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Original research paper

Sedimentary microfacies and palaeogeomorphology as well as their controls on gas accumulation within the deep-buried Cretaceous in Kuqa Depression, Tarim Basin, China[☆]

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Abstract

The gas and oil exploration in Kuqa Depression has entered the deep-buried and ultra-deep areas below 5000 m. This paper represents the systematic research accomplished which included microfacies observation and sandstone modeling in the outcrop, the lithofacies interpretation with imaging logging data, and the recovery of nappe tectonics as well as the folding analysis based on the single sedimentary factors in order to define the characteristics of lithofacies and microfacies, the background of paleography and their effects on gas accumulation. This study illustrated that the climate was mainly hot and dry during the sedimentary period of Bashijiqike within the deep-buried Cretaceous, and the deposited water was characterized by low to medium salinity. The deep-buried areas were controlled by three provenances, namely, the Kapushaliang River, the Kelasuhe River, and the Kuqa River. The Dabei-Bozi area was mainly the proximal deposit, the silty-fine sandstone with subrounded and well-sorting features developed in the main channel areas of underwater distributary channel which was constructed in the braided (or fan) delta front. The Keshen area, on the other hand was the distal deposit, the medium-fine sandstone with subangular-subrounded and medium-well sorting features developed in the main channel areas of underwater distributary channel which was constructed also in the braided (or fan) delta front. In the latter stage of the Yanshanian Period, the silty-fine sandstone of the underwater distributary channel had developed with the background of residual palaeohigh and drought climate in Dabei-Bozi area-meanwhile the medium-fine sandstone of the underwater distributary channel had developed with the background of residual palaeohigh slopes and humid climate in Keshen area. In addition, the gas accumulation within the deep zone was evidently controlled by the lithofacies paleography. The gas in the medium-fine sandstone lithofacies of paleoslope was significantly richer than the silty-fine sandstone lithofacies of the paleohigh; the silty lithofacies in the paleohigh was relatively poor. It was supposed that systematic studies would accelerate the oil and gas exploration and development in the deep zones, not to mention provide guidance for the trillion cubic prospects of gas reserves in the deep zones.

Keywords: Tarim Basin; Kuqa Depression; Deep-buried; Sedimentary microfacies; Paleography; Gas

1. Introduction

Kuqa foreland tectonic basin possessed characteristics of both north-south zonations as well as an east-west section. It formed series of strongly deformed thrust belt in the basin with the dual role of vertical shear and oblique compression generated in the South Tianshan uplift process. Deep major

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tectonic thrust belt spreads in a row, which is divided into two sub-units, namely, the Crassus tectonic belt in northern and the Crassus deep tectonic belt in the southern boundary of the Crassus fault [1–3]. Advances made in the oil and gas exploration and development in 2008 made it possible for features to be characterized in two ways: (1) The objective layer expands from the deep (≥6000 m, even 8000 m) to the mid-shallow (≤5000 m) area, which is in the Cretaceous Bashijiqike Formation of the Bozi-Dabei-Keshen zone from Tubei 1- Tubei 2- Kela 2- Kela 3 zone; (2) The sedimentary facies ranges from medium-coarse sandstone, conglomerate of the braided (fan) delta plain in the margin of the basin to the siltstone-fine-medium sandstone of the braided (fan) delta front in the basin. Complete well, such as Dabei 101, Dabei 202, Dabei 204, Dabei 3, Tubei 4, Keshen 2, Keshen 201, Keshen 5, Keshen 8, and Keshen 9, obtained industrial flow. In early 2013, all 30 exploratory wells within the deep Cretaceous have been completed, of which 20 wells obtained industrial flow that gave off a total of 4422×10^8 m^3 natural gas of three-grade reserves (Fig. 1).

Sedimentary facies are a combination of the sedimentary environment and the deposition formed in it. The sedimentary system is composed of the different sedimentary-facies assembled by means of the genesis relation and was formed under certain natural conditions; the practice of oil and gas exploration shows that the formation and distribution of oil and gas were strictly controlled by sedimentary systems, space-time distribution of sedimentary microfacies, and diagenesis history [4–6]. Previous studies [7–18] generally proposes that during the Cretaceous Bashijiqike sedimentary period, the Kuqa Depression developed various types of delta sedimentary system such as fan delta and braided delta within the different periods of the basin evolution. The Crassus Cretaceous thrust belt developed a typical braided river delta, the formed sandstone constitutes a major oil and gas reservoir; Bashijiqike Formation Section 1 and Section 2 are braided river delta deposit, and the Section 3 is a fan delta deposit. Mei Mingxiang et al. [19] observed northern Kuqa River outcrops and believed that the "high-energy fine sandstone" and "high-energy siltstone" in the Lower Cretaceous arid red layer belongs to the "aeolian sandstone". The entire deposition appearance of the Kuqa Depression Cretaceous is a desert. Zhu Rukai et al. [20] thought that Cretaceous sediment was a terminal fan system (due to the inherent factors, the water system completely disappears and no water flows go into the river system of the lake or ocean through surface under normal conditions), it was deposited without a stable body of water and a large part was the product of the exposed surface exposed surface environment.

Focusing on the understanding of the Cretaceous ultra-deep, high-pressure, middle-high productivity, fractured tight sandstone gas reservoir sedimentary microfacies, and sand body distribution traditional methods was mainly single well study and outcrop observation; fine characterization technology was relatively inadequate. In the condition with low current drilling density, less coring, low seismic data resolution, the sand and reservoir inversion being difficult the conventional logging lithofacies and microfacies identification extent became limited. For the purpose of revealing the lithofacies and microfacies, the ancient geographical features of deep layers below 6000 m–7000 m and its relation with natural gas enrichment, and forecasted the favorable facies zone and gas-rich region; Bozi-Dabei-Keshen structural zone within the Cretaceous Bashijiqike Formation is taken as an example in this article. According to outcrop microfacies observation and sand body modeling, imaging logging lithofacies characterization, construction over thrust napping prototype recovery, sedimentary univariate superimposed analysis, and based on multi-disciplinary theory cross including reservoir sedimentology, imaging logging and salt-related structural geology. Deep zone provenance compartment, typical micro-phase, lithofacies type, and sand body distribution was initially reconstructed in the late Early Cretaceous paleoclimate. Sedimentary environment and ancient geological background of the late Cretaceous denudation

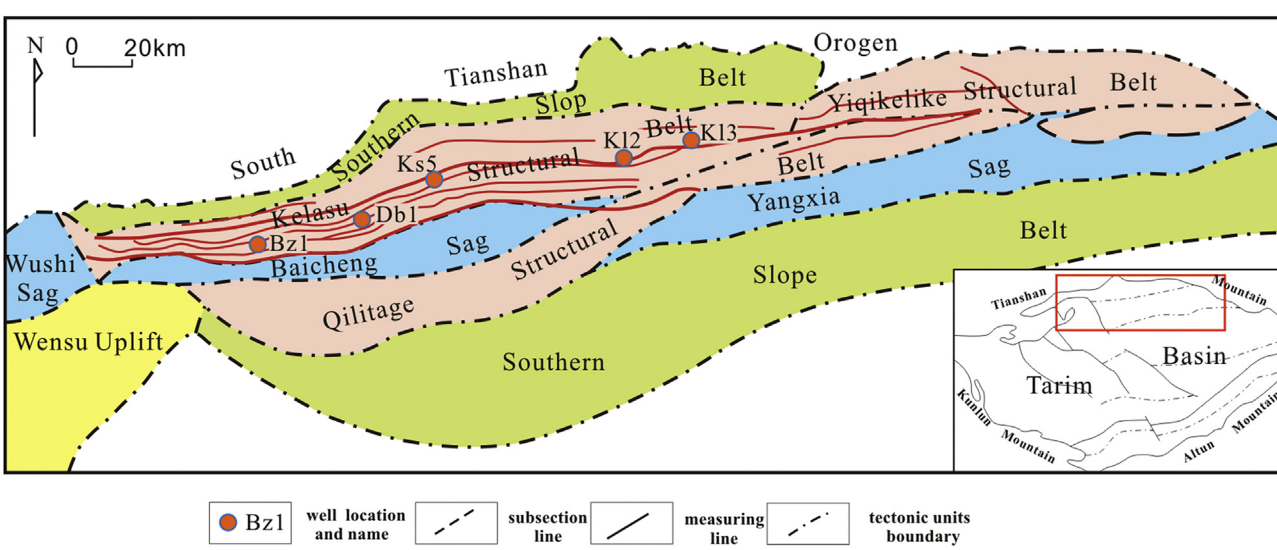

Fig. 1. The tectonic zoning of Kuqa foreland in Tarim Basin.

