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# Paleogeographic Evolution and Sedimentary Facies Analysis of Lake Basins in the Northwest Area of Qaidam Basin

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**Abstract:** Based on the observation and description of the systematic core samples, combined with the information on the evolution of lake basins and sedimentary background in the northwest area of Qaidam Basin, it was found that the area as a whole was in a lake environment. Accordingly, the sedimentary facies in the northwest area of Qaidam Basin were divided. The main subfacies were semi-deep lake and shallow lake. Meanwhile, based on the distribution of lithology, the microfacies were further divided into algal mat, beach, gray cloud flat and muddy flat. Among them, the algal mat microfacies was distributed very little, the gray cloud flat and muddy flat microfacies were more developed; the semi-deep lake subfacies also had a special microfacies type - turbidity fan, which mainly developed in the area of saline springs. After the spatial distribution of sedimentary microfacies in Qaidam Basin northwest area was clarified, the sedimentary facies in individual wells were divided. It was found that the sandstone and carbonate layers were stacked vertically to form relatively good reservoir and permeability combinations. Based on the above analysis, Qaidam Basin northwest area has been in a closed water environment for a long time, with no significant change in the base level, but it is very sensitive to climate change, and the frequent small fluctuations in the base level caused by seasonal changes determine the rapid alternation of sedimentary microfacies types.

**Keywords:** Qaidam Basin; Evolution of Lake Basins; Sedimentary Facies.

## 1. Geological Overview

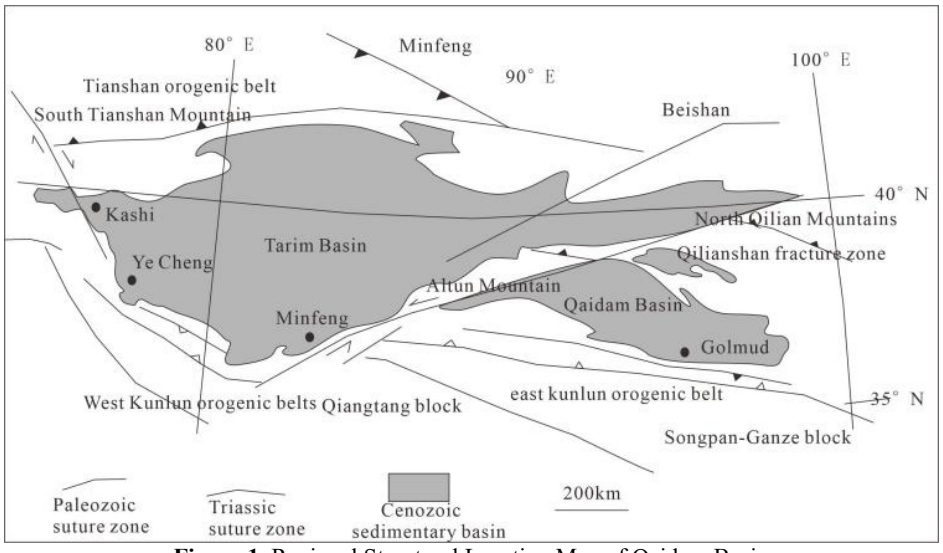



**Figure 1.** Regional Structural Location Map of Qaidam Basin

The Qaidam Basin is located in the northern part of the Qinghai-Tibet Plateau and is surrounded by the Qilian Mountains, the Alashan Mountains, and the Kunlun Mountains structural belts. It is the largest continental saline lake basin in northwestern China, with widespread overpressure [1] (Fig. 1). The basin is located in Qinghai Province, with an elevation of 2,600 to 3,000 m, generally higher in the northwest and lower in the southeast, with higher edges and lower middle. It is a typical continental plateau basin. The basin area is about $1.21\times10^4$ km$^2$, and the distribution area of Middle and Cenozoic sedimentary rocks is about $9.6\times10^4$ km$^2$, with a maximum sediment thickness of 17,280 m, making it the largest continental Middle and Cenozoic oil and gas basin in the Qinghai-Tibet Plateau[2-4]. The Qaidam Basin has undergone multi-period tectonic evolution processes under various dynamic backgrounds and different structural regimes, with complex material composition and geological structure, and also shows complex superposition and combination relationships in the relationship between the basin and the mountains[5]. The Middle and Cenozoic tectonic evolution is mainly controlled by the stage-by-stage subduction and closure of the Tethyan

in the south of the Eurasian continent in the Middle and Cenozoic, as well as the remote effect of the Indian plate colliding with the Eurasian plate to the north. The complex geological evolution process has important control over the tectonic, sedimentary, and oil and gas accumulation processes in the Qaidam Basin [6].

