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Study on Petroleum Reservoirs Controlled by Sedimentary Facies in Chepaizi Area

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Abstract. The purpose of this paper is to clarify the paleocurrent direction and sedimentary characteristics of Cretaceous Qingshuihe formation (K1q) in Chepaizi area. Based on the analysis results of structural maturity and compositional maturity, this paper makes a more detailed exploration on the sedimentary environment and the source of clastic materials in the sedimentary period of K1q. Based on the seismic and drilling data, the paleocurrent direction is analyzed by using paleogeo-morphology and seismic reflection structure. The analysis of rock slices of core samples shows that the content of rock debris and feldspar in sandstone reservoir in the study area is high, the content of quartz is low, the weathering degree of samples is deep, the particle sorting is medium to good, the roundness is subround to subangular, the cementation type is pore cementation, and the structural maturity of sandstone is medium to low. The results of particle size analysis demonstrate that the suspension transportation of fine particles is the main transportation mode in the study area, and the rolling transportation is less. The paleogeomorphology shows that the terrain of the study area is high in the north and low in the south. The seismic profile indicates that low angle imbricate progradation reflection is developed in the northwest and northeast. On the basis of results, the following conclusions are obtained: the paleocurrent of K1q in Chepaizi area carried the northwest provenance into the northeast and south, experienced medium and long-distance transportation.

Keywords. Paleocurrent, rock and mineral characteristics, seismic reflection, sedimentary environment

1. Introduction

Chepaizi area is an important oil and gas discovery area in Junggar Basin, China. At present, Chunguang, Chunfeng and Chunhui oilfields have been explored and exploited. Cretaceous (K1q) rocks are the focus focus of exploration in Chepaizi area, but there is no unified understanding of Cretaceous clast provenance and sedimentary system. This paper analyzes K1q provenance sources and paleocurrent direction. The analysis results provide more theoretical basis for the future exploration direction of Chepaizi area.

Methods for studying paleocurrent and paleoprovenance include geochemical methods and geophysical methods. At present, the widely used methods include heavy mineral analysis [1-5], cuttings composition analysis [2, 3, 5], geochemistry [6], paleo-magnetism [7], detrital zircon U-Pb dating [5] and formation dip logging [8-10]. Among them, the main strike of gravel long axis, the direction of sedimentary bedding, the

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characteristics of rock particle size and composition, and the direction of biological drilling can be used as indicators to determine the direction of paleocurrent [11]. With the development of high-precision seismic exploration technology, the application of seismic reflection structure to the analysis of paleocurrent [11] has attracted more and more attention of scholars. The error of one method is large, so the paleocurrent research in a certain area needs to combine a variety of methods to improve the accuracy of prediction results.

Because there are very few geochemical data in the study area, this paper will analyze the paleocurrent and paleoprovenance of the target layer in combination with geophysical data and analysis and test data. We will discuss sedimentary environment of K1q and source of clastic materials during sedimentary stage, based on studying the structural maturity, compositional maturity of Cretaceous clastic rocks in Chepaizi area. In addition, we will analyze the direction of paleocurrent with the help of paleo-geomorphology and seismic reflection structure.

2. Geological Overview

Chepaizi Uplift is located in the south section of the Western uplift of Junggar basin. It is a secondary positive structural unit with an area of 2340 km^2. It is connected with Shawan Sag and Zhongguai Uplift through Hongche fault belt in the East and close to Sikeshu Sag in the south [12, 13]. The main strike of Chepaizi uplift is from northwest to Southeast, which is an irregular triangle on the plane. On the whole, it tilts to the southeast and lifts to the northwest, with the characteristics of uneven lifting (Figure 1b). Chepaizi uplift is an ancient uplift formed in the Late Hercynian period [14]. In most areas of the uplift, Permian, Triassic and Jurassic have been denuded [14, 15]. According to previous studies [14-18], Chepaizi area has the potential to become a large oil and gas field.

