramp-type platform up to the Cambrian rim-type evaporation platform and finally the Late Cambrian rim-type platform where the northern edge of the platform was the sedimentary margin and the eastern platform margin was the fault-controlling platform margin. This provided significant evidence regarding the differences in the Lungu-Gucheng segmentation (Fig. 1).

During the Cambrian period, the body of the eastern platform margin was located within the line of Well Tashen 1-Well Tazhong 32-Well Gucheng 4 that extended to the southwest nearby Well Gucheng 4. The migration distance was approximately within the range 5−20 km, which showed fracture-controlling platform margin features. The southern edge of the southwest Tarim Basin can't be speculated due to the data provided. A new insight in the Kashi-Pishan-Hetian-Minfeng platform margin line was discovered, according to the seismic facies analysis and stratigraphic thickness maps. The band in the Early Cambrian period was an ancient land that had a “zero value zone” in terms of stratigraphic thickness. Not to mention the wedge onlaps feature showed underwater low swell during the Late Cambrian that developed into a platform margin during the last stage of the Late Cambrian. The northern platform margin was mainly developed within the line of the Sugaitebulake outcrop, specifically within the Aksu region-Well Yingmai 36-Well Yaha 10. The gentle slope type and large beach platform margin's small reef during the Early Cambrian were fully proved due to seism and drilling. However, the platform margin in the middle and upper Cambrian was not evident during the seism of the work area; speculations suggested that it developed outside the seismic area, if ever it existed, and that the migration distance was over 30 km which was consistent with the feature that the buildups of the sedimentary gentle slope platform margin migrated to particular distances.

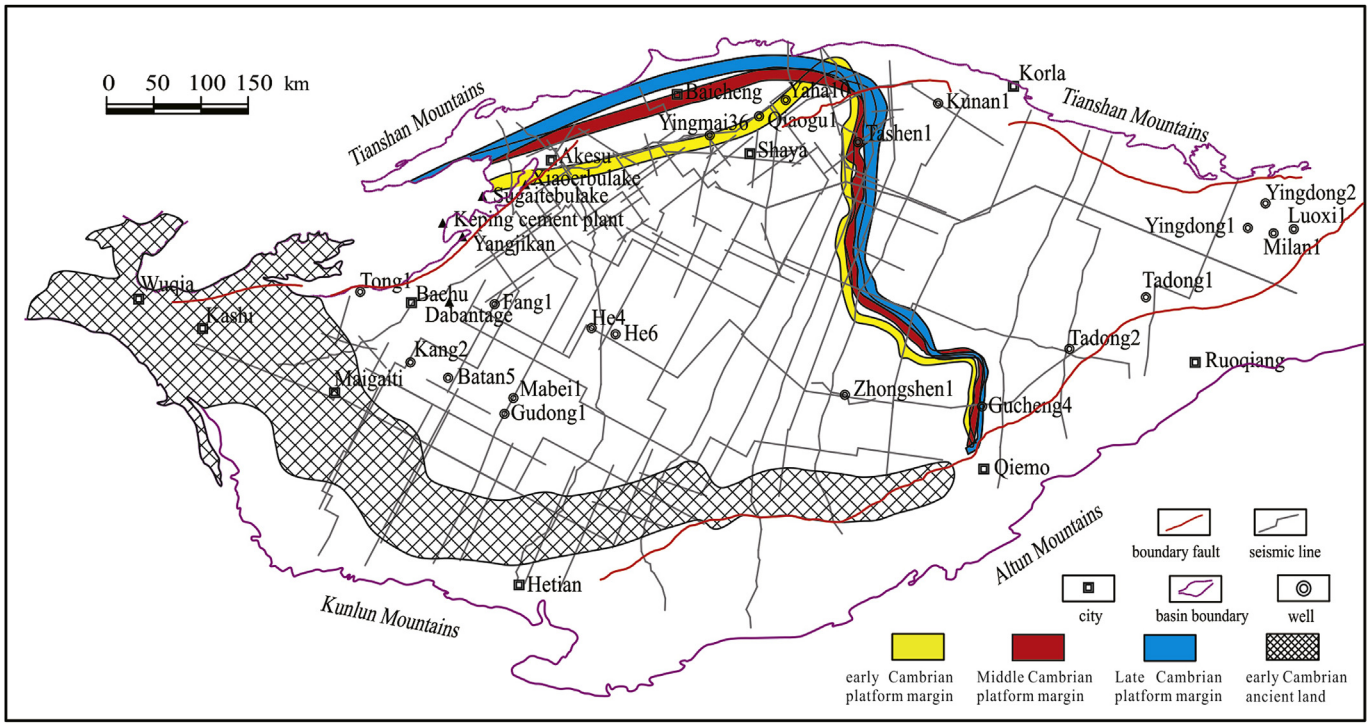

Fig. 1. Transition of the Cambrian platform margin belt in Tarim Basin.

3.2. Platform segment differentiation feature

The description of the Cambrian platform margin segmentation in this paper was based on seismic facies analysis techniques in combination with seismic parameters and waveform clustering that took full advantage of a large number of 2D and 3D seismic data. Succeeding parts took the northern platform margin during the Early Cambrian as the typical example, the exquisite description of the platform margin and other platform margin segments, features as well as vertical stacked relationship will be elaborated.

3.2.1. Northern platform margin belt

The northern platform margin in the Early Cambrian was mainly developed in the Sugaitebulake outcrop line in Aksu region-Well Yingmai 36-Well Guqiao 1. This platform margin was confirmed for the first time and the discovery process had two stages. Initially, the location of the platform margin belt was preliminarily determined through three geological data point. The Xiaoerbulake Formation of the Sugaitebulake outcrop was a typical platform margin brought about reef microorganisms' flat deposits [16,17] (Fig. 2(a)−(d)), Well Xinghuo 1 of SINOPEC were slope facies micritic limestone (Fig. 2(a), (e), (f)), and Well Yaha 5 was a foamy algae dolomite within the platform (Fig. 2(a), (g)). In the Wilson-phase mode, there must be a carbonate platform belt extending along the northeast Sugaitebulake outcrop through the space between Well Xinghuo 1 and Well Yaha 5. Therefore, 3-D seismic data were used in the Yudong-Yingmaili area to carry out seismic facies analysis, and to determine the specific location of the platform margin belt. The 3D seismic work area of Well Yingmai 7-Well Yingmai 8 area was taken as an example to explain the seismic description process of the reef beach platform margin. As proved by previous studies [2,15], the reef beach developed back-reef beach, reef beach main body, fore-reef beach, and slope sub-phase from intra-platform to the basin. Seen from the seismic reflection characteristics, the interior of the reef beach had a weak moundy reflection. Both the back-reef and fore-reef beach mainly consisted of a set of messy reflection features with some onlaps features, but the slope facies were a set of parallel intense reflection feature and the thickness became thinner towards the slope (Fig. 3). According to the seismic characterization of reef beach distribution, a single reef was 10−15 km wide, 32 km long, and the area was 61.7 km^2. The fore-reef and back-reef beach measured 10−15 km wide, 92 km long, and the area was 318 km^2; the thickness of the reef beach body had a huge scale of about 10−100 m.

