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Lithofacies Paleogeographic Characteristics of Ma3 Member in Eastern Ordos Basin

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Abstract

The Ordovician Magnolia Formation in Odors Basin is one of the core horizons of oil and gas exploration. The third member of Magnolia Formation (Ma3 member) is an important part of this formation, and its facilitates choreographically pattern profoundly controls the development and distribution of high-quality reservoirs. In recent years, the predecessors have made many new understandings on the study of the third member of the Madman Formation, but the overall research degree is weak, and the accumulation law and main control factors of the natural gas in the third member of the Madian Formation have not been clarified, resulting in difficult well deployment and high risk, which restricts the exploration and development process of deep natural gas under salt to a certain extent.In this paper, the main research goal is to restore the lithofacies paleogeography of the Masan Formation in the Ordos Basin.Based on the geological, logging, and seismic data, the' trichotomy ' of the Masan Formation was established. The pre-depositional paleogeomorphology was restored by the impression method. Combined with sedimentology, paleogeomorphology restoration and lithofacies paleogeographic analysis, the lithofacies paleogeographic characteristics of each layer of the Masan Formation were systematically described, and the changes of the internal uplift and depression of the Masan Formation and the resulting sedimentary microfacies evolution were analyzed. The study shows that the internal area of the platform in the sedimentary front of the Masan member is also relatively flat, accounting for about 70 % of the area, of which the low-lying area in the eastern platform accounts for about 45 % of the area. The southern platform margin area and the western denudation ancient land slope area account for about 30 % of the area ; the Ma3 member is dominated by the evaporative platform facies under the regression system, mainly developing the intra-platform lagoon and the evaporative tidal flat subfacies. The intra-platform lagoon is mainly the salt rock lagoon microfacies, and the evaporative tidal flat subfacies is further divided into ash dolomite flat, dolomite flat, mud dolomite flat, gypsum dolomite flat and other microfacies. During the deposition period of the third member of the Mashan Formation, the eastern Ordos Basin belonged to the transgressive system tract of the second stage of the Mashan Formation to the regressive system tract of the third stage of the Mashan Formation, and the seawater depth became shallow, but the low-lying areas along the Shenmu-Yichuan area still existed. Coupled with the strong evaporation of paleoclimate conditions, the low-lying areas became sulfates, that is, the favorable place for the deposition of gypsum-salt rocks, thus forming a relatively closed platform lagoon environment. The lagoon area is very large, from the Shenmu area Shuang 176 well-Shen 74-M 1 to the southern Yu 152-Yi 68 well line, becoming a salt rock sedimentary area ; from the lithofacies paleogeographic distribution map of each sub-layer of the Masan Member, the favorable microfacies intra-platform shoals are mainly distributed in the Masan 1 and Masan 2 sections, and the distribution of Masan 3 is limited.

Keywords

Ordos Basin; Majiagou Group; Lithofacies Paleogeography; Sedimentary Characteristics.

