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Paleogene Sedimentary Environment Analysis in the Xinjiang Jiashi Area of Western China

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Abstract: The Jiashi area is located in the southwestern Tianshan tectonic belt, within the northwestern margin of the Tarim basin. In this study, which was based on the Jiashi Tonghui copper drilling data, a large number of field measurement data profiles, as well as the particle size analysis of thin samples, were collected. Sedimentology, stratigraphy, and many other integrated technologies and methods were utilized for the purpose of analyzing the depositional environment and phase of the Jiashi area, as well as to identify the fan delta, mesa-lagoon phase, tidal flat, braided river delta plain facies, and braided river delta front. A total of five types of sedimentary facies and a variety of sedimentary sub-phases were identified. The depositional environment of the study area has overall undergone several transgressive regressions. In this paleo-climate, the plaster layers of gypsum veins clearly reflected the arid environment.

Keywords: *Jiashi area; particle size analysis; depositional environment; sedimentary facies; sedimentary evolution*

1. Introduction

At this point in time, many research studies have found sandstone copper deposits throughout the world, such as in the Katangan Basin in Africa, the Kodaro-Udokan Basin in Siberia, and the Kupferschiefer Mine in central Europe. Also, these sandstone copper deposits account for 23% of the entire world reserves [1], ranking the porphyry copper deposits second in the world. Therefore, sandstone copper deposits have attracted many geological researchers world-wide [2-3]. There have been many achievements made [1, 4] regarding sandstone depositional environments, facies, lithology, geochemistry, and so on. In China, the majority of the sandstone deposits are distributed in the south (Sichuan, Yunnan, Hu'nan Provinces), and most have been formed in marine facies. Therefore, it is very important to study the sandstone copper depositional environments.

In recent years, sedimentary type sandstone copper deposits (such as the Drip Kuqa Area Mines, Shalibai Copper Area, Garden Copper Point, Shahar Copper, and so on) have been found in the Paleogene strata of the western Tarim Basin, Xinjiang Province, China [5-10]. Although some researchers have previously studied the formation mechanism of sandstone copper deposits, and determined that the copper deposits are related to the sedimentary environments [9-12], there still remains a difficult unsolved problem, which is the sedimentary environment of sandstone copper. The sandstone copper depositional environment is the key factor influencing copper mineralization [15-16]. Therefore, it was very necessary in this study to examine the southwestern area of the Tarim Basin.

The Jiashi Area is located in the northeastern section of Kashi City, Xinjiang Province. The sandstone copper deposits in the Jiashi Area have only been discovered in recent years [2]. Ma (2011) put forward that sandstone containing copper are formed in lacustrine environments. Han (2011) found that deep lake-delta-fluvial environments formed Paleogene strata with copper deposits [3]. Zhang (2011) believed that a lacustrine environment was the main environment for the formation of the copper deposits in the Jiashi Mine [5]. Meanwhile, some researchers have noticed that sedimentary environments are also key factors influencing the formation mechanisms of copper deposits. However, there remains a great deal of controversy regarding the role of sedimentary environments. Therefore in this study, the Jiashi area copper mine was taken as a typical example for the examination of the sedimentary facies, and for the depositional environmental research through field geological sections, sedimentology analysis, and so on. The results of this research will be helpful for the future exploration studies of copper deposits.

2. Geological Setting

The Jiashi area is located in the northwestern margin of the Tarim Paleozoic foreland basin, southwest of Keping, with northern Jara Jun Akqi as the boundary [6], and is adjacent in the south to the Tianshan Late Paleozoic continental margin basins, which is a land of the northern margin of the Tarim basin [17]. The regional tectonic of the mine's position is located in the Paleozoic basement, and the Cenozoic rift basin or depression. The mine is positioned in the north basin of the Sahara bounded by Jun-Akqi fracture, which is adjacent to the south Tianshan Late Paleozoic terrigenous basin, and near the Tarim Basin Bachu phase [6, 18]. Inherent in the mining belt is located in the northwestern margin of the Tarim plate, which is north and south to the Korla Tianshan orogenic belt deep fracture, adjacent to the eastern part of the south as a ring fracture limit, approximately 300 km, with a width of 30 to 75 km, covering an area of approximately 15,000 Square kilometers. The minerals in the main belt of the sedimentary type, self-Sinian to Carboniferous stable and continuous deposition, in order to create a good environment for the formation of tectonic copper. Paleogene strata in the study area is divided into two sections, the thickness of the upper section is more 46 m, with the thickness in the lower being 47 m [19-20]. The lower section is mainly made up of red conglomerate, pebbly coarse sandstone, sandstone, fine sandstone, siltstone and mudstone. The upper tuffaceous section contains gravel, gray sandstone, mudstone, limestone, and gypsum. In this study, 11 geological sections were measured, and 11 samples were taken to study the Paleogene sedimentary environment (Fig. 1).