# 2. Stratigraphic Features

The geological strata in the Qaidam Basin are clearly divided, and the Cenozoic sedimentary strata are more developed in the western part of the basin [7]. The Paleogene-Neogene strata form a continuous belt within the basin, while they are scattered around the basin. The outcrops of the Paleogene-Neogene strata are mainly found on the hanging folds on the ground. They are mainly inland sediments, consisting of various rocks such as sedimentary rocks, clay rocks, carbonate rocks, and salt deposits [8]. The fossils and sedimentary features contained in them indicate that they are the products of a dry or semi-arid climate. The geological divisions and lithological features are described in descending order as follows:

(1) The Paleogene Eocene Epoch Lule River Formation $E_{1+2}l$: The middle and lower sections are mainly red sandstone and mudstone, while the upper section is composed of gray sandstone and gray-deep-gray calcareous mudstone and mudstone alternating layers. The western sedimentation center is located in the area of Hongliuquan-Ganzhaigou, where the rock texture is relatively fine.

(2) The $E_3^{l+2}{}_g$ Lower Cenomanian Formation of the Paleogene System: It is mainly composed of grayish purple mudstone, brownish gray and dark gray shale-like mudstone, interbedded with grayish yellow, brownish gray limestone, mudstone, shale-like mudstone, and fine to coarse sandstone. Dark colored rocks are mainly distributed in the ChaiXi area, where the Liongou-Hongliuquan and South Yishan are two carbonate rock enrichment areas, and Liongou is also an enrichment area for gypsum, salt rock, and potash.

(3) The $N_{1g}$ formation of the Recent System: It is absent only in the western parts of Alar, Qigequan and Hongliuquan, where it is finer in texture than the former formation. It is mainly composed of greyish-brown mudstone and greyish claystone, with thin layers of greyish grey shale and thick bedded greyish-brown to greyish-brown siltstone. In the western part of the area, the formation is mainly composed of semi-saline to saline lake mudstone, with river sandstone in second place. South of the Dianzhaogou-Youquanzi line, the lake water gets shallower from bottom to top, changing from grey to red. The area around Youquanzi-Nanyishan is a center of carbonate rock accumulation.

(4) The newly assigned $N_2^1$y oil shale formation in the New System underlies the Xiushan Group: it narrows and becomes greyer from east to west near the basin center, mainly consisting of a set of oxidized-colored sandstone and mudstone. The upper part is a grayish fine-grained mudstone interbedded with mudstone, while the lower part is a grayish and dark gray mudstone and muddy limestone interbedded. The carbonate rock concentration area is located at the southwestern end of the NanYiShan-YouQuanzi-DaFengXi, which is obviously eastward shifted compared to the former.

(5) The newly established $N_2^2$y oil shale formation in the New System: It is mainly a set of oxidized-colored sandstone and mudstone, with yellow, yellow-brown or brownish-gray, and light brown sandstone and mudstone as the main components. The content of carbonates is slightly less, and the concentration center is still in the area of Southyishan-Youquanzi.

(6) The recently strata of the N23s Liongougou Formation $N_2^3$s: are integrated above the Youshangshan Formation, and their distribution range has clearly shrunk. The Chaiyuan South area is a lake-advance type of sedimentation, with rock texture becoming finer, and gray sand-claystone being the main rock type. The Chaiyuan Northwest area has a noticeable change in rock type and color from the underlying strata, but the amount of carbonate rocks has decreased and the amount of mudstone, saltstone, and claystone has increased. Gray mudstone is the main rock type, with a small amount of calcareous mudstone and more mudstone and claystone containing mud.

(7) The Quaternary System: It has the widest distribution range and is composed of fluvial-lacustrine sedimentary rocks of alluvial and lacustrine detrital rocks, clay rocks, and chemical rocks, like the Paleogene-Neogene System, which are also a set of inland sediments under arid climate conditions. Among them, the $Q_{1+2}$q section of the Lower and Middle Middle Pleistocene in this area is gray, dark gray mudstone, shale and interbedded bituminous salt rock; the $Q_{3+4}$ section of the Upper and Recent Pleistocene is mainly gray, yellowish sand and gravel and powdery sediment and clay layers, as well as salt deposits.

# 3. Evolution of Lake Basins

## 3.1. The Stages of Lake Development

Due to the differences and segmentation of ancient tectonic, ancient climate, ancient sediment sources, and ancient topography, lake basins have a main sedimentation and subsidence center and multiple local subsidence centers, and with the passage of time, under the influence of tectonic movement, the sedimentation and subsidence center appears to have a regular transfer, which can be roughly divided into four stages [9-10].