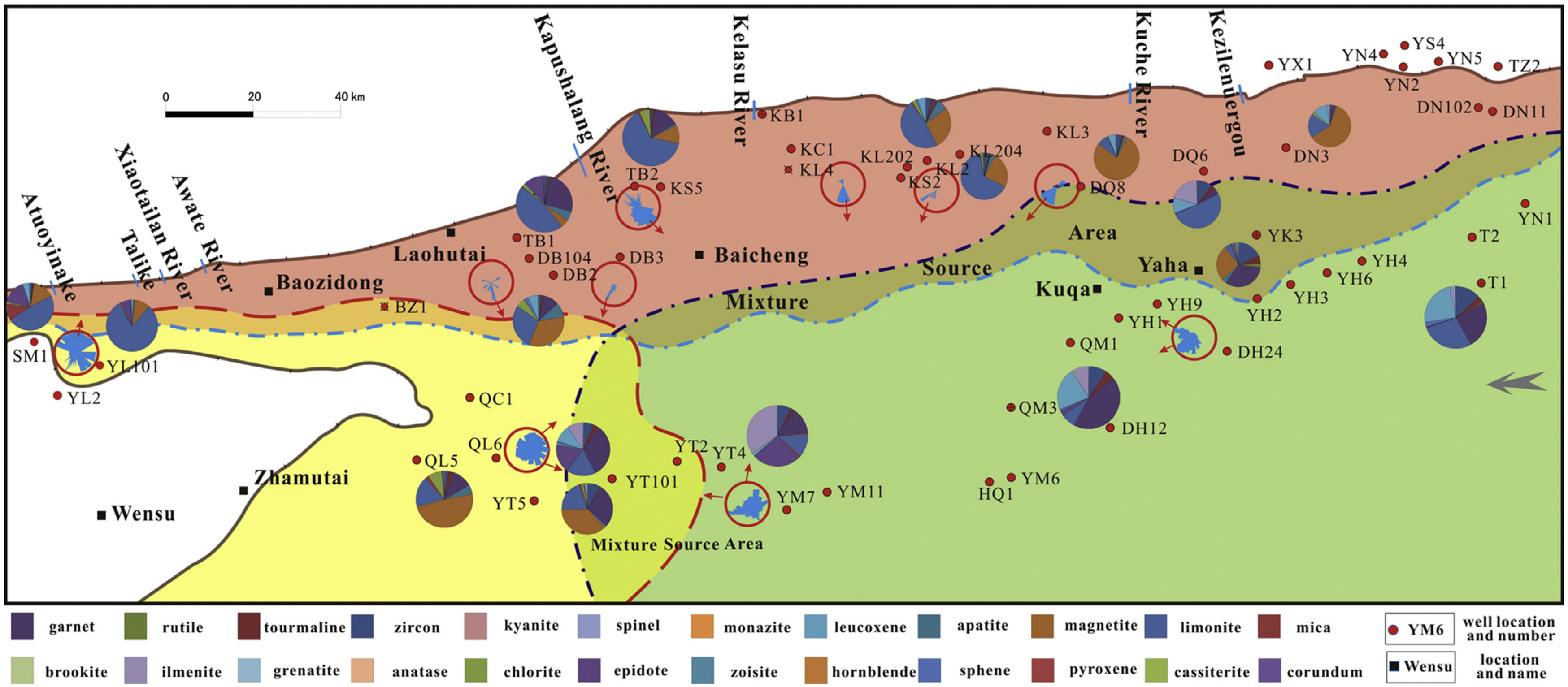

Fig. 2. Compositions of heavy minerals and provenance division of K_1bs in the Kuqa Depression.

remnants were systematically studied as well. Various lithofacies, palaeogeomorphology background, and gas accumulation relations were determined, hence it became a vital reference for expanding deep oil and gas exploration and development.

2. The source division in the deep zones

Comprehensive analysis of data considering heavy minerals in the Cretaceous of Kuqa foreland Bashijiqike group, paleocurrent, rock and mineral composed of gravel and sandstone, structure, and maturity showed the following results: in the latter part of the early Cretaceous, Kuqa foreland basin was controlled by three provenances, namely, a southern Tianshan source area in the north, Wensu source area in the southwest, and east Tarim source area in the southeast [21]. The Kuqa Depression of the southern Tianshan source area is located in the orogenetic recycling belts, and its heavy minerals were mainly magnetite. However, the rest of the minerals were mainly garnet, mica, chlorite. The gravel ingredient was mainly quartz and carbonate rocks Palaeocurrent direction was generally northwest-southeast or northeast-southwest, rock and mineral component was chiefly rock debris feldspar coarse middle-fine sandstone with good sorting and rounding, which can be subdivided into five sub-region material source from west to east (Awate River, Kapushaliang River, Kelasu River, Kuqa River and Yinan, etc.). The original source of the Bozi-Dabei-Keshen's deep-layer area within the Cretaceous Bashijiqike Formation was mainly supplied through the three supply source areas: Kapushaliang River, Kelasu River, and Kuqa River (Fig. 2).

3. Sedimentary microfacies and sand characteristics in the deep zones

One advantage of studying sedimentary facies via FMI imaging logging data was that it can carry on the long hole into the formation of continuous observation and description to be able to obtain abundant lithology, bedding, sedimentary cycle and other important facies marks of the rock structure and texture. The inclination of the feature extraction from images was used in the research on palaeocurrent direction. Identifying lithology was mainly based on the geometry of all kinds of geological features of image color and color changes. Under average conditions, the conglomerate and coarse sand have obvious characteristics of the image that can be directly identified. Due to restrictions in the resolution, medium-fine sand, silt and clay shale can't be identified according to the rock structure namely particle size, but it is for a certain distinction according to the logging data and rock sedimentary structure, namely, bedding characteristics [22−24].

3.1. Typical characteristics of sandstone and mudstone facies

3.1.1. FMI imaging lithologic characteristics

The analysis of core calibration and FMI imaging characteristics of deep zone Dabei, Keshen, and other regions showed that the particle size of the rock is thinner (siltstone and mudstone) and the FMI static image color was darker range from yellow-brown to dark. Layered properties also showed evident changes. The FMI image color was affected by permeability, property, and fracture development situation. Interval with good permeability and developed fracture, it is often brown, dark (water-based mud infection), and it needs to apply the natural and a jugged box and other conventional well logging curve to be distinguished. In the FMI image, clay boulder layer had dark spots of mixed and disordered distribution under the background of a bright color, yet having relatively high value natural gamma curve and characteristics. Thus, making identification is relatively accurate.

Medium sandstone: on the FMI image, was mainly brown and yellow in the Dabei area, and its layered property was poor. The value of the natural gamma curve was 50-70API. In the FMI static image, medium sandstone with relatively good porosity and permeability has a dark color that is mainly brown. Meanwhile, medium sandstone with relatively poor porosity and permeability has light color that is mainly yellow. The medium sandstone in Keshen area was mainly black and brown, massive, and the bedding characteristics were not obvious. The value of the natural gamma curve was 60-70API with its crack growing. On FMI static image, medium sandstone with good porosity and permeability from the Well Keshen 202 has dark color that's mainly black.

Fine sandstone: on the FMI image, from Dabei and Keshen areas in the FMI image was mainly brown and yellow in, and its layered property was good. However, the bedding characteristics were not obvious. The value of the natural gamma curve was 60-70API. Fine sandstone containing boulder clay was difficult to distinguish via conventional well logging curve. Additionally, the value of the natural gamma curve was high. Its shale content increased in logging cuttings, which was often labeled as argillaceous siltstone and silty mudstone layer. In the FMI image, its characteristics were obvious, and on the static image it characterized as dark brown with yellow plate; the mass was under the background of brown and yellow. The value of the natural gamma curve was 80-110API.