1. Introduction

The Ordos Basin is an important oil and gas basin in China, and the Lower Ordovician Majiagou Formation is the core layer of marine carbonate oil and gas exploration. In recent years, with the deepening of pre-salt exploration, Tong 74 well has obtained high-yield industrial gas flow in Ma 5 under salt. In 2021, well Mitan 1 in the eastern part of the basin has obtained an open flow of 352,400 m^3 / day in Ma 4 under salt [1], indicating that pre-salt has good potential for natural gas exploration. As an important part of the Majiagou Formation, the third member of the Majiagou Formation has become a research hotspot in recent years due to its unique lithofacies paleogeographic background and huge exploration potential. The Ma3 member has a wide distribution range and stable thickness, and has the geological conditions for forming large-scale oil and gas accumulation. The proven reserves in the central and eastern part of the basin have exceeded 100 billion cubic meters, indicating that the resource endowment of the strata is good. With the development of earthquake prediction technology, more and more hidden beaches have been identified. These beach bodies are widely distributed. If they are effectively matched with diagenetic traps, a large-scale lithologic gas reservoir group can be formed. Hou Mingcai et al. [2] pointed out that the eastern slope zone of the central paleo-uplift is a favorable area for beach development and lithologic traps, and is the key exploration direction in the future. At present, the mainstream view is generally believed that the Ma-3 inherited the paleogeographic pattern of ' two depressions sandwiched by one uplift ', that is, the central paleo-uplift divided it into the eastern Mizhi depression (evaporative lagoon) and the western Yanchi-Huanxian depression.In recent years, Zhao et al. [3] combined seismic geomorphology with drilling and logging to further identify multiple rows of NW-SE-trending grain beaches and reef complexes in the platform, revealing the complexity of the topography inside the platform, rather than a simple uniform gentle slope. The sedimentary facies are dominated by gypsum dolomite, salt rock, mud powder crystal dolomite, interbedded with calcareous dolomite and granular dolomite. The Mizhi area on the east side is characterized by gypsum salt rock deposition, reflecting the strong evaporation environment under arid climate. In the central and western regions and the western margin, more open platform-restricted platform facies carbonate rocks are developed, which is a favorable zone for the development of beach bodies. He Zixin [4], Shi Ji 'an et al. [5] believed that the third member of the Mashan Formation was formed in a restricted-evaporative platform environment, controlled by the epicontinental sea background of the North China Craton in the early Ordovician, and dominated by gypsum salt lakes, gypsum dolomite flats, and mud dolomite flats. Yuzhou et al. [6] thought that the development of dolomite reservoirs in the second member of the Maer Formation was controlled by sedimentary microfacies and diagenesis. Gypsum-bearing dolomite flats, grain beaches and bioturbation laid the foundation for reservoir development. Bao Hong et al. [7] believed that the bioturbation structure indirectly controlled the development of effective reservoirs by controlling the dolomitization.

The buried depth of Ma3 member is large, the resolution of seismic signal is low, and the shielding effect of gypsum rock on underlying strata seriously affects the accurate description of deep beach body morphology, fracture system and reservoir physical properties. Based on this, on the basis of previous studies, this paper takes the principle of sedimentology as the theoretical basis, through a large number of field samples, drilling cores, well seismic data, analysis and laboratory data, from the aspects of pre-depositional paleogeomorphology and sedimentary markers to study the characteristics of lithofacies paleogeography and its recovery, and to analyze and discuss the relationship between favorable lithofacies and high-quality reservoir distribution.