Consequently, the Early Cambrian northern platform margin belt became a part of the gentle-slope-platform margin type. The large beach developed a small reef, namely algal reefs (mound) and algae psammitic beach; fore-reef and back-reef beach developed as well. The platform margin band was about 7 km wide; it also extended large-scale (200 km). The middle and upper Cambrian platform margin belt was in the work area even though it was speculated to develop outside the earthquake work area; according to the feature, the buildup of the gentle slope platform margin migrates far away.

3.2.2. Lungu-Gucheng platform margin belt

The Lungu-Gucheng platform margin belt during the Cambrian period was divided into several sections, namely the

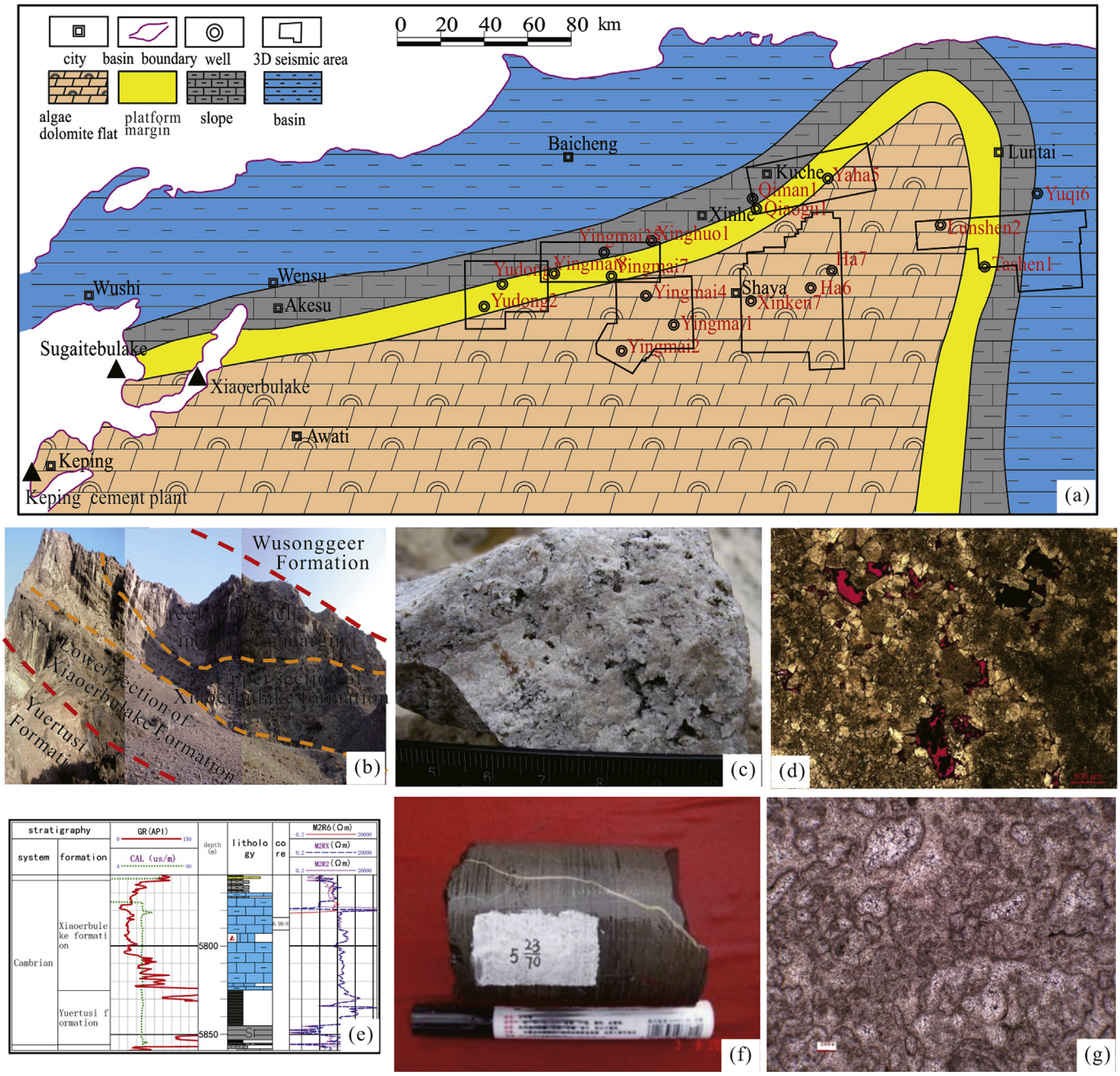

Fig. 2. Geological features of the Lower Cambrian platform margin belt in Tabei Area. (a) The lithofacies paleogeographic map of the Xiaoerbulake period in Early Cambrian in the Tabei area, (b) The macro profile of platform margin reef and beach in the Sugaitebulake outcrop, (c) Dolomite of the platform margin in the Sugaitebulake outcrop (porosity is 9.39%), (d) Algae doloarenite, algae bonding structure, intergranular pore, and intercrystal pore, (e) The integrated histogram of Well Xinghuo 1 slope facies, (f) Well Xinghuo 1, 5-23/70, argillaceous limestone of slope facies, (g) Well Yaha 5, 6393 m, spumescence algae dolomite in the platform.

eastern Lungu section, Yangwu section, Well Mancan 1 section, Well Tazhong 32 section, and the Gucheng section from north to south. Overall, the eastern Lungu section platform margin belt, possessing an aggradation-progradation feature, measured much larger. The eastern Lungu section platform margin belt was 7.2 km in the Early Cambrian that eventually became 22.6 km in the Late Cambrian. Presented as a narrow belt, the Gucheng platform margin measurement ranged from 3.2 km to 10 km, and it had a small reef within a large beach. The characteristics of each segment and the vertical stacked migration relationship was varied from north to south, these are demonstrated in the succeeding parts.