Siltstone: on the FMI image, from Dabei and Keshen areas in the FMI image were mainly brown. The bedding characteristics were obvious, and the value of the natural gamma curve was 60-70API. The porosity and permeability of the Siltstone from Well Keshen 202 was good and dark in color, specifically dark brown, which had a low angle of bedding.

Pure mudstone: on the FMI image, was mainly dark, specifically black. The bedding characteristics were difficult to distinguish, and the value of the natural gamma curve was high, around about 150 API. In the FMI image, the clay boulder layer had dark spots of mixed and disordered distribution under the background of a bright color. The natural gamma curve value was 100 API.

3.1.2. Sedimentary characteristics and structures in the FMI image

The Cretaceous Bashijiqike Formation developed six typical sedimentary structures, namely, trough cross-bedding, tabular cross-bedding, wavy bedding, parallel bedding, massive bedding, and wash surface. It developed eight kinds of typical sandstone facies, enumerated as groove cross-bedding fine sandstone, tabular cross-bedding fine sandstone, fine sandstone with wash surface structure, tabular cross-bedding fine sandstone containing mud gravel, parallel bedding fine sandstone, wavy bedding siltstone with mudstone, the massive bedding fine sandstone, and wavy bedding siltstone. The first four kinds of typical sandstone facies are main sandstone lithofacies (Fig. 3).

The trough cross-bedding formed the bedding with high energy flow. The relationship between formation interface and lamina was arc cutting. In the FMI image, it always showed a series of sine form stripes of different angle and amplitude, and each stripe truncated to each other presenting light and shade stripes.

Tabular cross-bedding was very common to see in the core of Dabei-Keshen area, and it always developed in deltaic front subaqueous distributary channel. Being the water stratification of which formation interfaces paralle and lamina groups converge to the bottom. The FMI image presented a formation that interfaces two groups of sine curve, between which were approximately parallel sine form stripes of different angle and amplitude that presented certain light and shade color changes.

Wash surface structure is generally a rough interface with a set of mud gravel layer. Dabei-Keshen areas would always take the form of dark brown mud gravel layer. The gravel diameter was 0.5–8 cm that's distributed along the layers. The FMI image showed remarkable characteristics. The structure took to developed dark spots and briquette of mixed and disordered distribution on the rough interface under the background of a bright color.

3.2. Typical sedimentary microfacies characteristics

A detailed study on sedimentary microfacies through the drilling and outcrop showed that it mainly developed braided delta front and fan delta front deposition in the deep zones. Among which braided delta front underwater distributary channel was the main sedimentary microfacies in the first and second member of Bashijiqike Formation. The fan delta front underwater distributary channel in the third member of Bashijiqike Formation accounts for over 70% of the thickness of the sand body (Fig. 4). The underwater distributary channel sand bodies were identified into two types of structure, namely, the main channel superposition area and main channel lateral area.

According to the outcrop sand body modeling, cross-bedding of the sandstone develops in the main channel of the fan delta front, mud gravel layer develops at the bottom, particle size is relatively coarse, sand body thickness is more than 1200 m, width is 2.4–9.6 m, the ratio of width and thickness is more than 125. On the contrary, mudstone inter-layer doesn't develop. The continuity was also poor, yet the lateral lapout was fast. The ratio of the thickness of sandstone of strata is more than 50% (Fig. 5). Mud gravel layer in the

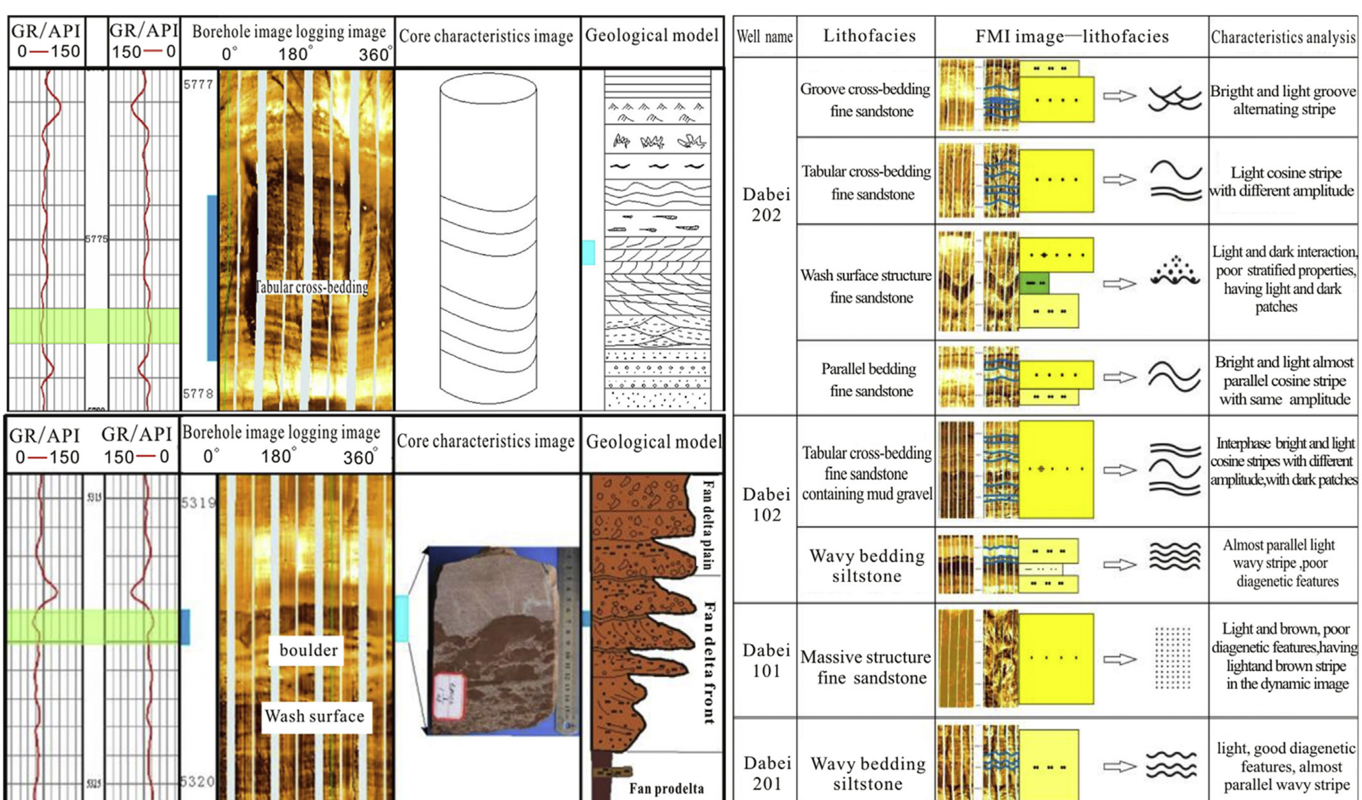

Fig. 3. The FMI features of typical sedimentary structures of K_1bs in deep zones.