2. Regional Geological Conditions

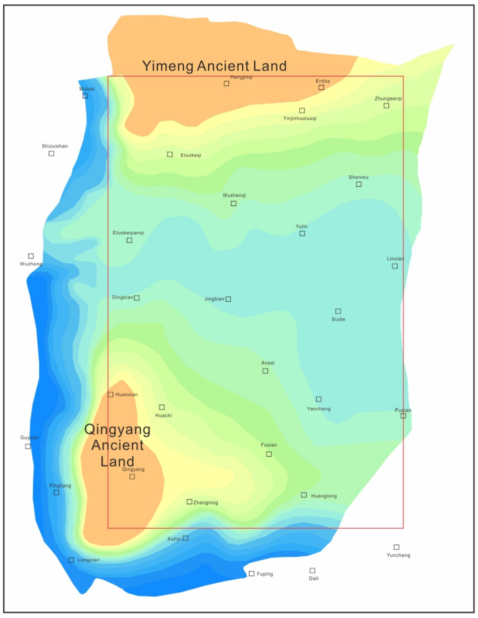

Fig 1. Regional geological survey map

The Ordos Basin is located in the western part of the North China Plate, across the five provinces of Shaanxi, Gansu, Ningxia, Neijiang and Shanxi. It is rich in oil and gas resources and is the second largest sedimentary basin in China. The development of the basin has gone through six major tectonic evolution stages. The current tectonic framework of the basin laid the foundation in the middle Yanshan movement and developed in the Himalayan movement. The stratigraphic development of the basin is relatively complete. In addition to the Silurian and Devonian strata, the strata of other ages are preserved. The Masan member is widely distributed in the basin, and the thickness is relatively stable, generally between 100-250 meters, showing the characteristics of thick east and thin west. Its lithology combination is mainly characterized by grayish brown, dark gray mud-powder crystal dolomite, gypsum dolomite, gypsum rock with thin layer of gray dolomite (Feng et al., 1998), which is a typical mixed sedimentary sequence of carbonate rock and evaporite [8]. It has an integrated contact relationship with the lower second section of the horse and the upper fourth section of the horse. There is an obvious multi-stage sedimentary cycle in the Ma3 member, which reflects the high-frequency fluctuation of sea level. During the Ordovician period, the Ordos Basin was located in the western part of the North China Craton, and the tectonic activity was relatively stable. The overall performance was a large west slope, forming a broad and flat carbonate gentle slope-evaporation platform environment (Hou et al., 2003)[9].During the deposition period of the third member of the Maxi Formation, under the control of the paleogeographic pattern of ' two depressions with one uplift ', the sedimentary facies belt showed a ring-like distribution : the eastern region (Mizhi Depression) : dominated by evaporative lagoon facies, widely deposited thick gypsum and rock salt, reflecting the arid climate conditions of limited water body and strong evaporation. In the western region, lagoon facies is also developed, but the proportion of gypsum salt deposition may be relatively low. The central and western margin area : located in the central paleo-uplift margin and slope zone, shallow water, high energy, is a favorable area for the deposition of restricted-open platform facies, with the development of granular beaches, microbial mounds and other sedimentary bodies (Zhao Junxing et al., 2008)

[10]. This paleogeographic pattern is controlled by the basement structure, and the existence of the central paleo-uplift plays a decisive role in the differentiation of sedimentary facies and the later diagenetic evolution.

In order to more in-depth and detailed research, in order to guide the exploration and development, this paper subdivides the Ma3 section under the salt and establishes the corresponding division standard. Comprehensive analysis of the collected core, cuttings, logging data, comprehensive interpretation conclusions, reference to the regional stratigraphic division of the marker layer, to the first sub-section and then on the small layer, cycle control, reference thickness, the final closure of the principle of review, the Masan formation three points, from bottom to top, respectively, Masan 3, Masan 2 and Masan 1. The stratification basis of each small layer is as follows :

The total thickness of the third member of the Masan Formation is about 17.7 ~ 211.2 m, with an average thickness of 102.9 m. The thickness of the first member of the Masan Formation is 6.0 ~ 106.0 m, with an average thickness of 34.5 m. The bottom of the first member of the Masan Formation is a thick layer of gypsum rock, and there are many sets of gypsum rock in the interior. The lithology is characterized by interbedded gypsum dolomite and gypsum rock, with local mudstone layers. The thickness of the Ma3 2 formation is 7.2 ~ 101.0 m, with an average thickness of 36.9 m. The bottom of the Ma3 2 is a middle-layer gypsum rock layer, and there are many sets of gypsum rocks in the interior. The development degree of the gypsum rock is equivalent to or slightly higher than that of the upper Ma3 1. The lithology is characterized by the interbed of gypsum rock and gypsum dolomite, and the GR curve at the top shows obvious step change. The thickness of the Masan 3 section is 4.5-100.0m, with an average thickness of 37.4m.The bottom of Masan 3 is marked by the end of the last gypsum rock layer. The development scale of the internal gypsum rock layer is equivalent to that of Masan 2. The gypsum rock layer is mainly thin layer, and the lithology is characterized by gypsum rock layer, gypsum dolomite and argillaceous dolomite.

3. Research Principle of Lithofacies Paleogeographic Restoration

The restoration of paleogeomorphology is usually based on the comprehensive analysis of seismic, logging, mud logging and other data to carry out sequence division, stratigraphic correlation, and fine three-dimensional seismic horizon interpretation of the top and bottom of the target layer. Then, the bottom surface of the depth domain is subtracted from the top surface to obtain the residual thickness. Combined with regional tectonic movement, sequence framework, paleoclimate and relative sea level change, the erosion recovery and residual thickness difference compaction correction are carried out, and then the paleogeomorphology of sedimentary period is obtained [11]. The methods of paleogeomorphology restoration usually include impression method, residual thickness method, sedimentology method, sequence stratigraphy method and so on.