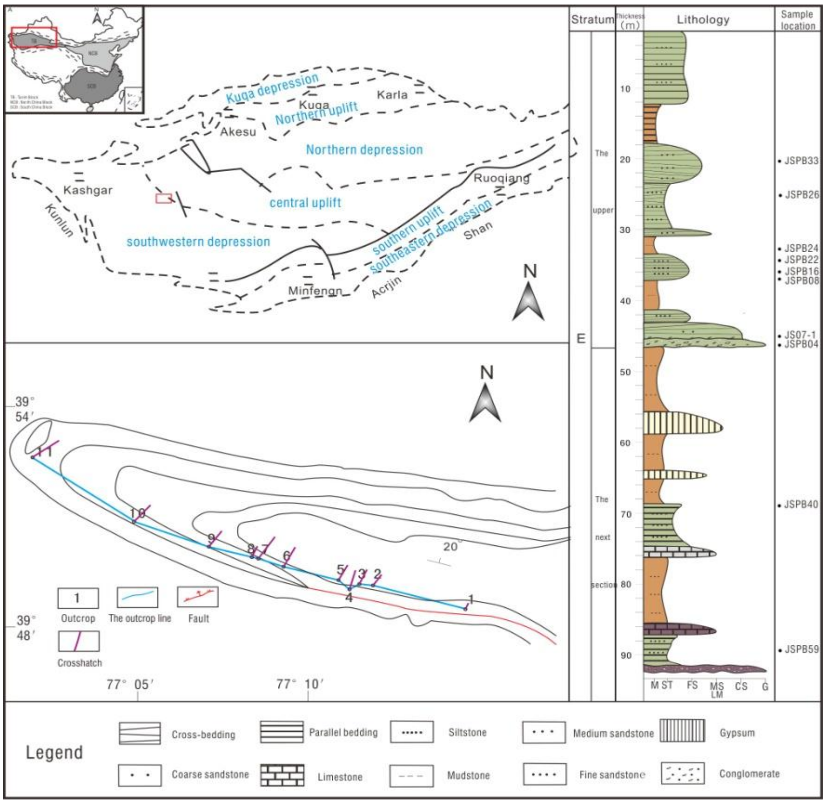

***Fig. 1** Jiashi regional geological map and lithology histogram*

M represents mudstone; ST is siltstone; FS represents fine sandstone; MS is Medium sandstone; CS stands for coarse sandstone; and G equals conglomerate.

3. Sedimentary Facies Analysis

3.1 Fan Delta Facies

The fan delta, which was deposited in a short duration, often can be found in the bottom layers, which are on the boundary between the Paleogene and Cretaceous strata. The lower part constitutes a tuff containing gravel, gray sandstone, and mudstone (Fig. 2), and reflects the current sea level rise.

The size of the tuffaceous conglomerate varies significantly, and 75% of the gravel has a lower composition maturity mainly in the volcanic tuff, with the chert gravel clast sorting moderate to poor, rounded angular edges. The gray sandstone grain sorting in general is well rounded, with developed cross and parallel bedding, which accounts for 3% of the interstitial, a material porosity of 10%. The main particles are quartz and clay cementation, and the cementation is denser.