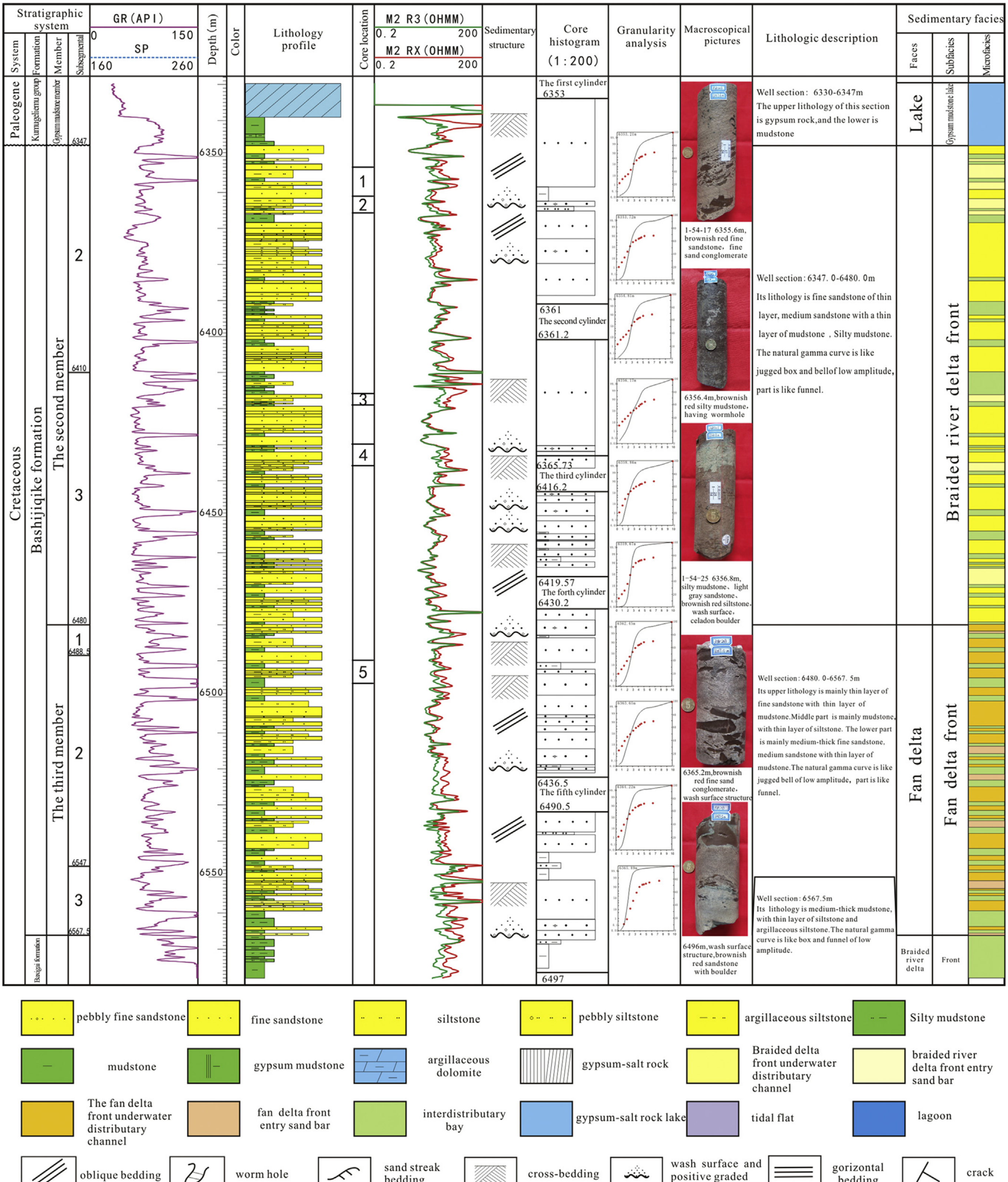

Fig. 4. The sedimentary microfacies column of K_1bs in deep zones (Well Dabei 203).

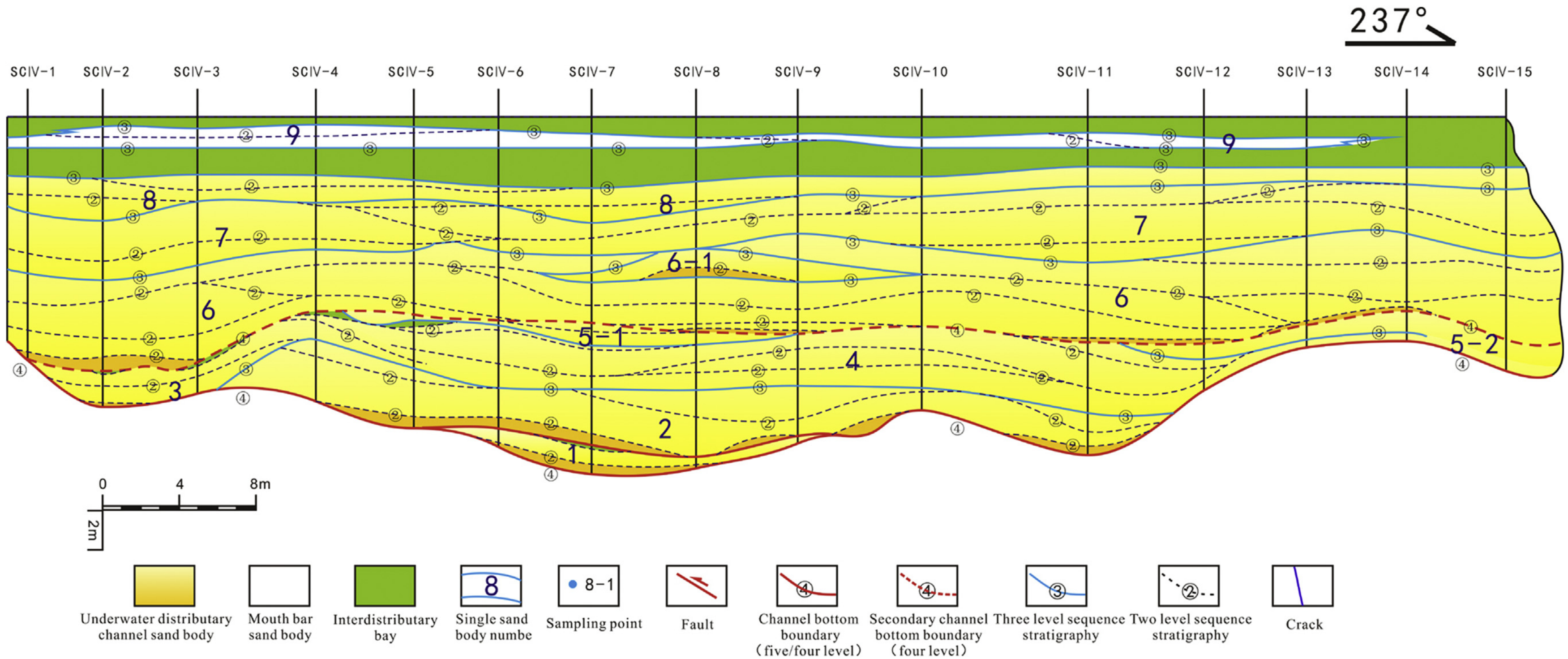

Fig. 5. Structural model of the main channel of underwater channel in the fan delta front facies of K1*bs*.

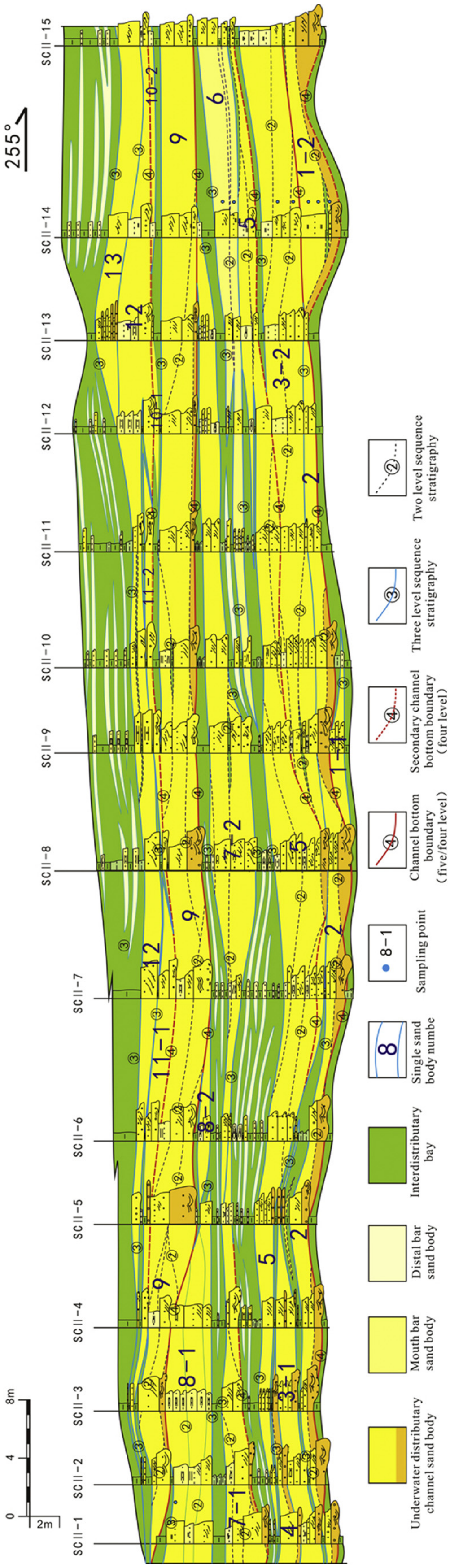

Fig. 6. Structural model of main channel's edge of underwater channel in the fan delta front facies of K1*bs*.

lateral margin of the main channel developed, its particle size got thinner. The ratio of width to thickness is 54–107.7. The mudstone interlayers developed as well with its continuity being good. The ratio of the thickness of sandstone to strata is less than 50% (Fig. 6).