(1) Eastern segment of the Lungu platform margin belt

The Lungu region's eastern platform margin in the Early Cambrian presented as a weak embroider ramp type carbonate platform, the reef mounds were exposed in the water surface

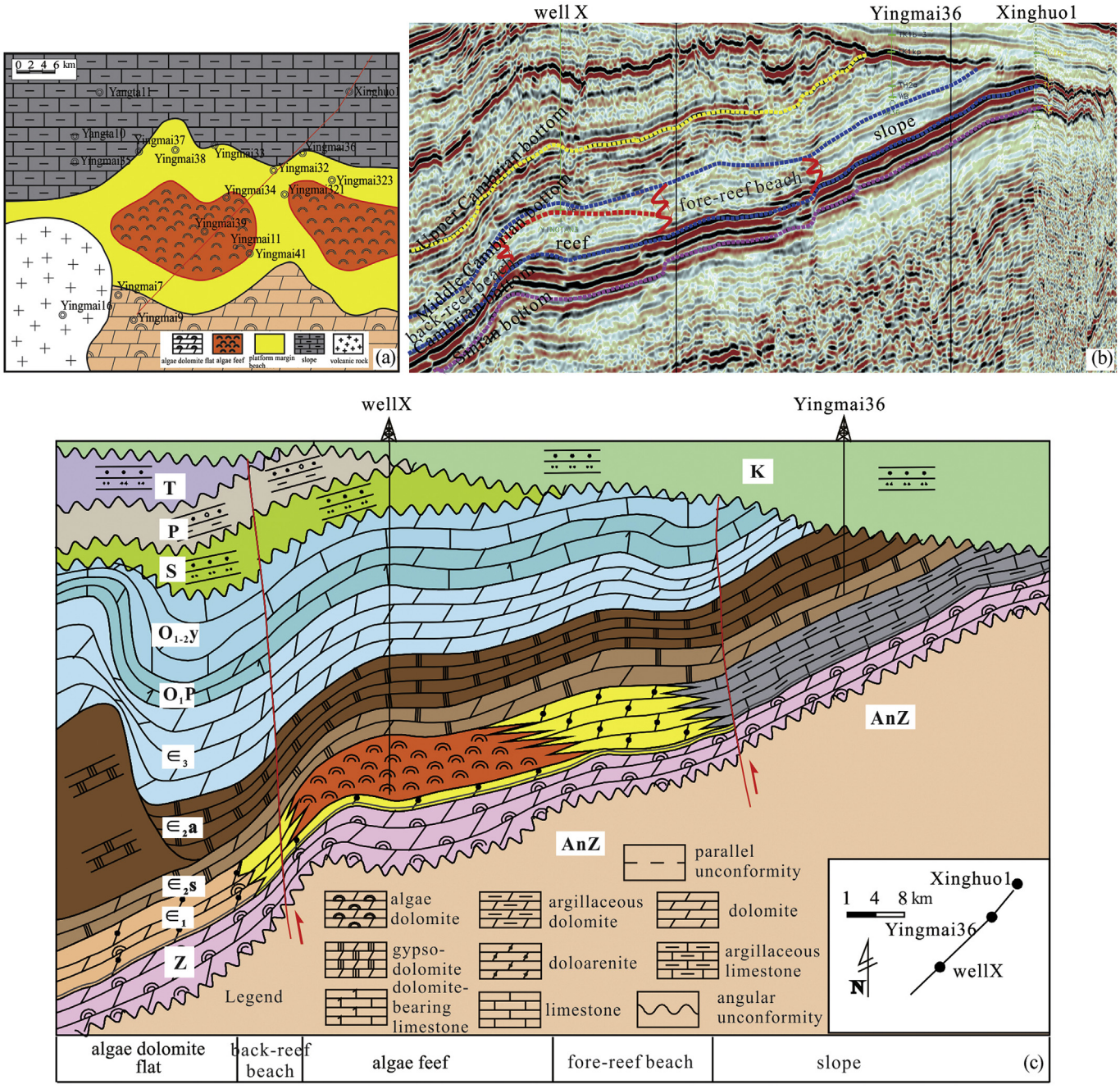

Fig. 3. Characteristics of reef-beach fine sculpting in Well Yingmai 7- Well Yingmai 8 area. (a) The Lower Cambrian sedimentary facies map of Well Yingmai 7- Well Yingmai 8 area, (b) Seismic reflection characteristics of reef in Well Yingmai 7- Well Yingmai 8 area, (c) Reef sedimentary geology structure section of Well Yingmai 7- Well Yingmai 8 area.

and had suffered erosion. The platform margin width was about 7.2 km, the width of the back-reef beach on the platform margin belt approximately measured 20 km. The decline in sea level caused the type of platform margin to change, in which a strong embroider reef mound platform edge developed in the middle Cambrian. However, the reef mound suffered strong erosion after it outcropped to the water surface. The strong embroider reef mound platform edge developed in all three stages of the Late Cambrian. Similarly, the reef mound suffered strong erosion after it outcropped to the water surface; the slope belt developed calcarenaceous turbidity formed by the carbonate from erosion truncation. As the mound beach body stacked in several stages, the platform margin became relatively wide (up to 22.6 km). Meanwhile, the back-reef beach was about 15 km. The change of platform and platform margin type controlled the distribution of the platform margin slope zone other than the development type and feature of the complex reef and beach [18]. Considering the influence of the mesa structure type, the Late Cambrian's complex reef and beach cross-sectional structure showed strong

aggradation-progradation type which was primarily affected by the platform structure (Fig. 4).