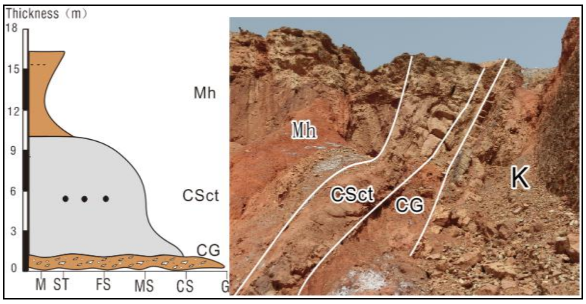

***Fig. 2** Fan delta lithology and histogram in the Jiashi area*

M represents mudstone; ST is siltstone; FS stands for fine sandstone; MS is medium sandstone; CS represents coarse sandstone; and G stands for conglomerate.

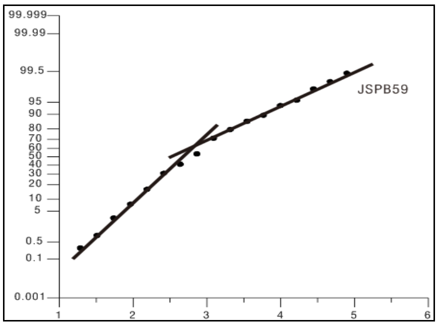

Fig. 3 *Cumulative probability curve of JSPB59*

According to the JSPB59 size analysis (Fig. 3), σi = 0.673 (0.50 to 0.70), and the sorting is better. In this study, it was found that from the accumulated probability curve, overall rolling time, and the jump times overall main content were 40%, 60%, total suspended for several times. This reflects the prevailing severe hydrodynamic conditions. The Kurtosis measure (KG) was 1.89; the frequency curve shape of the tip of the tail containing the (narrow) peak distribution skewness (SK) was 0.224; and the Kurtosis measurement was very narrow, positive bias based, and from top to bottom, thinner size.

3.2 Platform Lagoon Facies

Platform lagoon facies are made up of purple calcirudite, gray bioclastic limestone, fine sandstone, and interbedded mudstone (Fig. 4). The purple calcirudite is rounded gravel debris, with poor sorting, and a lower maturity structure. Calcite druse can be found at its surface, which accounts for approximately 15% of the content of quartz grains, characterized with round-cornered grains and rounded shapes, as well as better sorting. The Feldspar grains account for approximately 10 percent, which are characterized by rounded sub-angular particles and a rounded shape. The substrate and calcite are cemented. The gray bioclastic limestone is characterized by a crumbly and massive structure, with the main ingredient being calcite. It accounts for approximately 50% of the biological debris particles and organic matter content, and the biological structures are recrystallized calcite. The sorting is general, and the roundness is better. The bond type is base cementation.

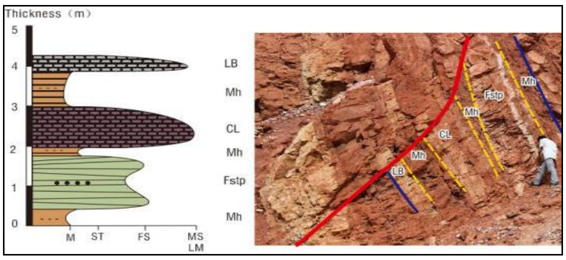

Fig. 4 *Platform lagoon outcrop*

M represents mudstone; ST is siltstone; FS stands for fine sandstone; MS is medium sandstone; CS represents coarse sandstone; and G stands for conglomerate

3.3 Tidal Flat Facies

The tidal flat area (Fig. 5) contains a shale lithology (Gypsum - mudstone - plaster), with locally developed fine gray-green sandstone. Also, mudstone gypsum veins are developed, and the plaster layer thickens in the Jiashi copper mines from east to west. There is also a partial cross-section of dolomite visible.

The region has developed sedimentary clay, siltstone, and fine sandstone, which rarely conglomerate. The sediment grain size distribution was found to be a ribbon of coarse to fine deposits, beginning from the sea to the land. In the inter-tidal flat, also beginning from the sea to the land, a sandy argillaceous sedimentary transition is visible from the deposits, which form a floor layer mix of sand and mud. The tidal arid climatic zones on the floor form a salt marsh, salt flat, and gypsum, as well as other sedimentary rocks.

The mine stratum contains gypsum, shale, and a sandstone lithology combination, which has formed on the floor of the tidal zone's arid climate. The plaster is a thin to thick layer, which is usually white, or due to impurities, an ash, yellow, beige, or white streaked color. Its cleavage is medium, and very complete.