3.2.1. Sand body in braided delta front underwater distributary channel

The main display was that the natural gamma curve was like wide fingers, bell, a juggedand a a jugged box of low amplitude. The lithofacies combination was commonly fine sandstone containing mud gravel, tabular cross-bedding fine sandstone, groove cross-bedding fine sandstone, and medium sandstone containing gravel. On the static FMI image, it was mainly characterized by brown, yellow, and bright stripes interactively appearing. On the dynamic image, tabular cross-bedding, oblique bedding, scour surface structure, parallel bedding, and other sedimentary structures were observed. The llargest set of fine sandstone, medium sandstone, and thin mud gravel layer were also observed in the core (Fig. 7).

3.2.2. Sand body in fan delta front underwater distributary channel

The natural gamma curve of the sand body in the fan delta front underwater distributary channel was like wide fingers, bell, a jugged box of low amplitude. For lithofacies combination, numerous mudstone interlayer tends to appear, boulder clay layer intensively appear as well. The static FMI image was mainly characterized well distributed bright and dark stripes, and the gradient color feature was not obvious. On the other hand, the dynamic image's tabular cross-bedding, wash surface, parallel bedding, and other sedimentary structures were seen. Simultaneously the separation of the rock was relatively poor in the core, the diameter of mud gravel was large (up to 10 cm). It has the characteristics of accompanying deformation structure and flame wash surface structure reflecting the near provenance sedimentary characteristics.

4. Characteristics of sedimentary paleoclimate and eroded paleogeomorphology in deep Cretaceous

4.1. Characteristics of the sedimentary paleoclimate

In early Cretaceous Epoch, the tectonic activity of Kuqa Depression was relatively strong, the slope gradient was big in terrain, the depocenter was close to the provenance (especially southern Tianshan Mountain and the provenance in Wensu), and the sediments of alluvia fan–fan delta and alluvia fan-braided delta were accumulated fast in short distances; the fragments of Carbonate rocks from the provenances went into sandstones without adequate wearing and washing. The final calculated salinity of shale K_2O and B content in the outcrop area of Kuqa Depression showed that in early Cretaceous Epoch, the climate was hot and dry, the amount of precipitation was relatively small in amount, and the ancient water salinization changed from medium to medium and high and eventually being generally lower in salinization. The middle-

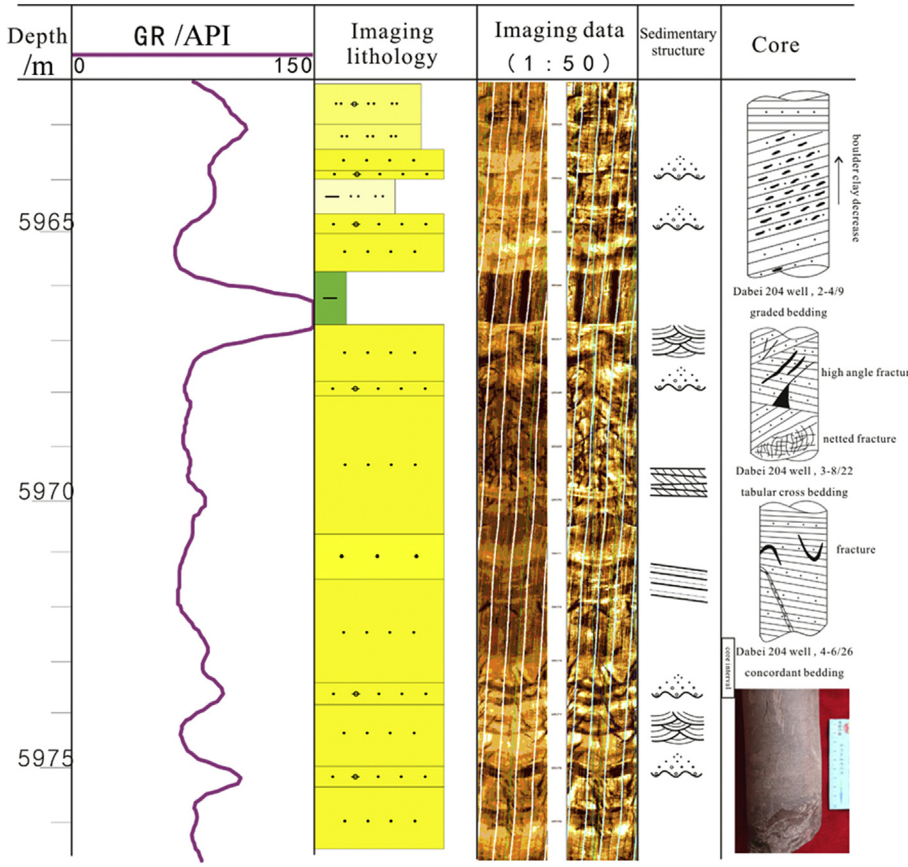

Fig. 7. FMI model of underwater channel in braided delta front facies of K_1bs in the deep area.

Table 1
The analysis of the lake's salinity during the deposition of the Cretaceous in Kuqa Depression.

Section position	Sample	Formation	Lithology	K_2O/%	B/(μg/g)	$B_{correcting}$/(μg/g)	Salinity/‰
Kuqa River	1	K_1bs_1	Purple red mudstone	2.38	28.20	100.71	2.80
	2	K_1bs_2	Purple red mudstone	1.16	29.00	212.50	13.72
	3	K_1b	Purple red mudstone	2.15	42.70	168.81	9.45
	4	K_1s	Purple red mudstone	4.30	42.30	83.62	1.13
	5		Purple red mudstone	1.85	35.60	163.57	8.94
	6		Purple red mudstone	1.69	54.40	273.61	19.69
	7		Purple red mudstone	2.40	69.70	246.85	17.07
Kapushaliang River	1	K_1bs_2	Purple red mudstone	1.72	44.10	217.94	14.25
	2	K_1bs_3	Purple red mudstone	2.84	58.40	174.79	10.03
	3	K_1b	Purple red mudstone	4.35	48.80	95.36	2.27
	4	K_1s	Purple red mudstone	2.35	38.00	137.45	6.39
	5	K_1y	Purple red mudstone	1.91	41.40	184.24	10.96
	6		Purple red mudstone	2.22	54.70	209.44	13.42
	7		Purple red mudstone	1.63	70.80	369.20	29.03
	8		Purple red mudstone	2.06	86.40	356.50	27.79
	9		Purple red mudstone	3.14	66.40	179.75	10.52
	10		Purple red mudstone	2.60	42.80	139.92	6.63
	11		Purple red mudstone	1.78	60.00	286.52	20.95
	12		Purple red mudstone	2.25	53.70	202.87	12.78
	13		Purple red mudstone	3.71	66.70	152.82	7.89
	14	K_1y	Purple red mudstone	2.65	50.80	162.94	8.88
	15		Purple red mudstone	0.92	24.50	227.10	15.14
	16		Purple red mudstone	2.66	69.80	223.05	14.75
	17		Purple red mudstone	2.10	62.60	253.38	17.71

Notes: $B_{correcting} = 8.5 \times B_{sample}/K_2O_{sample}$ (From Walker Formula), 8.5 is a theory of pure Illite of K_2O, B_{sample} and K_2O_{sample} refer to the measured value of the sample. $S = 0.0977X - 7.043$, in which S is Salinity,‰; X is corrected B content, 10^{-6}. The salinity are classified as fresh water 0–0.5, little salty water 0.5–5.0, middle salty water 5.0–18.0, more salty water 18.0–30.0, pure salty water 30.0–40.0, ultra salty water >40.0 (According to the literature [25]).