The stage of filling in and making up for deficiencies of the Lulehe Formation ($E_{1+2}$) and the lower section of the Shanggancun Formation ($E_3^1$): This stage mainly took place on the background of uplift during the Cenozoic period, with its sedimentary features characterized by red coarse-grained sedimentary rocks, representing floodplain and river-delta deposits. At the same time, in the composite area where the Alqin Mountain frontal fault and Kunbei fault acted together, the Liongou-Yingxiong area, due to the escape of tectonic forces, first formed a lake and deposited more than 1,000 meters of lacustrine dark claystone.

The upper section of Xiashanchaigou Formation ($E_3^2$) - the N1 section of Shangganchaigou Formation ($N_1$): During this large sag stage, the lake basin expanded rapidly. In the Chaiyuanbeidistrict, the lake shore had reached the front of the Altyn Tagh Mountains, while in the Chaiyuanshidistrict, it was basically close to the Kunlun Mountains and had reached the Sanhu area to the east, but the sedimentation center remained in the area of Shizaogou - Yingxiongling - Mangya. At the same time, due to the steeper terrain in the front of the Altyn Tagh Mountains, deep water turbidity currents were more developed, forming many fan-shaped sedimentary rocks such as lake bottom fans, fan-delta and slumping turbidity currents.

The rapid migration stage of the $N_2^1$ Oilshale Hill Formation to the $N_2^2$ Oilshale Hill Formation: Due to the rapid uplift of the Alqingshan and Kunlun Mountains caused

by the Late Qixiang Movement, coupled with a drying climate, the lake basin area began to shrink and rapidly migrated north and east. The sedimentation center has migrated to the area around Xiao Liangshan, Ketemilik and Youdunzi. During this period, the overall sedimentation was still mainly lake-related, but river floodplain, delta and fan-delta sedimentation developed extensively around the basin margins.

The Lake Contraction and Folding Return Stage of the Shizigou Formation ($N_2^3$): The basin generally rises, but the lake basin still exists, with the sedimentation center having moved east to the Yiliping area. During this period, floodplain river systems developed, and halite and rock salt layers formed during the lake basin contraction can be seen in the lacustrine strata.

Therefore, the Paleogene Neogene lake basin in the Chaixi region underwent three major evolutionary stages: occurrence, development, and extinction [11]. The period from the Paleocene to the Lower Oligocene ($E_{1+2}$-$E_3^1$) is the stage of lake basin formation, during which the climate is dry, the lakes are shallow, and evaporation is strong. Many areas are in a brackish water environment, and various types of authigenic carbonate minerals with high content appear accordingly; But there are relatively deep inherited faulted lakes in the Lion Gully, Nanyi Mountain, and Xiaoliang Mountain areas in front of the Altai Mountains. During the Oligocene to Miocene ($E_3^2$-$N_1$) period, the climate changed from arid to semi-arid, with an increase in freshwater supply, an expansion of the lake surface, and a deepening of the water level, entering the peak period of lake basin development. It was also the main development period of the Paleogene Neogene mudstone and carbonate oil bearing rock series in the basin. In the Pliocene ($N_2^2$-$N_2^3$) basin, a set of salt lake evaporite rock series containing gypsum, saltpeter, rock salt, etc. was widely present. In addition, as the water depth became shallower, the sediment layers became coarser and the lacustrine clastic rock layers increased significantly[12]. It is a sign of the shrinking of the lake surface and the trend towards the disappearance of the lake.

## 3.2. The Evolutionary Laws of Lake Basins

In correspondence with tectonic movements, the Qaidam Basin has had three major sedimentary cycles since the Mesozoic era, with frequent migration of sedimentation and subsidence centers (Fig. 2). In different tectonic regions and geological periods, three sets of hydrocarbon source rocks have developed: coal seam deposits developed in the mountain front of the Qaidam North margin and the Alqin South margin during the early to middle Jurassic period; lacustrine mudstone deposits developed in the mountain front of the Yili Ping depression area-East Kunlun orogenic belt during the late Paleogene and Neogene periods; and lacustrine mudstone deposits developed in the Qaidam Basin's central area during the Quaternary period [13].