(2) Yangwu area segment platform margin belt

In the Yangwu area, weak reef mound platform margin developed in the Early Cambrian. The reef mound did not outcrop in the water, yet it suffered from erosion. It had a small width of seven km, on the other hand, the back-reef intra-platform beach's width was much higher around about 18–20 km; this was typical in small mound large beach margin. Stronger buildups started from the Middle Cambrian, embroider reef mound platform margin developed and the reef mound suffered from erosion after it outcropped from the water. Strong embroider reef mound platform margin developed in Late Cambrian, reef mounds exposed from the water and which suffered strong erosion as well. The three stages of reef mound were recognized, and the identified stacking width went up to more than 20 km (Fig. 5).

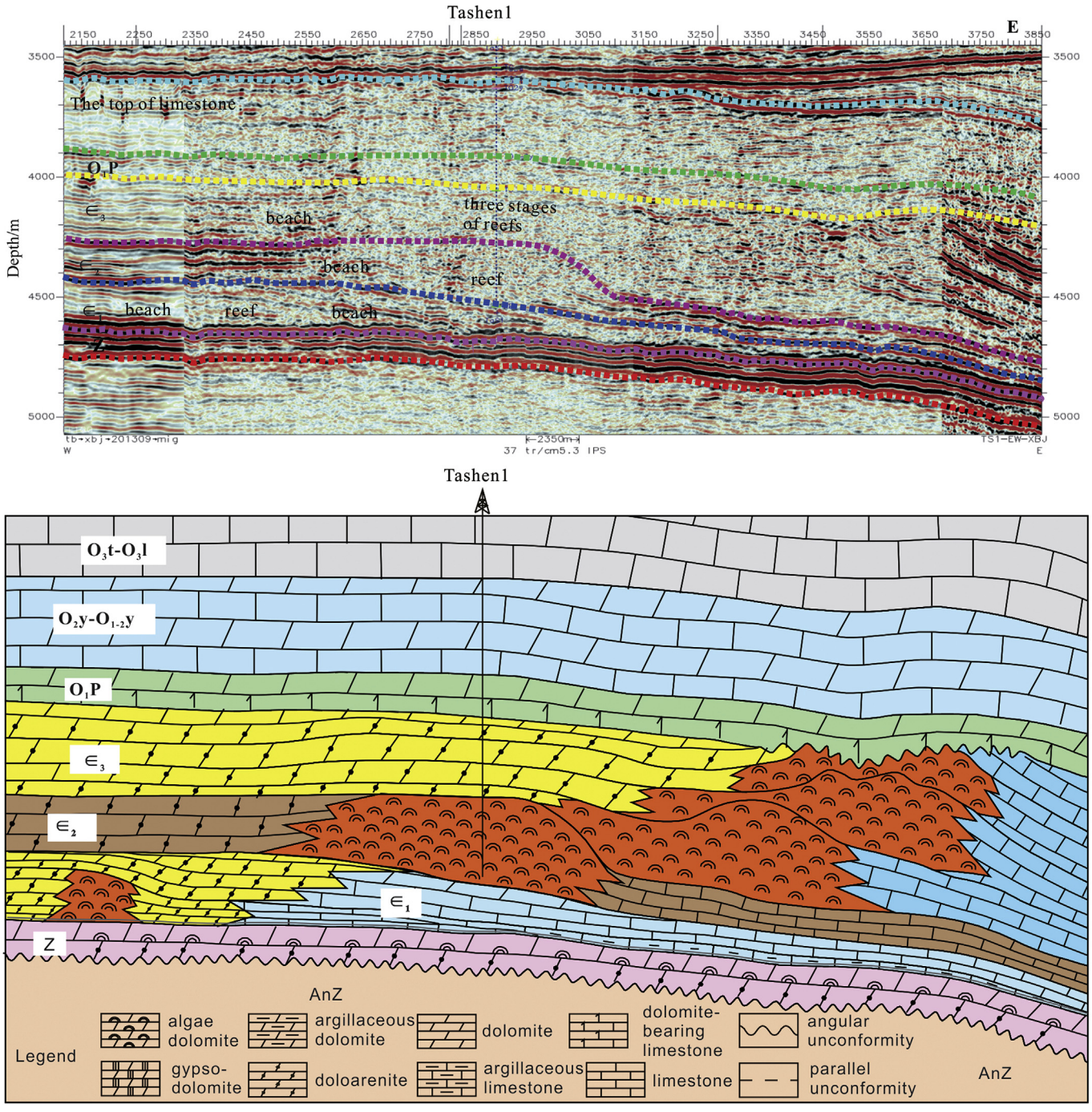

Fig. 4. Seismic and geological structure profile of the platform margin belt in the eastern section of Lungu.