The tectonic evolution of the strata in Chepaizi area can be roughly divided into three stages [19, 20]. The first stage is from the middle and late stage of Late Hercynian movement to the second episode of Yanshan movement [19, 20]. The time span is Late Carboniferous to Jurassic, which is a strong uplift stage [19, 20]. In this process, some strata of Permian, Triassic and Jurassic are missing [19, 20]. The second stage is the third episode of Yanshan movement, with a time span of Cretaceous to Paleogene, which is a slow subsidence stage [19, 20]. The third stage is the Himalayan movement period, the time span is Neogene to Quaternary, which is a rapid subsidence period (Figure 1c) [19, 20].

The thickness of the lower Cretaceous of Mesozoic varies within 0-500 m. The stratum of this section is thinned from southeast to northwest until pinching out, and is in angular unconformable contact with the underlying Jurassic stratum. From bottom to top, it is divided into K1q, Hutubihe formation (K1h), Shengjinkou formation (K1s) and Lianmuqin formation (K1l) (Figure 1c). The main horizon of this study is K1q located at the bottom of Cretaceous stratum, with a thickness of 60-360 m. The lithology of the upper part is mainly the interbedding of horizontal gray green mudstone and siltstone; and the middle part is dark gray mudstone and gray green fine sandstone. Its lower part is wavy and grooved grayish green sandy mudstone. The bottom is grayish green conglomerate layer, which is medium fine gravel as a whole and coarse gravel in some parts.

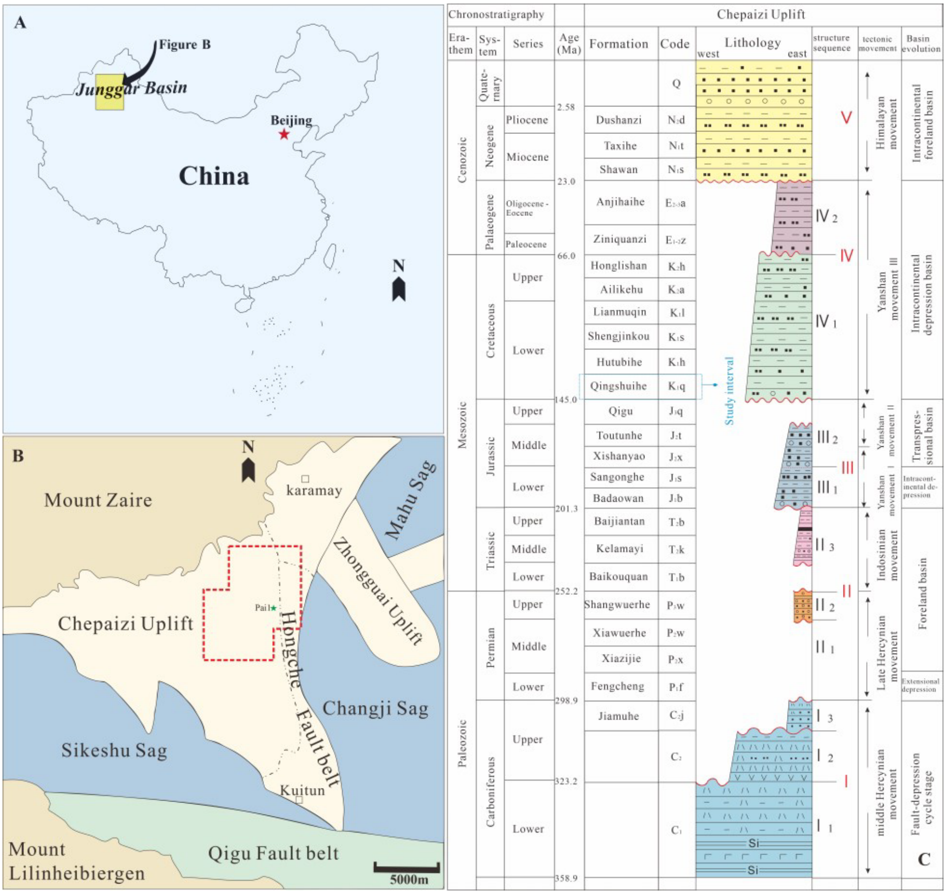

Figure 1. A: The map of China (The yellow area is Junggar Basin. Chepaizi Uplift is located in Junggar Basin); B: The map of Chepaizi Uplift (The red dotted box is the study area. The area is about 780km^2. The green points are the positions of well P1 and P103 [14-16]); C: Stratigraphic column of Chepaizi area (From Well-Pai1) [20].