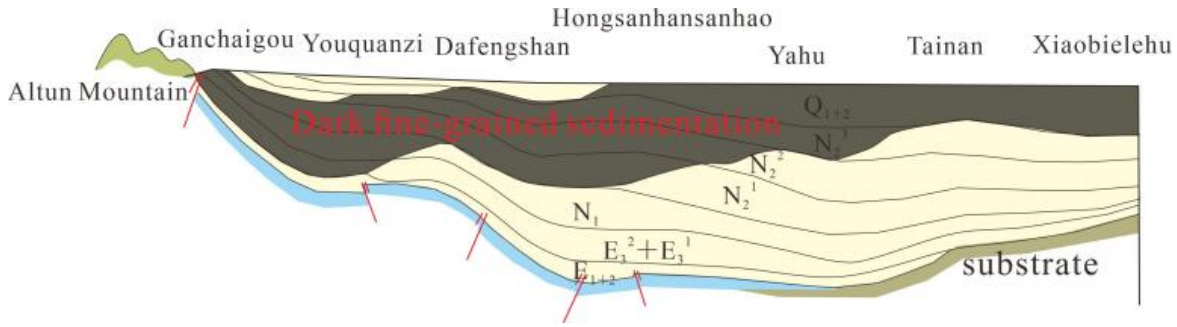



**Figure 2.** Schematic diagram of sedimentary center migration in Qaidam Basin

In the northern part of Chaixi area, there were relatively stable sag basins in the Alqin Mountains front during the Mesozoic era, with some lakes continuing to develop into the Quaternary period. Based on a comprehensive analysis, these hereditary lakes appeared in the areas of Southji Shan, Xiao Liang Shan, and Jian Ding Shan; during the $E_{1+2}$ period, their range was smaller and relatively isolated. Entering the E31 period, these small lake basins expanded and connected, forming the initial lake surface of the area, with the sedimentation center located in the areas of Xiao Liang Shan and Southji Shan. The lake shore followed the distribution of Gou 4 - Yueya Shan - Jian Ding Shan - Luan Shan Zi. During this period, the Niuniuzi Lang - Dafengshan alluvial system began to develop and formed a raised terrain. Because of its long-term existence ($E_{1+2}$-$N_1$), it not only hindered the lake from expanding to the east, but also caused great differences in the sedimentary features of the eastern and western districts of Chaixi Northwest.

In $E_3^2$ period, the Chai Northwest and Chai Southwest areas entered the maximum lake aggradation stage simultaneously, and the sedimentation center in the study area remained basically unchanged, but the lake shore expanded to the line of Yueyashan-Hongzhong1 Well-Jian1 Well. From $N_1$ to $N_2^1$ period, the lake as a whole maintained a high-water level, and even a large lake aggradation occurred in the latter part of $N_2^1$. During this period, the sedimentation center slightly shifted north and east, with its southern boundary reaching Xianxiaquan-Youquanzi to the north. The trend of the lake expanding to the east was obvious. By the time of $N_2^2$-$N_2^3$ period, the sedimentation center of the lake was clearly shifted eastward, and the area west of Nixiwangshan became a marginal lake or shallow lake, and almost all the area from it to Dafengshan was a semi-deep lake.

In summary, the lacustrine basin in Chaixi area during the Paleogene-Neogene period had a west deep and east shallow structure, with the western slope being steep and the eastern slope being gentle. The western area was mainly semi-deep lakes, with shallow lakes in second place, and two maximum lake flooding events occurred at $E_3^2$ and $N_2^1$. The eastern area had long-term development of marginal and shallow lakes, with lake water gradually deepening from the bottom up until the late $N_2^2$ period when it reached semi-deep lakes.

## 3.3. Sedimentary Environment

Due to the differences and segmentation of the ancient tectonic, ancient climate, ancient sediment source, and ancient topography, the sedimentary evolution of Mangya depression is mainly divided into three periods: $N_1$, $N_2^1$, and

$N_2^2$. In terms of plane, Mangya depression is separated from Yingxiongling depression by Yongnan ancient uplift, and the $E_3^2$-$N_2^1$ period is characterized by continuous semi-deep lake-shallow lake sediment filling (Figure 3).