The restoration of erosion amount is the key to establish the tectonic evolution history of the basin and is an important part of the restoration process of the prototype basin. Strata denudation widely exists in sedimentary basins, especially in superimposed basins with complex tectonic movements, serious strata loss and great changes in unconformity types, where denudation is strong. The amount of denudation has an effect on the generation, migration and accumulation of oil and gas. When the amount of denudation is not too large, the effect can be ignored. When there is a large-scale denudation, it will affect the generation, migration and storage of oil and gas [12].

Decompaction correction is actually the recovery of formation porosity. The existing compaction correction method is based on the theory of ' constant volume of formation skeleton ' and ' constant quality of formation skeleton '. The core is the calculation and application of porosity-depth function and density-depth function. One of the most mature methods is to use acoustic time difference data to obtain the porosity-depth relationship curve, so as to carry out the decompaction calculation [13].

In the process of restoring ancient landforms, the residual thickness method selects an overlying isochronous interface as the datum plane, and then selects a relatively isochronous underlying isochronous interface. The thickness between the two is the residual thickness. The size of the residual thickness reflects the ancient landform. The larger the residual thickness value is, the higher the structural high point of the original paleogeomorphology is, and the smaller the residual thickness value is, the lower the structural low point of the original paleogeomorphology is.

The sedimentary method fully considers the structural characteristics and stratigraphic denudation before deposition, and analyzes the geomorphological morphology before deposition in combination with sedimentary facies and sedimentary environment. Through the ancient structural pattern and the erosion of the stratum, according to the genesis and development environment of the sedimentary facies, the original thickness of the stratum before deposition is restored, and the thickness of the original sedimentary stratum is calculated according to the compaction rate of different lithology to restore the ancient landform.

The core of the sequence stratigraphic method is to combine the base level with the maximum sea / lake flooding surface to determine and compare the base level cycles of different levels. By establishing the isochronous sequence stratigraphic framework, the regional isochronous interface that can reflect the original sedimentary thickness is selected to reflect the original appearance of the ancient landform. Through cyclic comparison, the isochronism of paleogeomorphology restoration is stronger and the accuracy is higher.

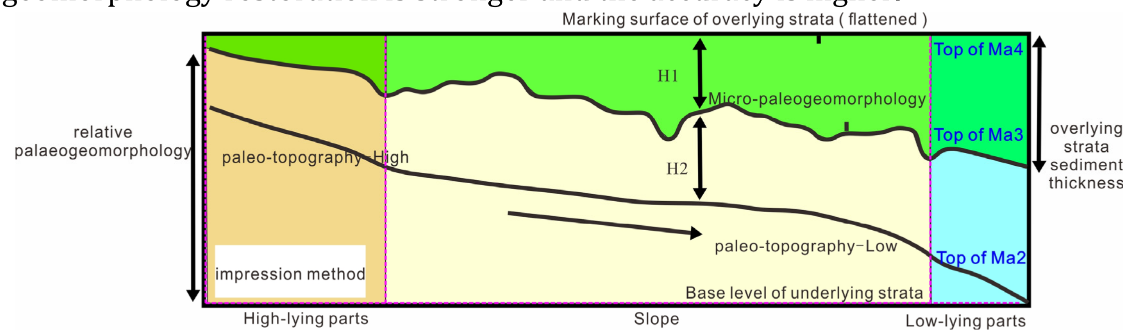

Fig 2. Flow chart of ancient landform restoration by impression method

The method of paleogeomorphology restoration in this paper mainly adopts the impression method. The impression method is a method of paleogeomorphology restoration based on the principle of filling and filling. The unconformity surface that begins to accept sediment deposition is the underlying isochronous interface, and the isochronous interface that can reflect the stable deposition of filling and filling is selected as the overlying isochronous interface. The thickness of the stratum between the two interfaces can qualitatively and semi-quantitatively reflect the paleogeomorphology before filling and filling. Especially in the area of multiple wells, the underlying isochronous interface and the overlying isochronous interface can be determined according to the characteristics of logging curves, and the thickness between the two isochronous interfaces can be used to restore the paleogeomorphology. The greater the thickness of the impression, the lower the structural point of the original paleogeomorphology, and the smaller the thickness of the impression, the higher the structural point of the original paleogeomorphology.