3. Data and Methods

3.1. Data

The data used in this study are from Shengli Oilfield. Seismic data are used to characterize paleogeomorphology. Drilling data are used to analyze hydrodynamic and sedimentary environment. The coverage area of 3D seismic data is 780 km^2. The bin spacing of seismic data is 25 m * 25 m. The sampling interval of seismic data is 2 ms. The main frequency of seismic data is about 25Hz, and the effective frequency range is 15-75 hz. The core samples were taken from wells P1 and P103 in the Chepaizi area, of which 11 samples were taken from well P1 and 1 sample from well P103. The core samples were used to make rock-thin sections, and the lithological characteristics of the study area were analyzed indepth with the help of general thin section microscopic characteristics, rock composition characteristics, and particle size characteristics. The rock composition of the flakes was determined using the point-counting method, and the flakes were photographed using a ZEISS polarizing microscope, and particle size measurements and statistics were performed using image pro software.

3.2. Methods

Differences in parent rock lithology and sediment transport distances in the source area can directly lead to differences in the lithological characteristics of the depositional zone [19], while differences in lithological characteristics also reflect geotectonic conditions [20]. The compositional maturity of clastic rocks refers to the degree to which clastic sedimentary components are close to the most stable end product under their modification by longterm weathering, transport, and deposition [21-24]. The compositional maturity of clastic rocks reflects the time and intensity of the geological action that the clastic fraction has undergone, and it is known that the higher the compositional maturity is, the more distant it is from the source area. In this paper, the compositional maturity is determined by dividing the content of quartz by the content of feldspar plus clasts (Q/(F+R)). The particle size distribution and sort-ability of clastic rocks are important measures of the energy of the sedimentary medium and are good indicators of the depositional environment as well as hydrodynamic conditions [25-29]. The depositional environment of sedimentary rocks can be determined by plotting C-M diagrams using the C and M values of samples and comparing them with typical C-M diagrams of known depositional environments. The C-M diagrams of gravity flow deposition are distinctly different from the C-M diagrams of traction flow deposition in that turbidity flow deposition points are characterized by parallel C=M baselines, while the typical point graph of traction flow can be divided into N-O-P-Q-R-S segments, of which only the Q-R segment is parallel to the C=M baseline.

In this paper, geophysical methods are used to infer the direction of paleocurrent, including paleogeomorphic map and seismic reflection. The paleogeomorphic map shows the height of the terrain during stratigraphic deposition. The direction of paleocurrent is inferred according to the principle of “water flowing to the lower part”. And the seismic section can provide more evidence. The progradational reflection configuration from seismic section is a reflection structure extending to deep water [28]. We can also use the evidence to figure out the direction of paleocurrent.

4. Results

4.1. Reservoir Lithology and Physical Source Analysis

The analysis of rock thin sections of eight core samples from the K1q in the Chepaizi area concluded that the sandstone reservoir in the study area has a high clastic content and a low quartz and feldspar content. Quartz is mainly monocrystalline quartz, accounting for 3%-55% of the total volume of debris, with an average of 25.15%; feldspar is mainly potassium feldspar and plagioclase, accounting for 1%-60% of the total volume of debris, with an average of 25.79%; rock debris is mainly igneous rock debris and metamorphic rock debris, followed by sedimentary rock debris, accounting for 20%-96% of the total volume of debris, with an average of 44.59%. The sandstone rock type in the study area is mainly feldspathic clastic sandstone (Figure 2). The Cretaceous contains more igneous rocks, metamorphic rocks, and sedimentary rock debris. Before the deposition of this formation, the northwest margin overburden was formed, the old strata were exposed and denuded by the uprush, and the Carboniferous, Permian, and Triassic were weathered and stripped sequentially to form a mixed clastic fraction [21]. The source is inferred from the tectonic uplift at the northwest and north edges of the study area.