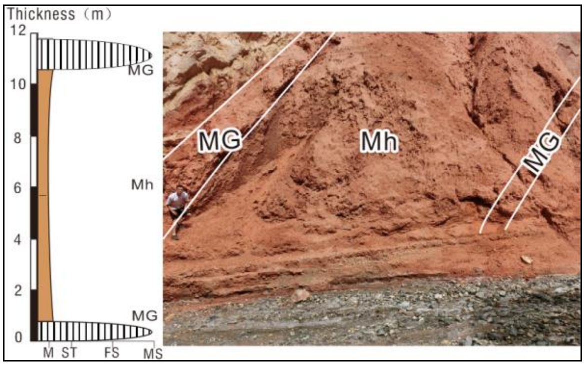

Fig. 5 *Jiashi tidal flat profile and histogram*

M is mudstone; ST stands for siltstone; FS represents fine sandstone; MS is medium sandstone; CS represents coarse sandstone; and G stands for conglomerate

3.4 Braided River Delta

The Paleogene strata in this area are a conglomerate from the bottom up the lithology, containing yellow-green pebbly coarse sandstone, yellow-green sandstone, yellow-green fine-grained sandstone, red sandstone, fine interbedded mudstone, and yellow-green siltstone. The area contains developed cross-bedding, horizontal bedding, tabular cross-bedding, graded bedding, and so on. In the study area, ripples are common, as well as hail marks, which indicate an alternating sea sedimentary environment.

3.4.1 Braided river delta plain facies

The braided river delta plain's composition consists of a large number of braided channel and braided river plain phases. It has relatively flat bottom surface erosion, and the performance of a low undulating terrain. Its channel fill sequence is mainly composed of sandstone, and conglomerates are also common. The braided river's interbedded sedimentary unit includes a transverse shaba or longitudinal shaba, and rich mixed mud-filled sand or small to medium-scale erosion grooves can be seen. Its detailed internal structure is complex, and often consists of widespread thick layers of sand deposited by the multi-phase composite units.

The sedimentary facies lithologies contain conglomerates of pebbly yellow-green coarse sandstone, yellow-green sandstone, and yellow-green fine-grained sandstone, with a clear erosion surface (Fig. 6) on the conglomerate layer. It has a large tabular and trough cross-bedding, a parallel bedding conglomerate, and a massive sandstone conglomerate. From the bottom upwards, the bedding scale management is from large and medium cross-bedding, parallel to the floor small cross-bedding, and the top is horizontal bedding. The lithology and depositional structural features reflect the deposition process of a hydrodynamic waning process.

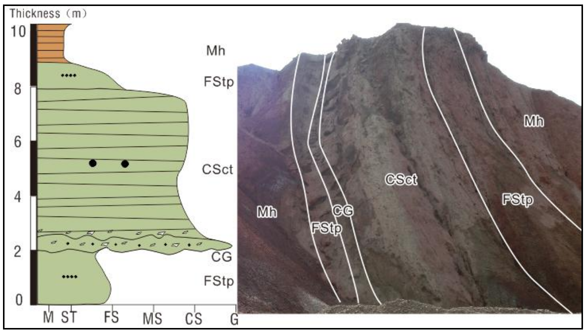

Fig. 6 *Jiashi braided river delta plain facies outcrop and histogram*

M represents mudstone; ST is siltstone; FS represents fine sandstone; MS is medium sandstone; CS stands for coarse sandstone; and G represents conglomerate

The yellow-green conglomerate, which is made up of gray-green or yellow-green gravel-based quartz, accounts for approximately 65 percent of the gravel. The sorting is medium, with a high roundness. Upward, gravel size becomes smaller and gravel decreased, and the local alignment was a gravel-like structure. The yellow-green coarse pebbly sandstones are mainly quartz gravel, with visible tuff gravel. The sorting was poor to moderate, with sub-rounded to sub-angular low compositional maturity. The partially visible gravel aligning upward in particle size becoming smaller and there is a development of large plate cross-bedding, with calcareous cementation or argillaceous sandstone, and the matrix contains copper mineralization. The yellow-green sandstone's sorting is general to well-sorted, with developmental tabular cross-bedding, as well as parallel bedding. The sandstone mineralization contains malachite; roundness is the second round - sub angular, and general sorting. The particulate support contact is cement. For the red mudstone, which is severely weathered with the broken surface, the structure or silt mashed common structure is massive textures, with locally visible ripples, containing argillaceous and calcareous cementation cement, and abundant clay minerals. The bedding is either not developed or is horizontal bedding, also contains the late filling of the gypsum fine veins.