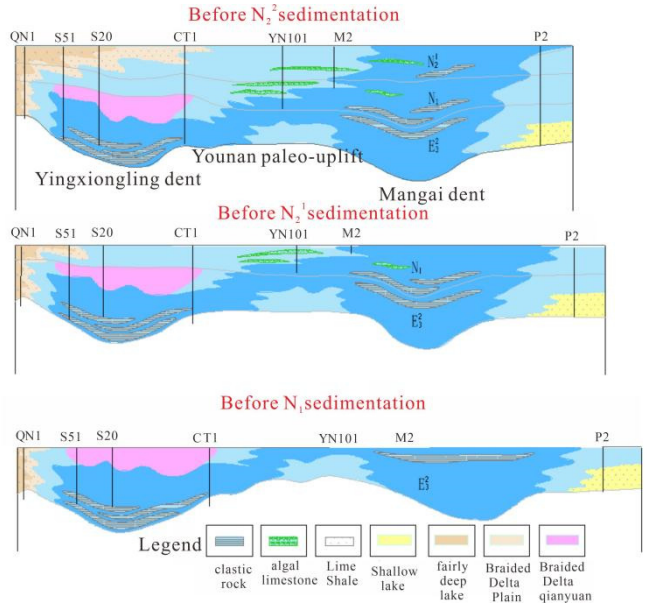



**Figure 3.** Evolution map of planar sedimentation in Mangya depression

Spatially, the $N_1$ depression in Mangya is located in the transition zone between the source rock development areas of the $E_3^2$ source rock in Zahaquan depression and the $N_2^1$ source rock in Qi Xibeizu, which provides a sedimentary background for the development of large-scale source rocks (Fig. 4).

During the $N_1$ period, the entire Mangya depression was characterized by a high salinity, deep water bodies, and strong reducing conditions, indicating a saline-shallow to intermediate lake sedimentary environment. This environment was characterized by a closed and stable system, with a gradual change in water depth from deep to shallow [14]. During this period, the lake surface frequently changed. From early to late N1, the water body as a whole gradually became shallower, and the entire process was characterized by frequent changes in the lake surface. Based on this, the high-quality shale sections mainly developed in the middle and lower sections ($N_1$ sedimentation early-mid period) (II-V oil layer group).

During the $N_2^2$-$N_2^1$ period, influenced by the western Alarl sediment source, the lake basin migrated eastward and gradually contracted, and the Ketemelik area developed a shallow lake-shallow lake-salt lake sedimentary environment. During the early $N_2^2$, the area was mainly composed of shallow lakes, with interbedded deep lakes. Shale, gray limestone, gravel bars, and algal mats were deposited in a superimposed manner. During the late $N_2^2$, the area was mainly composed of shallow lakes and salt lakes, with sedimentary microfacies such as clastic bars and brine mud flats gradually increasing.

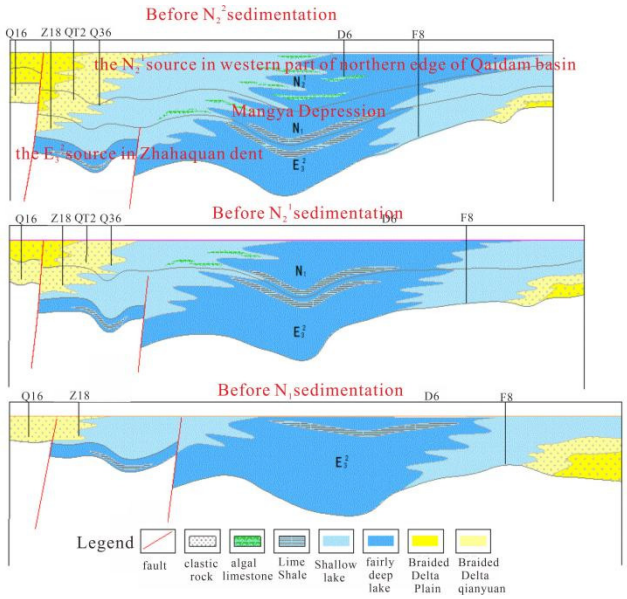



**Figure 4.** Spatial sedimentary evolution map of Mangya depression

# 4. Sedimentary Facies Types and Distribution

## 4.1. Sedimentary Facies Types

Based on the sedimentary background and well logging curves, the shallow lake and semi-deep lake subphase are further divided into four microfacies (Table 1): algal mat, beach, gray cloud marl, and muddy marl. The shallow lake subphase in the slope belt is relatively narrow, and the lithology mainly consists of light gray and light brown mudstone, sandy mudstone, muddy limestone, and thin bedded quartz sandstone. There is a lack of red rock, which represents an oxidized environment. In the gentle slope belt of the shallow lake subphase, in addition to the development of gray mudstone, muddy siltstone, etc., occasional purple red mudstone can be seen.