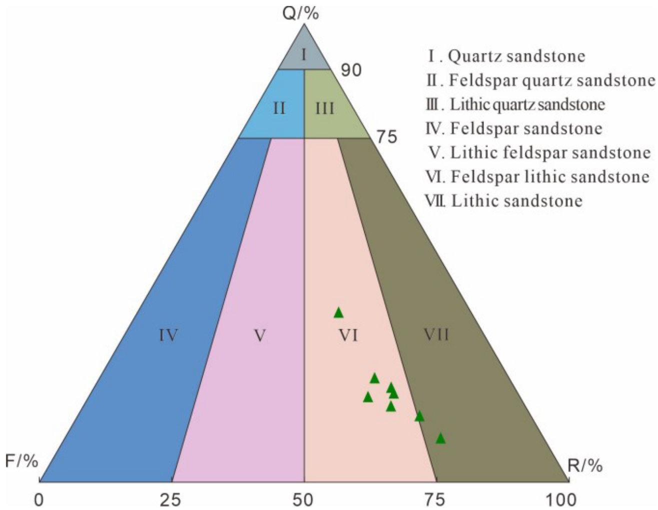

Figure 2. Triangular map of the K1q sandstone types in Chepaizi area [22, 34].

The samples of the K1q have a maximum grain size of 13 mm, with the main grain size ranges between 2-9 mm and 0.063-1 mm, deep weathering, moderate to good sorting. The roundness is subcircle-subedge, grain support, point contact, and line contact, and pore cementation. Considering the grinding roundness, sort-ability, support mode, contact mode, and cementation type together, it can be seen that the structural maturity of the sandstone of the K1q of the Chepaizi Chalk is moderately low. The sandstone particles are mainly subround to subangular, with medium sorting and medium-low structural maturity. All the above indicate that the clastic particles were deposited after medium and long-distance transport and modification, the hydrodynamic conditions were better at the time of deposition, and the sorting effect was better. Among the samples of the K1q in the Chepaizi area, the compositional maturity of well P1 is much higher than that of well P103 to the west of it (Table 1), and it is assumed that the direction of clastic material transport is roughly from west to east.

Table 1. Statistical table of composition maturity of single well in K1q.

Well name	Horizon	Sample number/piece	Compositional maturity (Q/(F + R)) (mean)
P1	K1q	11	0.2
P103	K1q	1	0.03

The C-M diagram (Figure 3a) shows that eight sample points of the well P604 are located in the Q-R segment and one sample point is located in the R-S segment. The Q-R segment represents the progressive suspension deposition, indicating that the suspended material in the fluid gradually becomes finer in size and lower in density from the bottom up. The four sample points of the well P606 are all located in the R-S segment

(Figure 3b), which is a homogeneous suspension deposition, a water transport mode above the recurring suspension, in which the sediment size is fine and the particle size and density do not change with the depth position. The analysis suggests that the overall transport mechanism of the K1q in the Chepaizi area is moderate hydrodynamic conditions, mainly suspension transport of fine grains, with fewer rolling transport components.