According to the JS07-1 size analysis (Fig. 7), σi = 0.673 (0.70 to 1), and the sorting is medium. The cumulative probability curves are Sec line in leap second overall based and at approximately 80%. This reflects that the prevailing hydrodynamic conditions were severe. The Kurtosis measurement (KG) is 1.17 (narrow Kurtosis), and the skewness (SK) is 0.22 (moderate kurtosis), with a positive based bias, and from top to bottom, thinner size.

3.4.2 Braided river delta front

The braided river delta front includes the underwater distributary channel deposits, estuary sand bar, sheet sand, and distal bar. Among these, particularly in regards to the active underwater distributary channel, the large deposits in front of the sub-phase portion are the leading edge of the main sub-phase deposition. The distributary channel between the sedimentary lithology is smaller, often consisting of pink sandstone and mudstone [20-22]. Color is gray and gray green.

In this study, it was recognized that the braided river delta front (Fig. 8) lithology contains red mudstone interbedded with fine-grained sandstone and mudstone, and green siltstone. There is developed parallel bedding and small cross-bedding visible, with ripples and waves in the common marks impression, which reflects the prevailing low power conditions.

The area contains thin developed interbedded sandstone and mudstone, as well as yellow green and red sandstone interbedded mudstone. The thickest sandstone is 50 cm, and the thinnest is 10 cm. There is a pillow-like structure containing balls, and the sandstone sorting is general to well sorted, with well-rounded particles which have developed in staggered or parallel bedding. The yellow-green siltstone's rounding is moderate with good sorting, and a developed level or cross-bedding. The sand-like crumb structure also has good sorting, with rounded to angular corners. For the miscellaneous group support, the cementation type is a cement base.

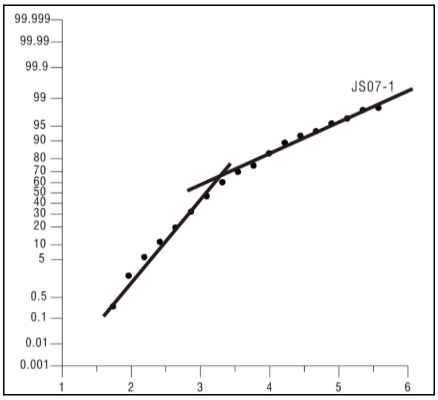

Fig. 7 *Cumulative probability plot of JS07-1*

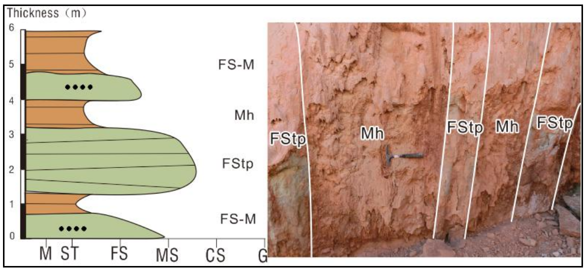

Fig. 8 *Braided river delta front outcrop and histogram*

M is mudstone; ST stands for siltstone; FS represents fine sandstone; MS, is medium sandstone; CS represents coarse sandstone; and G is the conglomerate

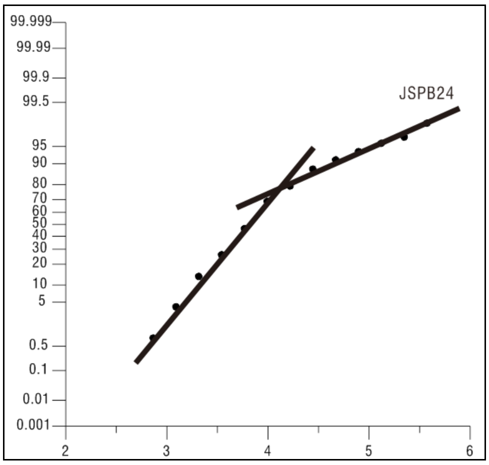

Fig. 9 *Cumulative probability plot of JSPB24*

The JSPB24 size analysis (Fig. 9) shows that σi = 0.484 (0.35 to 0.50), with good separation. The cumulative probability curves are Sec line in leap second overall based and at approximately 70%. This reflects that the prevailing hydrodynamic conditions were more intense. The Kurtosis measurement (KG) is 1.05 (moderate kurtosis), and the skewness (SK) is 0.146, with a positive based bias, and fine and medium grain mainly.