**Table 1.** Petrophysical Microfacies Subdivision Chart for the Chaiyu North Area

| Sedimentary facies | Sedimentary subfacies | Sedimentary microfacies | Rock type |
|---|---|---|---|
| Lacustrine Facies | Shallow lake facies | Algal mat | Algal limestone |
| | | Beach | Limy siltstone, Pelitic siltstone |
| | | Gray Cloud Plain | Grey limestone, Muddy limestone |
| | Semi deep lake facies | Clay meadow | Calcareous mudstone, Dolomite Limestone, Mudstone, Clay mudstone |

(1) Shallow lake subphase

1) algae mat

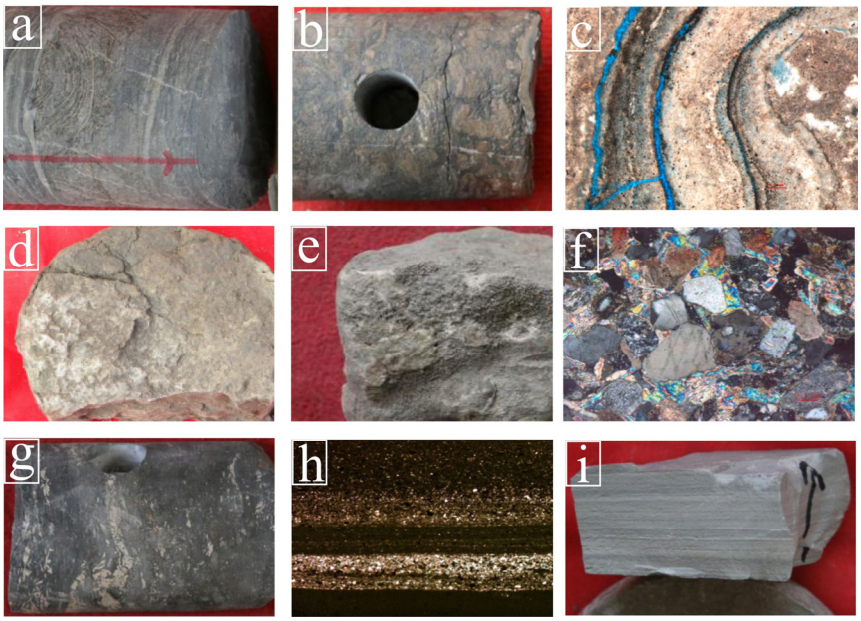
Consisting mainly of algal limestone, it is often adjacent to muddy limestone and shale with a single layer thickness of about 10-40 cm. On the imaging logging, the algal stromatolithic limestone can clearly see the stromatolithic structure, the white and bright areas indicate high resistivity, while the dark areas indicate low resistivity. The bright and

dark alternating areas correspond to the rich algal layers and rich carbonate layers; the imaging characteristics of algal laminae limestone are similar to those of algal stromatolithic limestone, with the rich algal layers and rich carbonate layers being horizontal or wavy and relatively flat (Fig. 5a-c).

The algal limestone in the Qiqihaer Northwest area mainly developed in the upper Ganchaigou Formation ($N_1$) to the lower Youshashan Formation ($N_2^1$). Due to the gradual activation of tectonic movements during this period, the supply of sediment sources became increasingly abundant, resulting in the thin single layer thickness of algal limestone in algal microfacies. The vast majority of them are less than 0.5 m in thickness, with an average cumulative thickness of about 1.6 m per well, accounting for 0.63% of the total thickness of the formation. The algal limestone is extremely thinly interbedded with dark muddy claystone, mudstone, and various transitional rock types, and the content of terrigenous detritus is markedly increased, often forming algal claystone with sand or sandy algal wackestone. It is mainly distributed in the Xianshuiquan, NanYi Mountain, Dafengshan, and Jian Dingshan areas.

2) Beach

The distribution of sand plains is mainly influenced by the northeastern direction of the Niuniuzi Lang material source and the northwestern margin of the Alqingshan Fan-delta. The distribution of sand plains changes significantly over time and is mainly distributed in the areas of Dafengshan, Youquanzi, and the southern part of Nanyishan. The rock type is mainly fine-grained sandstone (Figure 5d-f).




a. Mao 2 well, 2526.7m, algal limestone; b. Liang 108 well, 1733.23m, algal limestone; c. Liang 105 well, 1620.37-1626.17 meters, algal limestone; d. Liang 101 well, 711.24m, gray fluorescent mudstone sandstone; e. Liang 101 well, 750.83m, medium fine sandstone; f. Liang 101 well, 788.08m, gypsum fine-grained feldspar lithic sandstone; g. South 8 well, gray black snowflake shaped, spotted gypsum limestone; h. South 105 well, 1723.75m, interbedded with silt strip and mud crystal dolomite; i. Open 3 wells, horizontally layered mudstone and limestone.