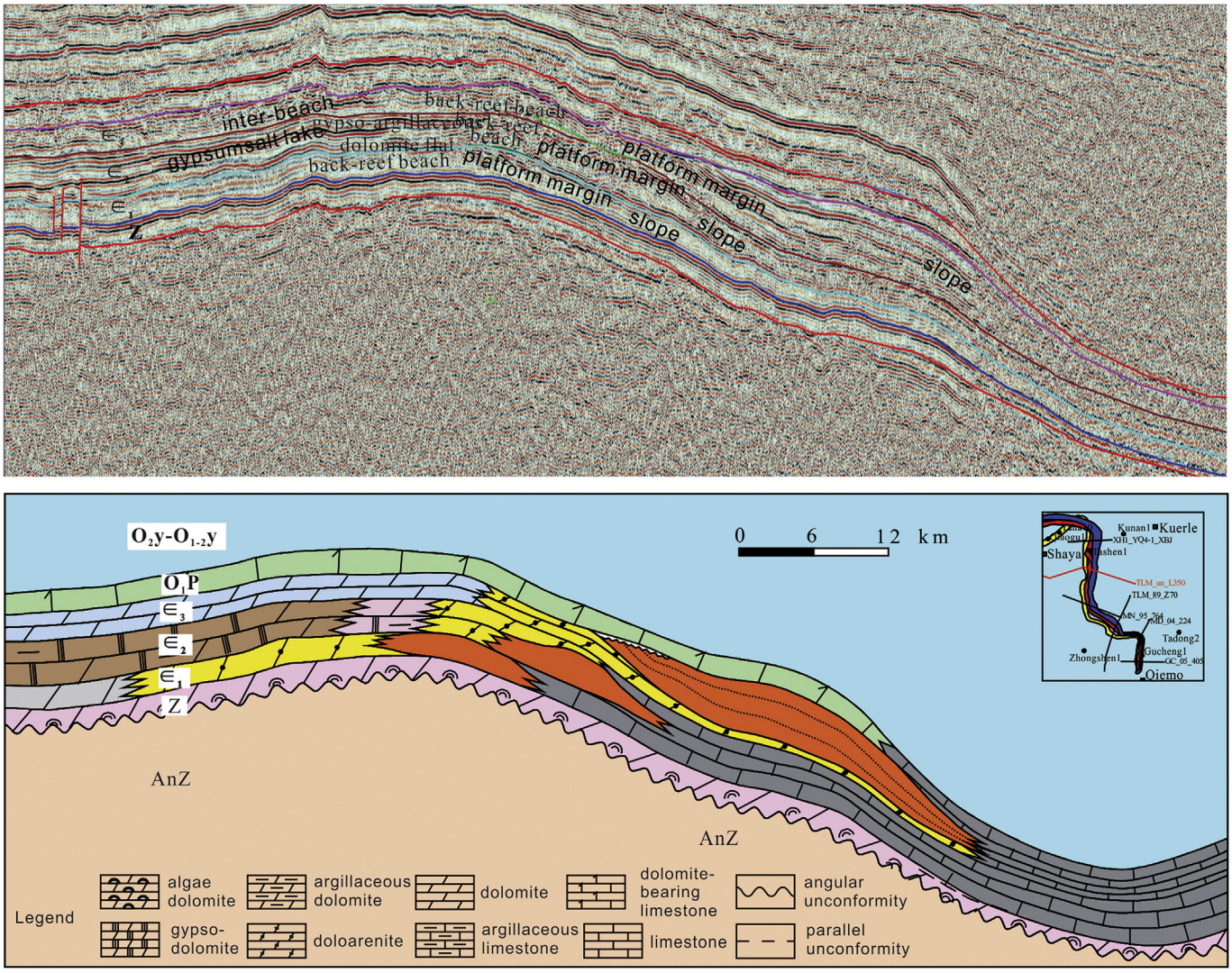

Fig. 5. Seismic and geological structure profile of the platform margin belt in the Yangwu section (red line represents the seismic line in the bottom figure).

(3) Well Mancan 1 segment platform margin belt

In the Well Mancan 1 area, no observable reef mound beach platform margin developed in the Early Cambrian. Buildups arose in the Middle Cambrian with the development of reef mound platform margin, and the reef mound was rarely exposed in the water, yet it suffered from erosion. Thus, the reef mound and back-reef beach width approximately became 30 km; it measured to be wider than other areas. Embroider reef mound platform margin developed in the Late Cambrian in which the reef mound suffered weak erosion after outcropping from the water. On the seismic section, the top truncation phenomenon was very significant, but the three stages of reef beach were not very clear. According to the developmental characteristics of the north-south upper Cambrian platform margin, the three stages of the reef mound body also developed (Fig. 6). Supportive to the features of longitudinal migration, both the Middle and the Upper Cambrian platform margin superposed while the lower Cambrian platform margin migrated further and the platform margin migrated towards the seaside of the boundary by 15 km.

(4) Well Tazhong 32 area platform margin belt

In the Well Tazhong 32 area, the beach facies platform margin developed in the Early Cambrian with no evident platform margin buildups; its back-reef sand beach width was approximately 15 km. The weak reef mound platform margin developed in the Middle Cambrian, but it wasn't the typical buildups, moreover, it was algae mound. The weak embroider reef mound platform margin developed in the Late Cambrian with unapparent three stages of buildups; the beach body's other segments did not have any platform margin developed (Fig. 7).

(5) Gucheng segment platform margin

In this paper, the existence of the Lower Cambrian strata (presently facing controversy) in the Gucheng area was