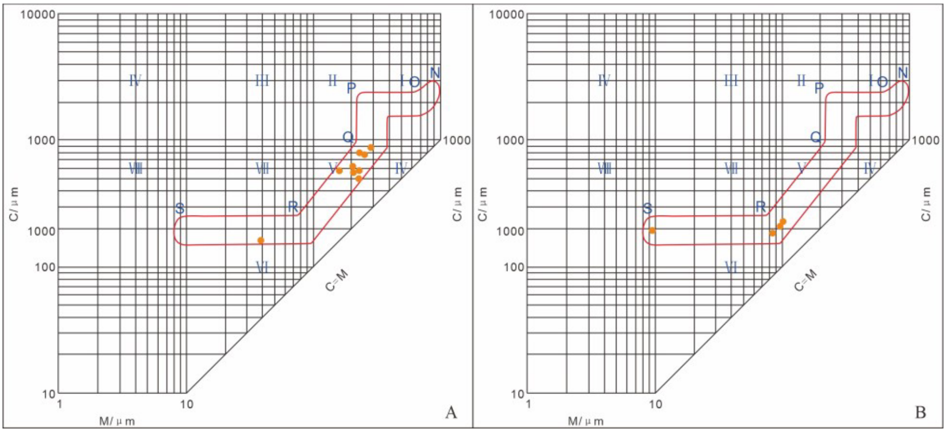

Figure 3. (a) C-M diagram of K1q of well P604; (b) C-M diagram of the K1q of well P606.

4.2. Paleogeomorphology and Paleocurrent

Other scholars have restored the Cretaceous paleogeomorphology in Chepaizi area based on seismic and logging data, but few data show that the paleogeomorphology of K1q is restored alone [11]. Based on the restoration of Cretaceous paleogeomorphology in Chepaizi area by Zhang [11], the paleogeomorphology of K1q in the northeast of Chepaizi area is restored according to high-precision three-dimensional seismic data. We have interpreted the bottom boundary of Qingshuihe formation from the seismic profile (Figure 4c). And we use the time depth relationship formula (Figure 4b) to convert the strata in the time domain into the depth domain. We display the strata of the depth domain in a three-dimensional window (Figure 4a). In this method, we can get the paleogeomorphology map.

The paleogeomorphic map (Figure 4a) shows that the ancient landform is high in the north and low in the south, gentle in the west and steep in the east. The faults are not developed, and the gullies with large altitude drop are not developed. However, there are small slopes in the northeast of the study area. There are small gullies and small “strip” bulges in the northwest. And the distribution direction is north to south. The terrain in the south is the lowest, which is a depression area.

From seismic reflection data, the direction of paleocurrent can be dissected by the external shape and internal structure of the event axis [11]. Obvious progradation reflection structure can be observed on the seismic profile of the study area (Figures 4d-4f). For the whole study area, low angle imbricate progradation reflection is developed in the northwest and northeast of the study area. It usually indicates the direction of the delta advancing to the lake basin (lake center). That means the flow direction of paleocurrent. The progradation reflection structures in the work area are mostly low angle imbricate progradation and hidden progradation reflection structures (Figure 4e).

So, it is inferred that the water environment in this area is relatively shallow. The advancing direction of progradation structure can correspond to the results of paleogeomorphic analysis (Figure 4a). And progradation is carried out from high to low terrain. The direction of paleocurrent in small gullies in the northeast is from the northern highland to the lower area in the south, and the lower area in the south is the area mainly receiving provenance deposition.