**Figure 5.** Location and stratigraphic distribution characteristics map of Chaixi structure

3) Gray Cloud Plateau

They are mostly light gray or bluish gray clay-rich micrite limestone, with less pure ones and also containing grease, rock salt, etc. They are widely distributed in the study area (Fig. 5g-h).

(2) Sub-deep lacustrine facies

In the sub-deep lake subphase of the mudstone microfacies, the rock color is mainly gray, dark gray, and black (Figure 5i). It is mainly found in the Ketermik area, with a lithology of fine-grained carbonate rock, mudstone, and thin bedded or lenticular siltstone and gypsum rock. Iron sulfide is commonly found in the rocks. Horizontal bedding and gentle undulating bedding are common.

There is also a relatively special microfacies type in the sub-deep lake subphase - turbidity fan, which mainly develops in the area of saline springs. Turbidity fans usually develop in the semi-deep lake area on the steep slope side of the lake basin, formed by the sediment carried by turbidity currents. The rock properties of the turbidity fan are quite complex, and conglomeratic breccia, containing gravel claystone, fine sandstone, mudstone, and mudstone can all appear, with gray and dark gray predominating in color.

## 4.2. Sedimentary Facies Types

By statistical analysis of the lithological development thickness percentage of a single well, it was found that the dominant microfacies is closely related to the lake invasion and withdrawal system and its high-frequency sequence. That is, the carbonate sedimentation mainly develops in the lake withdrawal system domain of the third-order sequence, and the sandstone mainly develops in the lake invasion system domain; the carbonate sedimentation such as huicping and zhaoqiu mainly develops in the descending half-cycle of the fourth-order sequence, and the sandstone sedimentation such as shapa mainly develops at the sequence boundary of the fourth-order sequence; the gray limestone is relatively developed at the interface of the fifth-order sequence, and the sandstone and carbonate sedimentation form a relatively good reservoir combination and good permeability combination vertically. For example, the sandstone and gray limestone combination developed at 3090-3110m of M2 well shows good oil-bearing properties, as evidenced by fluorescence, oil

spots, and oil stains (Figure6).

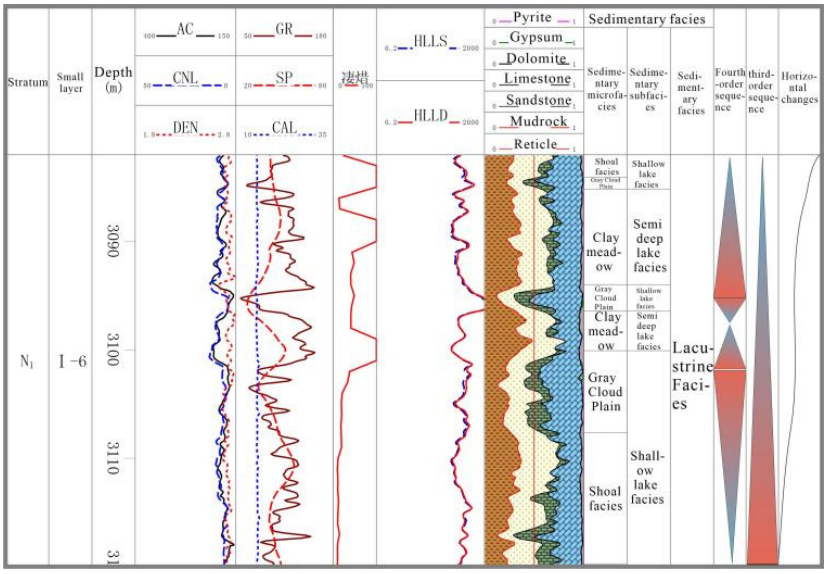



**Figure 6.** Comprehensive column chart of sedimentary microfacies in M2 well

The manuscript should include a conclusion. In this section, summarize what was described in your paper. Future directions may also be included in this section. Authors are strongly encouraged not to reference multiple figures or tables in the conclusion; these should be referenced in the body of the paper.

## 4.3. Sedimentary Facies Characteristics of the Connected Wells

Based on the above analysis, the Chaihe Northwest area has been in a long-term closed water environment with no significant change in the base level, but it is highly sensitive to climate change. The seasonal changes cause frequent minor fluctuations in the base level, which determines the rapid alternation of sedimentary microfacies types. In this study, a regional sedimentary relative-age profile was established on the basis of the previously established sequence stratigraphic framework, extending across the study area.