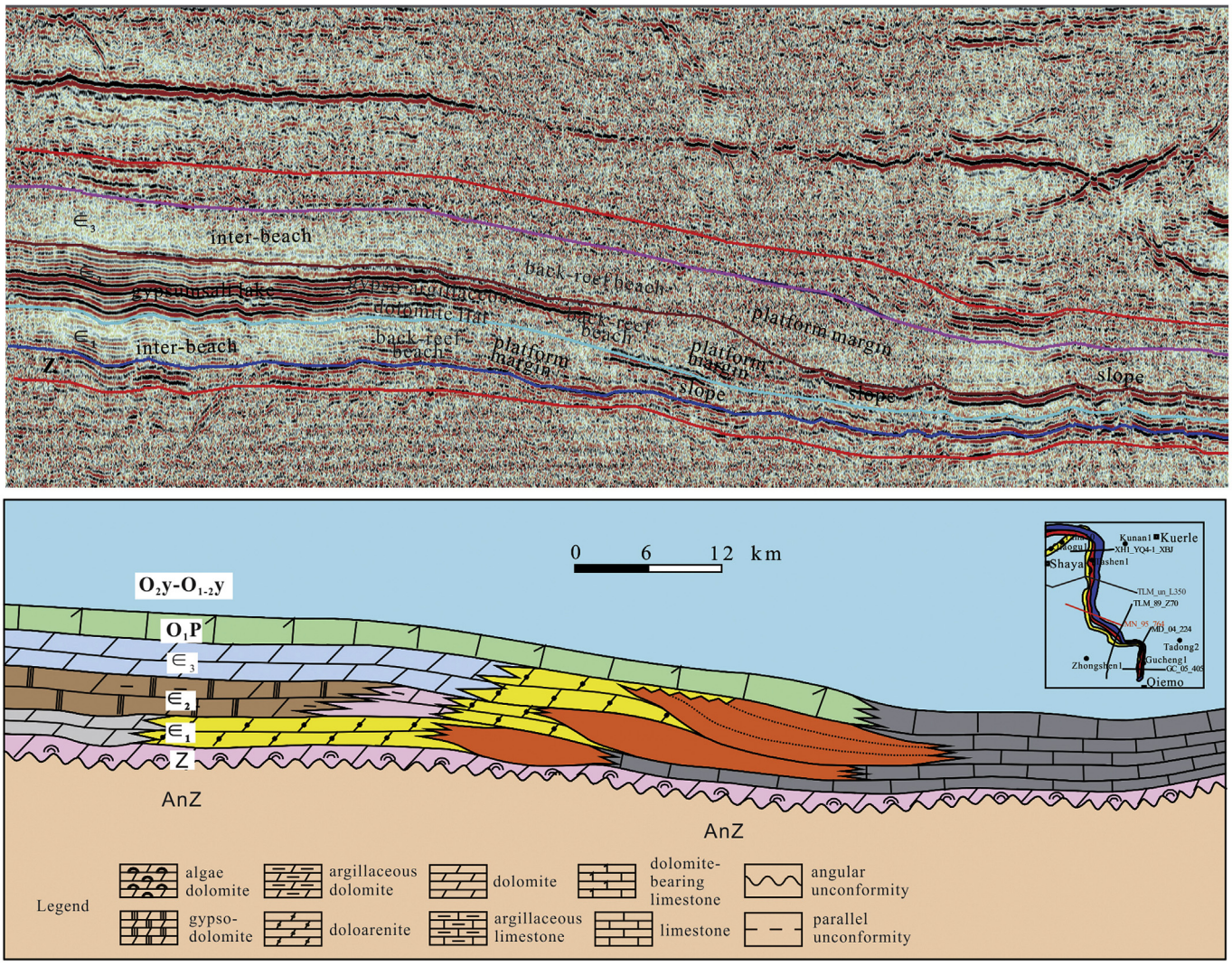

Fig. 6. Seismic and geological structure profile of the platform margin belt in Well Manshen 1 area (red line represents the seismic line in the bottom figure).

believed to be relatively thin and existing in the lower structure part. The Early Cambrian transitioned beach facie to ramp facies by means of unclear platform margin, but it had evident progradation on the slope. The Gypsum-salt lake and parts of the gypsodolomite flat sediment developed in the Gucheng area during the Middle Cambrian. Nonetheless, no apparent platform margin exists on the seismic profiles; it is speculated that the beach facies' sediment developed towards the sea in the Gucheng area. Aggradation-progradation type algal reef beach platform margin developed in the Late Cambrian in which four stages of the reef mound developed together with the imbricated distribution the progrades strongly moved to the seaside where the fourth stage suffered erosion after it outcropped from the water (Fig. 8). Thus, a set of carbonate gravity flow sediment developed in the Gucheng area during the Upper Cambrian. The 45 m thick, deep-water carbonate gravity flow sediment developed in the Upper Cambrian in the Well Gucheng 4, wherein the well logging interpretation showed the average porosity was within the range 2.1%–3.8%. The set of deep-water carbonate gravity flow deposited carbonate rocks that became the carbonate on the slope brought by strong truncation from the top strata of the Upper Cambrian.

3.2.3. Southwest Tarim apophysis area discourse

Several hypotheses analyzing the Cambrian sedimentary type in the southwest Tarim Basin area are enumerated as follows: (1) Feng Zengzhao et al. [4] claimed that the West Kunlun platform developed in the southwest Tarim Basin area during the Cambrian causing to develop two small lands; (2) Liu et al. [5] alleged that the Early Cambrian had a synsedimentary apophysis while the Late Cambrian developed a low apophysis underwater; (3) Zhao Zongju [9] supposed that the Kashi-Maigaiti-Yecheng-Hetian area was a basin facies sedimentary during the Cambrian Period while Yutian-Mingfeng area was a platform facies sedimentary. Based on the residual layer thickness map and seismic data analysis, this study validates Liu's findings [5] that the southwest Tarim Wushi-Kashi-Maigaiti-Hetian-Mingfeng area was an ancient land during the Early Cambrian. However, through the Late