Friedman (1979) delineated the beach and river sand discrete boundaries, and it can be seen that (in JSPB59, JS07-1, JSPB24 as the research object), JSPB59, JS07-1, JSPB24 fall within the scope of the river sand. Also, JSPB59, JSPB24 lie in the river and beach sand near the boundary, and will be in line with the characteristics of the coastal sandstone.

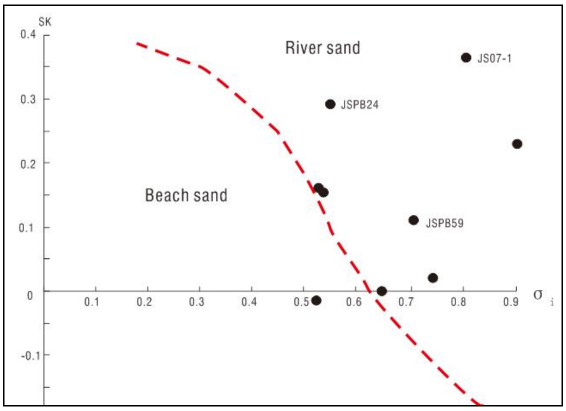

Fig.10 *Standard deviation (σi) and skewness (SK) discrete map of the samples from the Jiashi mine*

4. The Evolution of Sedimentary Environment

In Fig. 10, the Jiashi lithological column can be seen, with the sea level changes and depositional environment. Fig. 11 illustrates the evolution of the sedimentary fan delta environment as follows: in the early Palaeogene period, there was a main fan delta environment in the Jiashi area, and the sediment thickness ranged from 0.5 to 2.6 m. As for the platform and lagoon environment: later on, the climate was either warm and dry, or hot and dry. When the sea level rose, the Jiashi area was below sea level, forming a platform and lagoon environment, relative to the sea level becoming gradually shallow from east to west. At that time, the effects of the seawater were minimal; biology developed, and then formed carbonate rocks. The relative sea level reached its maximum during this time. In the tidal flat environment, the sea level began to decrease, and environment of the study area gradually became a tidal flat environment. In the sedimentary environment, the sea level fluctuation fell, and the environment from the supra-tidal zone gradually became the inter-tidal zone. The relative sea level gradually became deeper from east to west. In regards to the braided river delta plain environment, after a short humid period, the climate changed to a semi-arid climate again, moving towards an arid climate. The sea level dropped, forming a braided river delta plain environment. In the littoral sedimentary environment, the water had high energy with strong wave action, and the thin layer extends far, which indicates that the coastline was straight, while the bank face was flat and wide with a small angle. The variable quasi front environment across the river delta experienced slow sea level rising, and a braided river delta front environment was formed. The effects of the seawater decreased, and widely developed horizontal bedding and small-scale cross-bedding took place. Smaller angle explained sedimentary base level was gentle. The braided river delta plain environment experienced fluctuations in the sea level's falling and rising, and a braided river delta plain was formed.