This section is the focus research area of this thesis, and it passes through 7 wells. In the southern area (Figure 7), the Shaoshan Formation of the Lower Oil Sand Group is widely developed in deep lake facies, while the Xianshuiquan area in the northwestern part is developed in turbidite fan bodies; in the northwestern Xianshuiquan area of the Upper Oil Sand Group, the fan-delta facies is developed; the overall area is mainly a shallow lake margin, with the main feature being the superposition of sand plains and gray plains, and the north-south belt distribution feature is basically consistent.

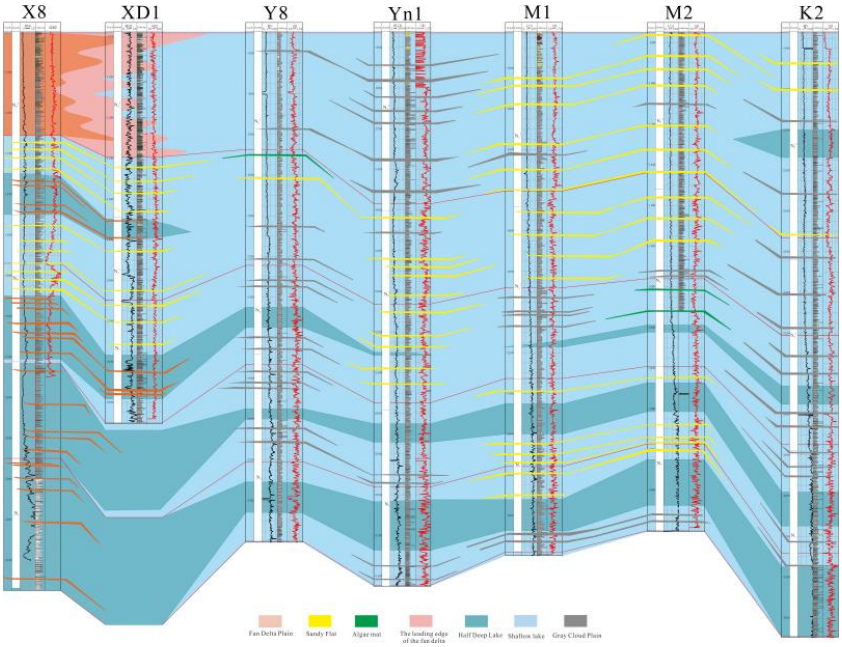



**Figure 7.** X8-XD1-Y8-YN1-M1-M2-K2 Neogene sedimentary well profile in the northwest region of Chai

# 5. Conclusion

(1) The Paleogene Neogene Lake basin in the Chaixi region underwent three major evolutionary stages: occurrence, development, and extinction. The period from the Paleocene to the Lower Oligocene ($E_{1+2}$-$E_3^1$) is the stage of lake basin formation, during which the climate is arid and many areas are in a brackish water environment; During the Upper

Oligocene to Miocene ($E_3^2$-$N_1$), the climate changed from arid to semi-arid, with an increase in freshwater supply, an expansion of the lake surface, and a deepening of the water level, entering the peak period of lake basin development. It was also the main development period of the Paleogene Neogene mudstone and carbonate oil bearing rock series in the basin; A set of salt lake evaporite rock series containing gypsum, saltpeter, rock salt, etc. was widely present in the Pliocene ($N_2^2$-$N_2^3$) basin. As the water depth became shallower, the sediment became thicker and the lacustrine clastic rock layers increased significantly. It is a sign of the shrinking of the lake surface and the tendency of the lake to disappear. In summary, the Paleogene Neogene lake basin in the Chaixi area is deep in the west and shallow in the east, with steep western slopes and gentle eastern slopes. The western region is dominated by semi deep lakes, followed by shallow lakes, and there are two maximum lake floods at $E_3^2$ and $N_2^1$. The eastern region has been continuously developing coastal and shallow lakes, gradually deepening from bottom to top until reaching a semi deep lake in the late $N_2^2$ period.

(2) In the Chaihe Northwest area, there are two mains sedimentary subfacies and four sedimentary microfacies, with the shallow lake facies of Huichunping and the semi-deep lake facies of Nihuiping being the main ones, which are widely developed in the study area. Vertically, the deep lake area gradually shrinks, and the dominant microfacies is closely related to the third-order sequence lake invasion and retreat system and its high-frequency sequence: the carbonate sedimentation mainly develops in the lake retreat system domain in the third-order sequence, and the sandstone mainly develops in the lake invasion system domain; the carbonate sedimentation such as Huichun and algal mounds mainly develops in the lower half of the fourth-order sequence, and the sandy sedimentation such as sandplain develops mainly at the sequence boundary of the fourth-order sequence; while the limestone develops relatively more at the fifth-order sequence boundary.

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