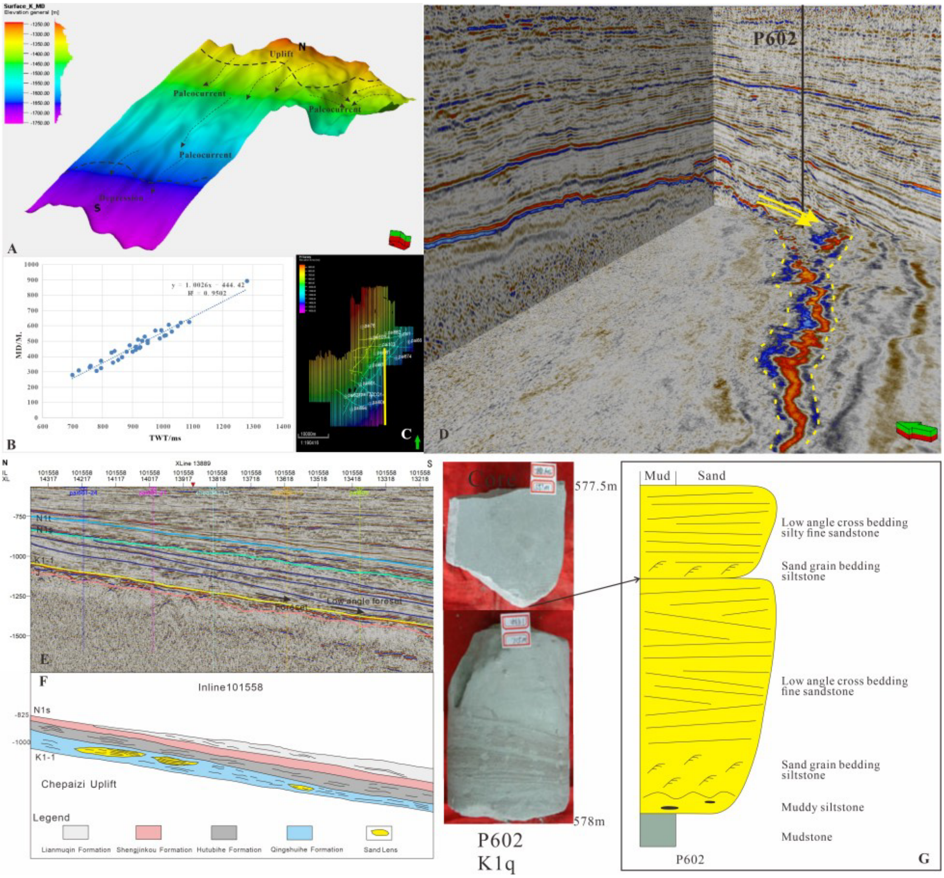

Figure 4. (a) Paleogeomorphic map of K1q in Chepaizi area (The dotted arrow direction represents the flow direction of paleocurrent. The direction is from north to south); (b) Relationship between time and depth (The formula is Y=1.0026*X-444.42. Y means measured depth (MD). X means two-way-travel (TWT)); (c) Map of seismic interpretation in time domain; (d) 3-dimension windows of seismic data (The picture shows that ancient river flows across well-P602. The yellow dotted lines represent ancient river); (e) Seismic section of inline 101558 (The picture shows that there are some low angle progradational reflection configurations (or foresets) in K1q); (f) The hand drawing of seismic section (The original profile is Figure 4e. It's K1q of inline 101558. In this way, the reflection configuration can be showed more clearly. The black lines in the layer represent strong seismic reflection axis); (g) Single-well sedimentary facies map of P602 well (The sand bar is distributed parallel or oblique to the shoreline and is long or irregularly elliptical. The sand bar in the study area is composed of gray siltstone, siltstone, and fine sandstone, with a small amount of conglomerate sandstone and muddy siltstone. It is characterized by few layers but large thickness in the vertical direction and the thickness of a single layer is generally greater than 2 m, mostly inverse rhythm or inverse rhythm after positive rhythm. The sedimentary structures mainly include low-angle cross bedding, parallel bedding, sand-grain bedding, and wavy bedding).

5. Conclusions

The study of K1q in Chepaizi area shows that: (1) The results of structural maturity and grain size analysis of clastic rocks show that the provenance direction of K1q converges from the tectonic uplift position of the northwest and North edges to the central and southern depressions. The clastic materials have experienced medium-long distance transportation. At the same time, the overall hydrodynamic condition of K1q is medium, and its transportation mechanism is mainly fine-grained suspension transportation. (2) The paleocurrent of the K1q in Chepaizi area carried the northwest provenance into the northeast and south, and experienced medium-long distance transportation. (3) Paleocurrent controls the transportation of sediments. The results of paleogeomorphology and seismic reflection structure show that paleocurrent flows from the north and northwest of high terrain to the south depression of low terrain.

Due to the lack of analysis and test data, this paper makes more use of seismic data for the analysis of paleocurrent. In the future, the research on paleocurrent in this area will focus on collecting sufficient analysis and test data to control the seismic results. However, the research results are sufficient to provide theoretical guidance for the follow up exploration focus in the study area.

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