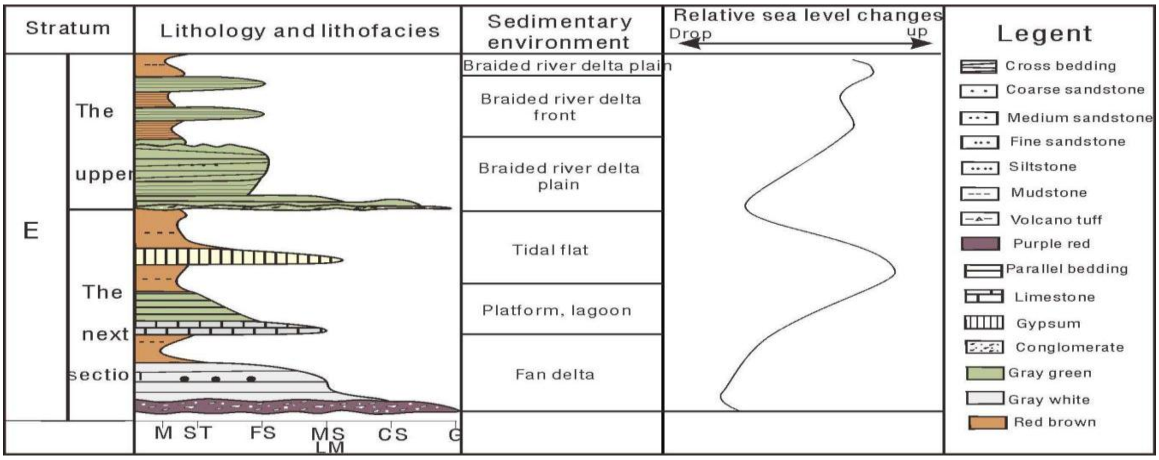

Fig.11 *Lithology histogram, sedimentary environment, and sea-level change map in Jiashi*

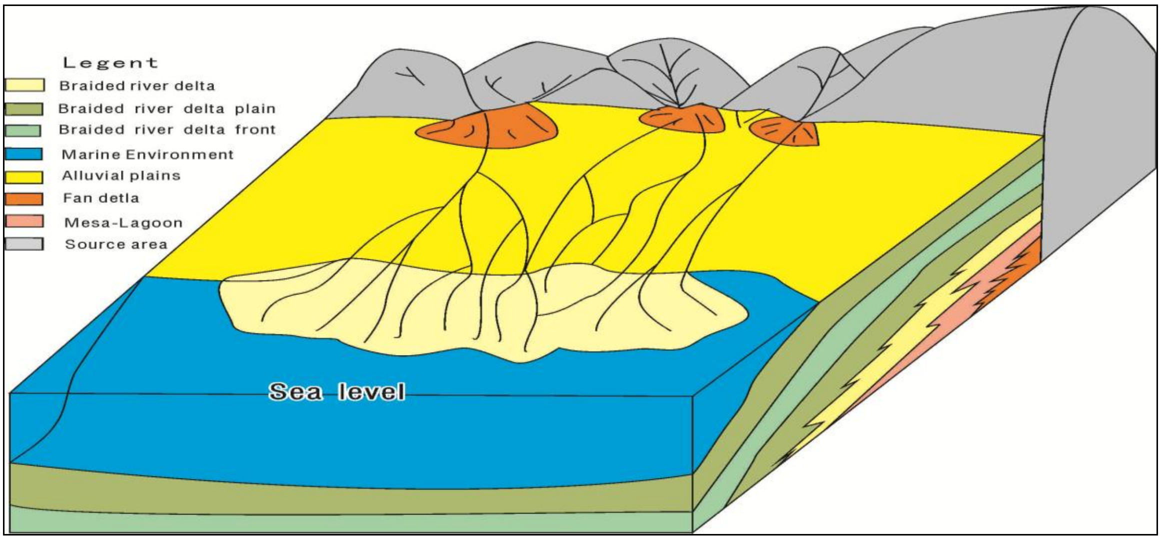

Fig. 12 *Sedimentary environment in Jiashi*

5. Conclusions

The field observations and analysis of the measured profile were combined to analyze the depositional environment of the Jiashi Paleogene strata, and determine the order of the fan delta, mesa, lagoon, tidal flat, braided river delta plain, braided river delta front, and braided river delta plain.

Through field observation and interior finishing materials, it can be seen that the deposited phases contain tuffaceous conglomerates at the bottom; red and gray sandstone mudstone as the fan delta facies; limestone; a sandstone layer as the platform; lagoon facies; tidal flat deposits comprised of plaster and mudstone; conglomerate and sandstone as the lower part of the braided river delta plain sediments; fine sandstone and mudstone; and siltstone as the braided river delta front facies.

From bottom to top, the Jiashi Paleogene strata consist of mudstone, limestone, gypsum, conglomerate, and sandstone. The samples were analyzed by size. In this study, it is concluded that the Jiashi Paleogene stata's sedimentary environment is mainly in a beachfront phase.

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