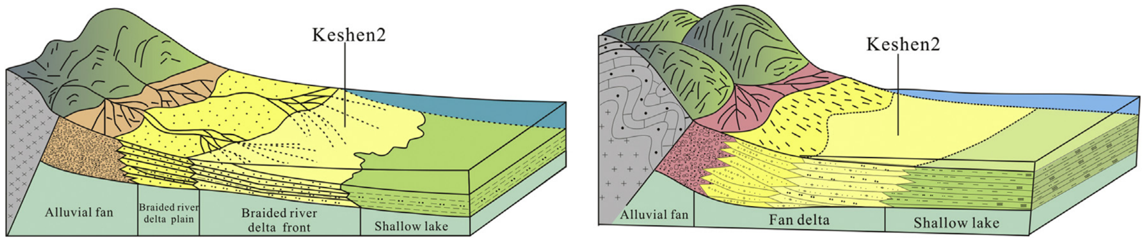

Fig. 8. Depositional model diagram of the Cretaceous Bashijiqike Formation in the central Kuqa Depression.

Shushanhe Formation represented the maximum salinity, and the paleosalinity in Baxigai Formation continued to decline. The salinity in the sedimentary period of Bashijiqike Formation increased slightly and showed low-medium salinization (Table 1). The salinity of ancient sedimentary water in the provenance in Carp Sand River was 8.85‰, and the salinity of ancient sedimentary water in the provenance in the provenance in the Kuqa River was 8.66‰. The former was slightly higher than the latter, which indicated that the latter was generally in the multiprecipitation area, and the poured fresh water diluted the salinity of sedimentary water [25].

As a summary, during the sedimentary period of the Bashijiqike Formation of Kuqa Depression in the deep Cretaceous, the climate was mainly hot and arid, and the sedimentation water was in low-medium salinization. The Dabei area belonged to a deposition far from the provenance and mountains, and with more arid climate and obviously less seasonal fresh water; Keshen area belonged to a deposition near the provenance and mountains, with relatively wet climate and much seasonal fresh water.

4.2. Characteristics of eroded paleogeomorphology in deep Cretaceous

According to six regions, the evolutionary recovery of kinematic equilibrium profiles of Mesozoic−Cenozoic eraever since had 5Ma, on the whole, the quantity of thrust nappe has changed with regularity from east to west from the Cretaceous sedimentary period to the present: Keshen-Kela areas with the maximum thrust: respectively 17.2 km and 15.7 km, the Kuqa River and Carp Sara River with the medium thrust: respectively 11.8 km and 10.8 km, and northern Turpan and Alvart areas with the minimum thrust: respectively 6.7 km and 5.8 km (Fig. 8).

Based on the data, the characteristics of the well drilling FMI imaging lithofacies and microfacies, paleocurrent identification, outcrop microfacies observation, contour line of area, sandy ratio, and the lithology thickness ratio lead to comprehensive analysis and it showed that in the early sedimentary period of the Bashijiqike Formation, Bozi-Dabei-Keshen areas were part of the sedimentary fan delta front, and mainly developed pebbly sandstones, as well as silt-fine stone in the subaqueous distributary channel. In general, the sand-stratum ratio was 30%−70%, and the sandstone thickness was 10−80 m. Generally, the compositional and structural maturity was lower. This showed the sedimentary characteristics, gravity flow, and traction current of the near provenance. In the middle and late sedimentary period of the Bashijiqike Formation, the Bozi-Dabei-Keshen areas became a part of the braided river delta plain. Thus, developed powder-fine-medium sandstones were in the subaqueous distributary channel. In general, the sand-stratum ratio was 50%−90%, and the sandstone thickness was 120−160 m. Overall, the composition and structural maturity were higher, which showed the sedimentary characteristics of the distant provenance and traction current. Within the Cretaceous Bashijiqike Formation, the sand bodies of Bozi-Dabei-Keshen areas overlaid vertically as a whole and tended to be contiguous laterally. Examples are the Well Keshen 5, Well Kela 5, Well Kela 3, and others deposited in delta lobes. Lithofacies were mainly siltstones and muddy siltstones with fine sandstones. The sand-stratum ratio was generally less than 50% (Figs. 9−11).

5. Relationship between microfacies, eroded paleogeomorphology, and gas enrichment

Research on sedimentary facies and palaeogeography and apparent display of oil and gas indicated that the gas enrichment degree in the deep area was evidently controlled by sedimentary microfacies and eroded paleogeomorphology. In the eroded paleo uplift area, medium-fine sandstone facies developed and the reservoir was corroded severely by early supergene leaching. The matrix porosity was mainly dissolution pores. The porosity was generally 5%−7%. The area had the richest natural gas with a reserve of (20−25) $\times$ 10^8/km^2. The gas production was generally high, around about (35−50) $\times$ 10^4 m^3/d (6 mm nozzle); among them, the Keshen area was the most typical, specifically the Well Keshen 2 area, Well Keshen 201 area, and Well Keshen 202 area.

In the high part of paleo uplift area, silt-fine stone facies developed and the reservoir was also corroded. The matrix porosity was mainly residual primary particles, and the porosity was generally 4%−8%. In this area, natural gas was relatively rich and had a reserve of (15−22) $\times$ 10^8/km^2. Gas production was generally around (20−30) $\times$ 10^4 m^3/d (6 mm nozzle); among them, the Dabei area was the most typical, especially Well Dabei 101 area, Well Dabei 102 area, Well Dabei 103 area, Well Dabei 3 area, and Well Dabei 301 area. In the paleo uplift siltstone lithofacies area, reservoir property

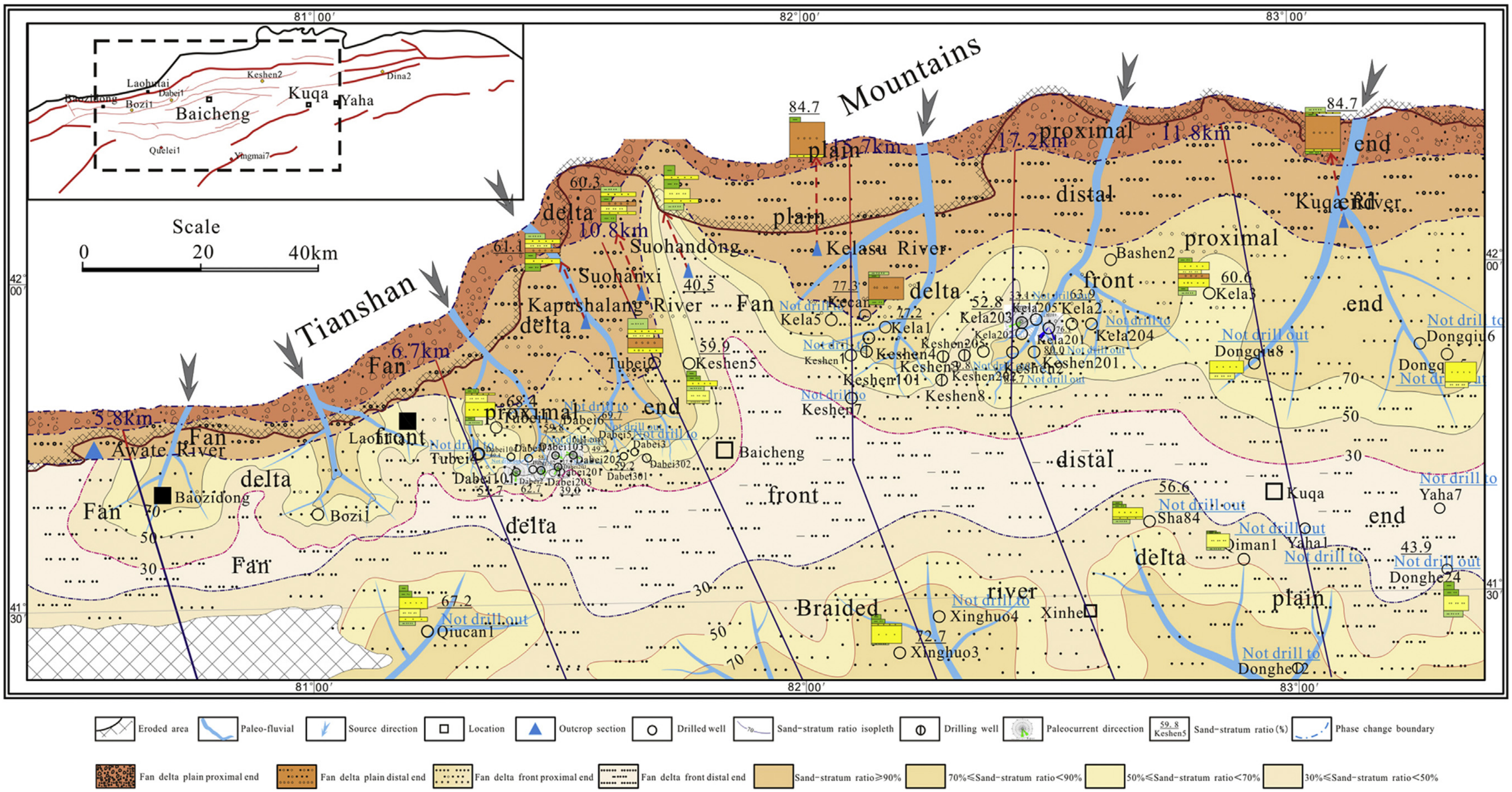

Fig. 9. The distribution of sedimentary subfacies and lithofacies of K_1bs^3 in the central Kuqa Depression.