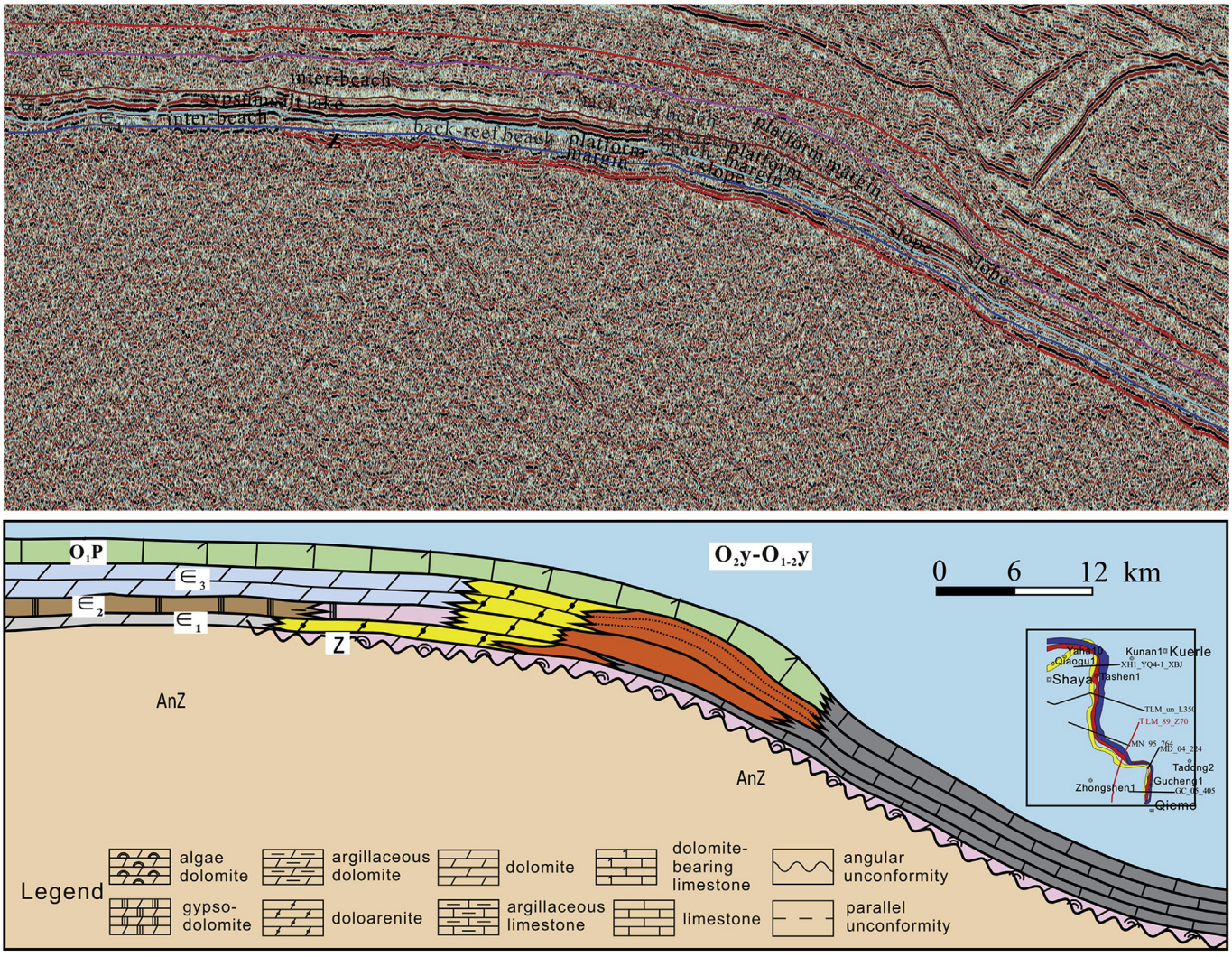

Fig. 7. Seismic and geological structure profile of the platform margin belt in the Well Tazhong 32 area (red line represents the seismic line in the bottom figure).

Cambrian's rising sea-level, it evolved into a low apophysis underwater that later developed into platform margin deposits in the Late Cambrian. The strata residual thickness map showed that the lower Cambrian stratigraphic thickness was zero, but truncation and the overlapping phenomenon were perceived in the seismic profiles that indicated that the region was a high ancient terrain during the Early Cambrian. Nonetheless, its deposit area was most likely zero-value. The uplifted southwest side still has the developed Lower Cambrian and the seismic reflection features were similar, not to mention, thickness had a trend of attenuation. Thus, it was presumed that the high-energy platform margin facies were probably located outside the uplifted zone, but it may have appeared as a carbonate ramp. The Middle and Upper Cambrian strata thickness maps showed that the stratigraphic thickness of the area was thinner than the adjacent area, for example, the residual thickness of the Middle Cambrian was roughly 350 m, but the thickness of the adjacent areas was greater and could reach up to 500 m.

4. Controlling factors of the reservoir-cap combination as well as suggestions for exploration

Research shows that the Cambrian Tarim Basin primarily consist mild and steep ramp carbonate platform margin type, this form different reservoir-cap combination that results to various oil and gas exploration prospects. Current drillings in the eastern Lungu area and Gucheng area, within the Upper Cambrian, confirmed the steep carbonate platform margin. Though, the ramp carbonate platform margin is not yet confirmed is presumed that aforementioned margin probably exists in the Lower Cambrian at the western Tabei by integration of the outcrop by means of earthquake information. The following is about how two different types of platform margin sedimentary characteristics control reservoir-cap combination.

The eastern Lungu and Gucheng area mainly developed acceleration and progradation platform margin in the Late Cambrian. Meanwhile, the reef flat formed in at least three

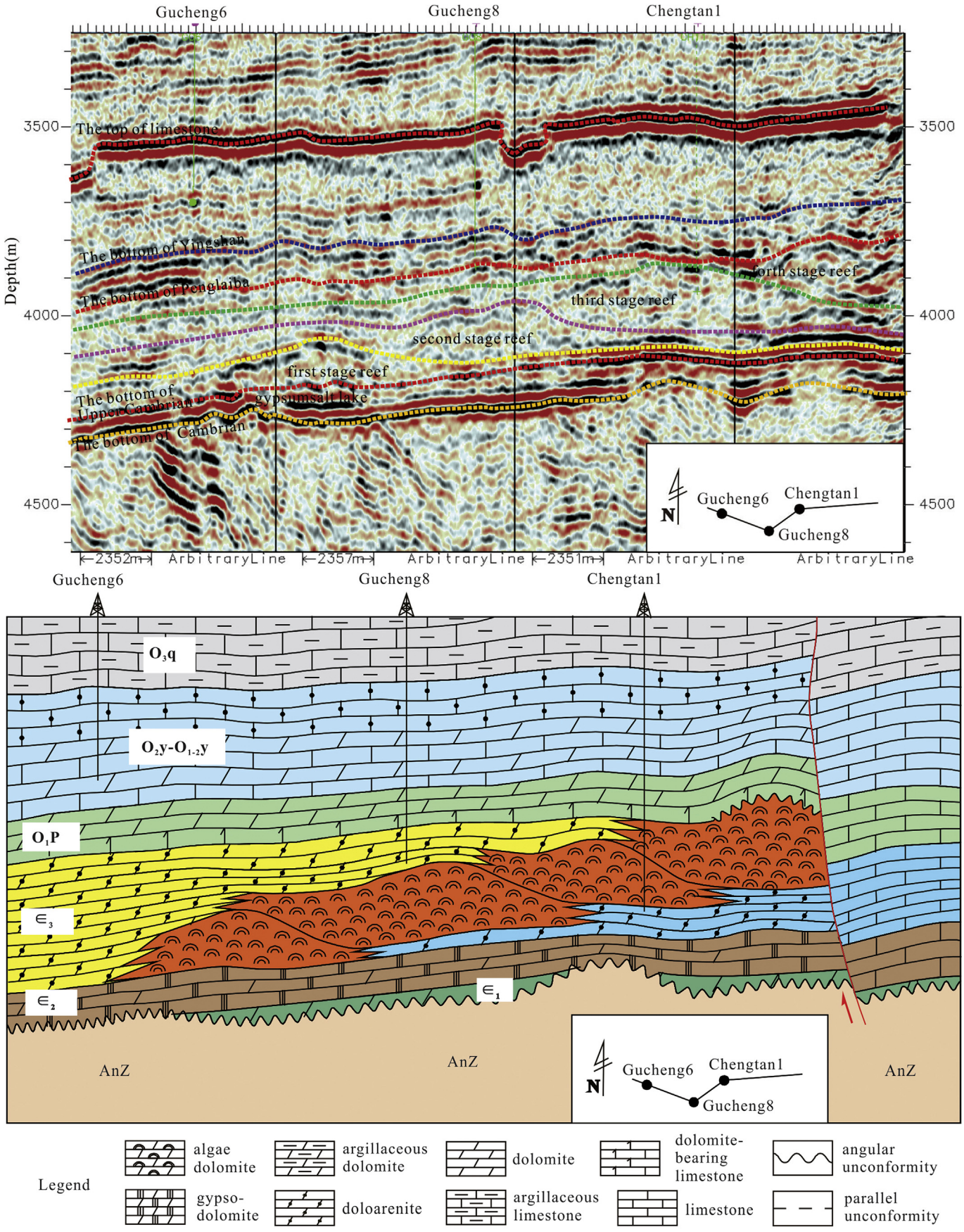

Fig. 8. Seismic and geological structure profile of the platform margin belt in the Gucheng section.