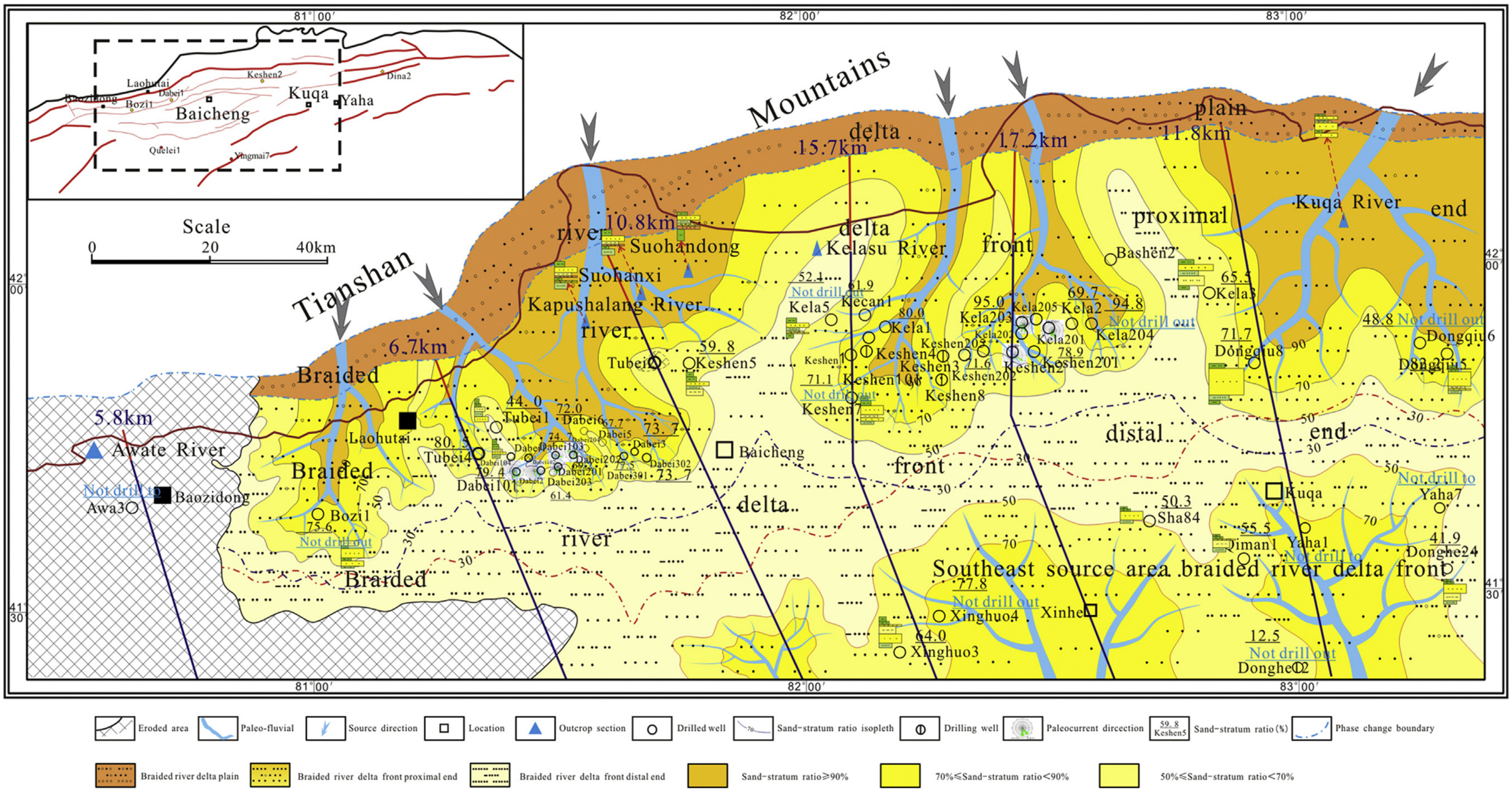

Fig. 10. The distribution of sedimentary subfacies and lithofacies of K_1bs^2 in the central Kuqa Depression.

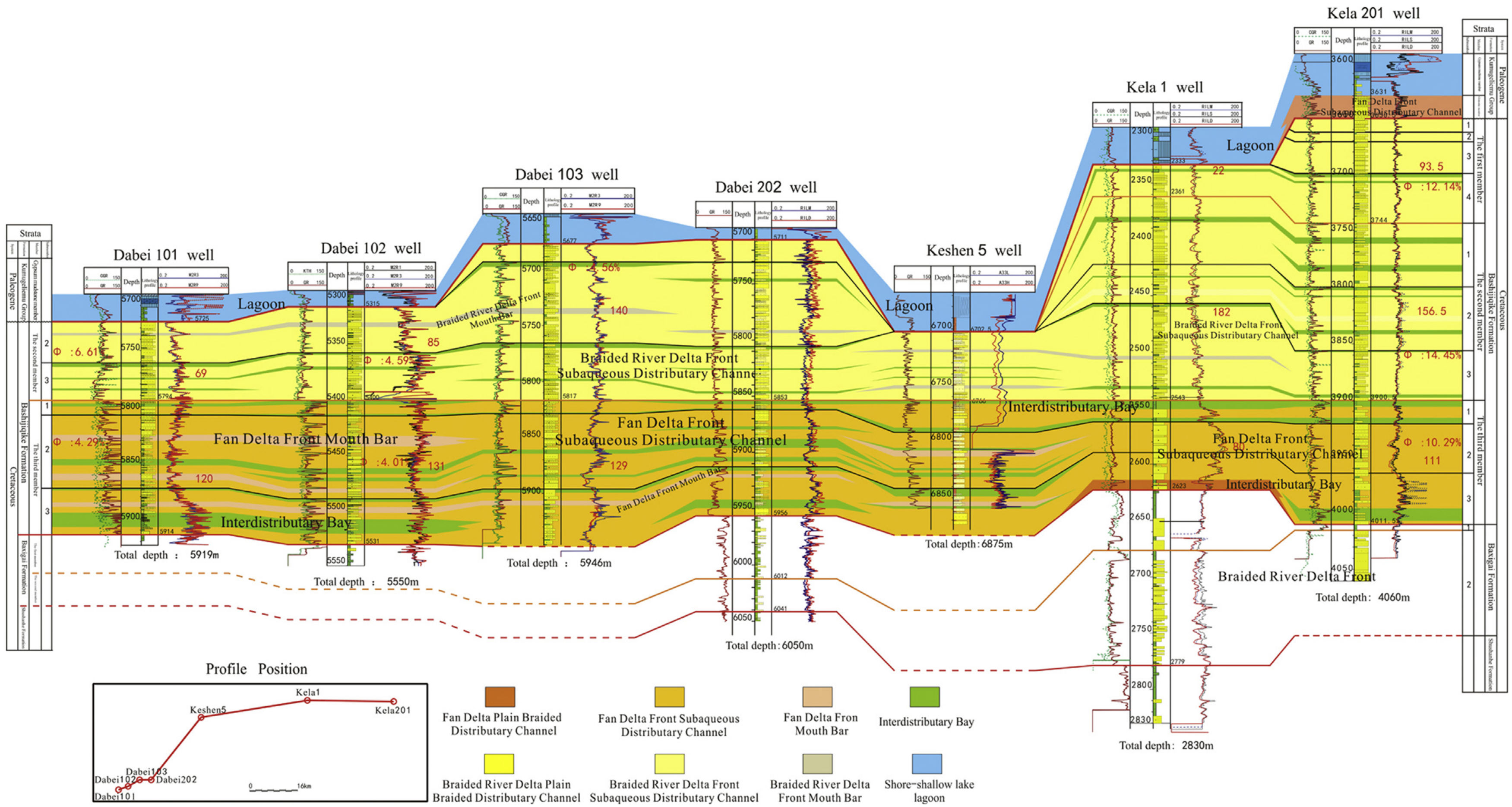

Fig. 11. Well section of Sedimentary facies of K_1bs in the Kelasu tectonic belt of Kuqa Depression.

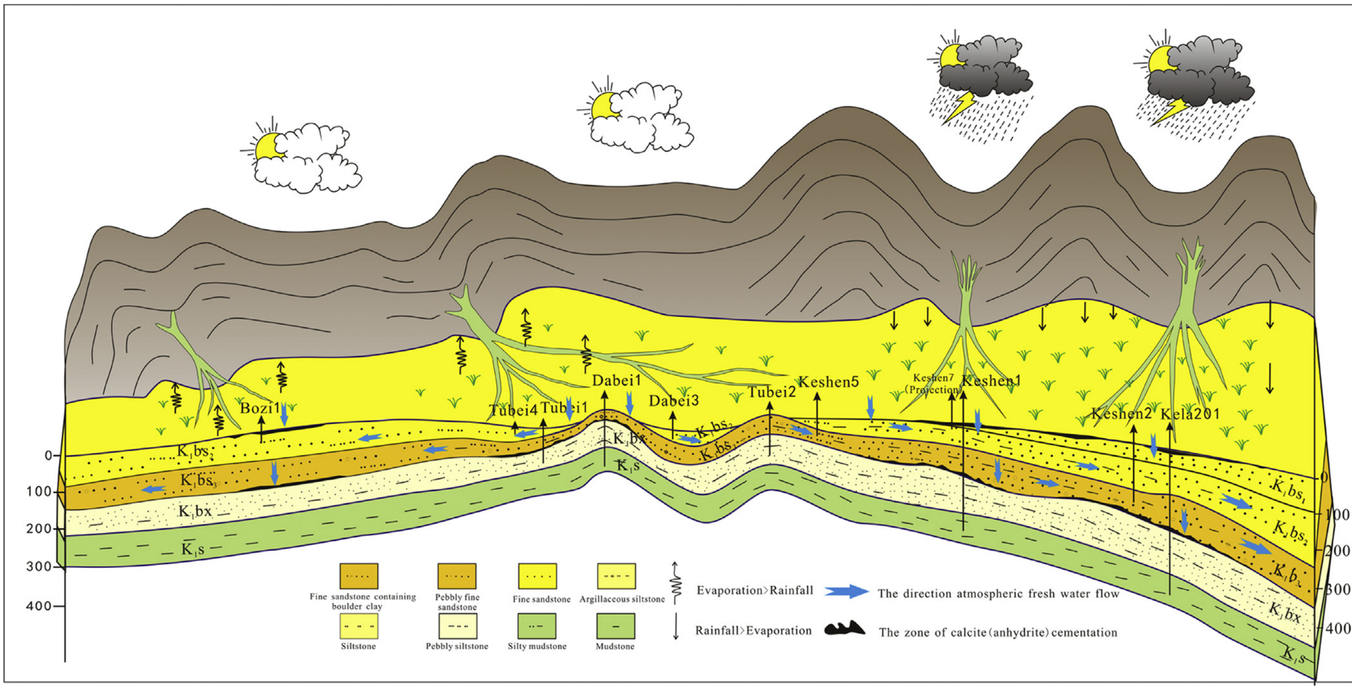

Fig. 12. Ancient erosion landforms of the Lower Cretaceous in Dabei and Keshen areas of Kuqa Depression.

was relatively poor and the natural gas was relatively meager. AIt had a reserve of about 15 $\times$ 10^8 m^3/km^2 Gas production was around 20 $\times$ 10^4 m^3/d (6 mm nozzle); among them, the Keshen 5 was the most typical (Fig. 12, Fig. 13).

6. Conclusions

(1) The sedimentary period of the Cretaceous Bashijiqike Formation in the deep areas was mainly controlled by three source areas, that is to say, Carp Sara River, Kelasu River, and Kuqa River. Within the period, two typical microfacies sand bodies (underwater distributary channels of the front braided delta and front fan delta), two underwater distributary channel structures (main river area and the lateral margin of a main river area), and four typical sandstone facies (medium-fine sandstone in groove cross bedding, fine sandstones in plate cross bedding including scour surface and plate cross bedding with mud pebble) were mainly developed.

(2) In the sedimentary period of Bashijiqike Formation in the deep Cretaceous, the climate was mainly hot and arid in general. The sedimentation water had low-medium salinization. The Dabei area belonged to a deposition far away from the source area and mountains, which possessed more arid climate and less seasonal fresh water. The Keshen area belonged to a deposition near the source area and mountains with relatively wet climate and relatively much seasonal fresh water.

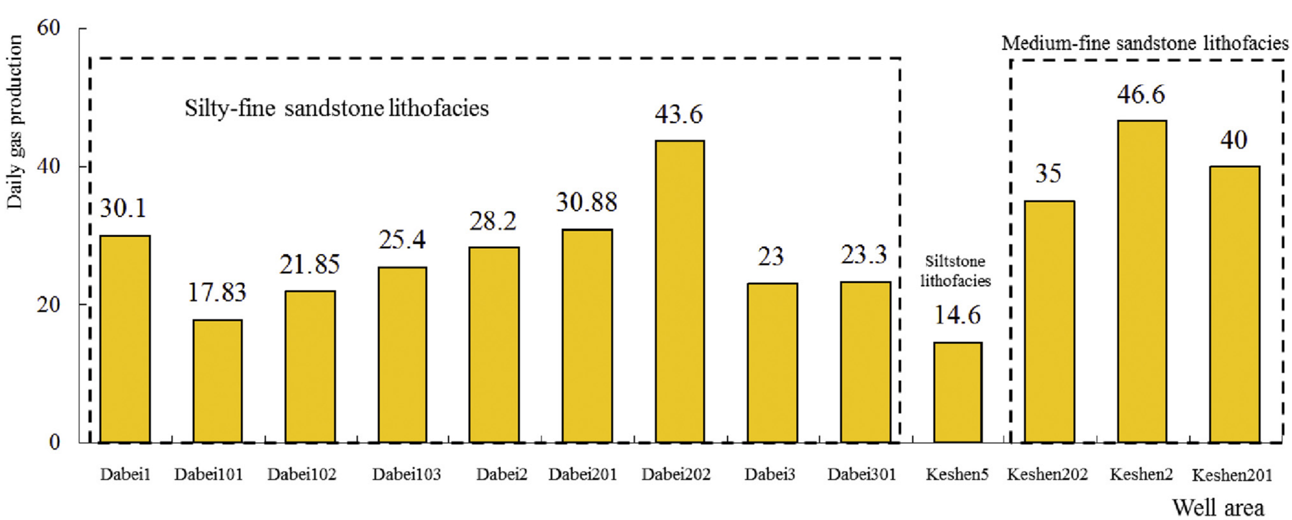

Fig. 13. The histogram of gas test capacity (6 mm nozzle) in various facies in the deep zones.

(3) In the latter stage of the Yanshan movement, the Dabei-Bozi area belongs to eroded residual palaeohigh that mainly developed powder-fine sandstone effective reservoir stratum in the underwater distributary channel of front braided delta and front fan delta. The Keshen area belonged to eroded residual palaeohigh that developed relatively high-quality medium-fine sandstone reservoir stratum high-quality in the underwater distributary channel of front braided delta as well as front fan delta; the sand body in the deep area overlaid vertically as a whole that tended to be contiguous laterally and was 160−220 m in residual thickness.

(4) The enrichment degree of natural gas in the deep area was obviously controlled by sedimentary facies and paleo eroded geomorphology. Natural gas was the richest in medium-fine sandstone lithofacies area of paleo slope areas, richer in palaeohigh powder-fine sandstone lithofacies area, and relatively poor in palaeohigh powder sandstone lithofacies area.

Conflict of interest

The authors declare no conflict of interest.

Foundation item

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