different periods. In addition, the top of the seismic intersection showed noticeable truncation, and the rocks in the place were primarily fine particles-coarse crystalline dolomite that developed in a high energy reef and a shoal environment. Several wells were drilled into the reservoir, for example, Well Tashen 1, Well Lunshen 2, Well Yuqi 6, Well Gucheng 4, Well Gucheng 7, Well Gucheng 8, and Well Chengtan 1. The reservoir mainly consisted algal reefs (mound) type of dolomite; the dolomite was fine-coarse crystalline dolomite with few algae bond structures. The majority of the porosity formed due to the original rock porosity inheritance and re-adjustment while less porosity developed from the burial dissolution. For instance, solution vugs and intercrystal pores were very common in the Tashen 1 reservoir and its porosity was roughly 9.7%. There was a fair amount of evidence to test oil and gas, furthermore, abundant bitumen was found. Nevertheless, test results for oil showed water and only a small amount of gas were found. Additionally, the height of the flame was 0.5−1 m [19]. The absence of an effective dense layer capping led to less oil production in the Well Tashen 1 [20] (Fig. 4). The reef flat in the Gucheng area developed at four different periods. Chengtan 1 is located in the main body of the reef flat, whereas Well Gucheng 8 drilled through psammitic beach (or back-reef) at the top of the reef flat in the Qiulitage Formation of the Cambrian. The reef flat mainly developed algae framework residue pore and solution vugs, whereas the psammitic beach developed essentially more homogeneous solution vugs. Comparison between the reservoirs in the two wells showed that the reservoir at the psammitic beach environment was more homogeneous than the reef flat environment. This suggested that the reservoir developed fine at aggradation-progradation type platform margin environment; caprock likewise played an important role in this type of reservoir. Thus, the back-reef beach body which was located on the rear platform margin and the seaside of the lagoon were favorable reservoir development area; the reservoir was often capped by dense carbonate. All of these lead to an excellent reservoir-cap combination.

A ramp platform margin was identified in the Well Yingmai 7-Well Yingmai 8 3D area within western Tabei. The Early Cambrian lithofacies paleogeography study showed a general development of small reef and large beach type of platform margin, and it predominantly established a set of seepage reflux dolomite reservoir. The outcrops of both the Xiaoerbulake and the Sugaitebulake mostly had powder crystal lattice structure of gray dolomite that retains the original rock particles and algae (mound) lattice structure. The reservoir consistently developed on top or flank of the reef (mound) with an average thickness of 35−40 m. It had a layered distribution that could extend as far as 15 km from north to south. The research about the platform margin in western Tabei showed that the reef flat body was a favorable reservoir development zone; this was located on top or flank of the platform margin within a lagoon near the sea (Figs. 2 and 3). The gentle slope platform margin lead to relatively large changes, for instance, the platform margin of the Middle Cambrian migrated 30 km outside the study area and directly overlaid mud or micrite dolomite in the Wusonggeer Formation. As the Aoyipike section of the Wusonggeer Formation in the Sugaitebulake outcrop showed, it also developed more than 60 m of micritic dolomite and shale formations. The micritic dolomite and shale formations developed more than 60 m just as the Aoyipike section of the Wusonggeer Formation in the Sugaitebulake outcrop showed. Furthermore, the developed micritic dolomite and gypsum rock in the Middle Cambrian formed regional coverage [21−23]. The 35 m thickness of the micritic dolomite in the Cambrian Shayilike Formation developed in a lagoon environment in the adjacent areas of the Well Yaha 10. The breakthrough pressure of the micritic dolomite at the depth of 6448.95 m reached 23.061 MPa, and its breakthrough radius was 6.189 nm. Thus, it was indeed a high-quality regional cap. Most of all, the reservoir which was located at the ramp platform margin in the Lower Cambrian had a significant amount of reef and shoal dolomite reservoir; the reservoir was controlled by the algal and the shoal environment. The caprocks were mostly micritic dolomite, gypsum dolomite, clay dolomite, and other dense rocks in the Lower Cambrian. The reservoir-cap combination was better than the steep platform margin in the eastern Lungu and Gucheng area. As a result, exploration prospects were more optimistic.

5. Conclusions

(1) The Cambrian carbonate platform in the Tarim Basin underwent three evolutionary processes, namely, the Early Cambrian ramp platform, the Middle Cambrian edging evaporative platform, and the Late Cambrian edging platform; the northern platform margin was the deposition type, whereas the eastern platform margin was for fault control, additionally, the Lungu-Gucheng had evident sectional differences. The line from Wushi-Kashi-Maigaiti-Hetian to Minfeng of the southwestern Tarim Basin was an ancient land in the Early Cambrian. Through evolution, the sea level raised the underwater lows in the Middle and Late Cambrian period that possibly developed it to platform edge deposits in the Late Cambrian.

(2) The carbonate platform margin of both steep slope and gentle slope formed various reservoir-seal assemblages. The Upper Cambrian aggradation-progradation platform margin reservoir in the steep slope of the eastern Lungu and Gucheng Area was developed with good connectivity, its caprock had been always the key of the platform margin reservoir-seal assemblages. Therefore, the reef beach located behind the platform margin belt near the side of the lagoon had favorable reservoirs; the reservoirs often overlaid carbonate caprock which formed good reservoir-seal assemblages. The platform margin belt in the gentle slope in the Well Yingmai 7-Well Yingmai 8, in west Tabei, was a dolomite reservoir for algal mound and reef-bank complex with caprock of middle-lower Cambrian dolomicrite, gypsum dolomite, and mud dolomite. Aforementioned dense layers' reservoir-seal assemblage was superior to that of the eastern Lungu and Gucheng that had better exploration prospects.

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Conflict of interest

The authors declare no conflict of interest.

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