The selection of marker layer is very important when the ancient landform is restored by impression method. It is mainly based on the lithology of the bottom of Ma5 (the top of Ma4) and the reference surface of the logging marker layer (Fig.2). It is mainly because the lithology and electrical identification marks of the interface are clear, which is an isochronous interface distributed in the whole area. In addition, the distance between the sedimentary interface and the paleo-tectonic surface is moderate, which makes the paleo-tectonic surface less affected by the later activity and tectonic influence on the relative fluctuation of the paleo-geomorphology, and it is also a strong wave resistance surface.

4. Multi-method Lithofacies Paleogeographic Reconstruction

4.1. The Restoration of Paleogeomorphology Before Deposition Framed the Macroscopic Sedimentary Pattern

4.1.1. Compaction Correction

In this paper, the ancient landform restoration method uses the impression method, which needs to be compacted and corrected to formally reflect the ancient landform characteristics before the original sedimentary period. It is generally believed that the porosity of sediments, especially detrital sediments, decreases with the increase of burial depth. Compaction correction is a key technology in basin analysis, stratigraphic restoration and paleogeographic reconstruction. Its core purpose is to remove the influence of overlying sediment load compaction on the formation and restore the original thickness and porosity of the formation during deposition. This process is of great significance for accurately calculating the original deposition rate, restoring the ancient water depth, evaluating the hydrocarbon generation potential and predicting the quality of deep reservoirs. Sediments usually have high primary porosity at the beginning of deposition (e.g., mudstone up to 50-80 %, sandstone up to 40-50 %). With the continuous thickening of the overlying sediment, the effective stress of the formation under the action of gravity gradually increases, resulting in the rearrangement of particles, the plastic deformation of soft minerals, and the discharge of fluids, thereby reducing the porosity, reducing the volume, and thinning the thickness of the formation (Allen & Allen, 2013) [14]. The essence of compaction correction is the reverse deduction of this physical process. By establishing a quantitative relationship model between formation porosity and burial depth (or effective stress), the thickness (or porosity) of the compacted formation observed today can be traced back to its original state at the end of deposition (Sclater & Christie, 1980) [15].

The core of compaction correction is to establish a porosity-depth relationship model. The most commonly used is the Athy (1930) formula based on the exponential decay model :

$$\varphi = \varphi_0 \exp^{(-cz)} \tag{1}$$

In the formula: φ-depth is the porosity at z. φ_0-surface porosity, c-compactioncoefficient, z-depth

The above formula can be used as the basis for restoring the burial history. With the different lithology in the formation, the compaction coefficient C and the surface porosity φ will also be different [16].

The degree of sediment compression and drainage are proportional to the compaction coefficient. Different lithology compaction coefficient will be different ; in the case of the same lithology, different compaction coefficients in the buried depth stage (compaction stage) are often different. Therefore, when the above formula is used for calculation, the compaction coefficient should be givenfirst according to the lithology and compaction stage.

Mudstone is rich in clay minerals, fine particles, high porosity in the earlystage of deposition, and prone to plastic deformation and pore fluid discharge under compaction, so the compaction coefficient is the largest and the compaction effect is the most obvious (Giles, M.R., 1997) [17]. Compaction coefficient(k) range : 0.0005-0.0009 m 1 (or 0.5-0.9 km 1) This range is a common

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value for mudstones in global basins. The initial porosity (φ_0 is usually 0.6-0.7. In the rapidly deposited undercompacted strata, the k value may be small ; in areas with strong tectonic activity, the k value may be too large.

Table 1. Impression method to compaction correction thickness statistics table (part of the well)

well number	After correction by impression method		
	Mawudi-Masan2 top thickness	Mawudi-Masan3 top thickness	Mawudi-Masan3 bottom thickness
Mitan3	216.0	289.3	389.8
Tao91	192.6	248.5	289.1
Yi13	94.4	113.0	138.5
Tao59	378.5	431.9	485.8
Mitan1	246.9	342.1	477.1
Shuang175	137.0	168.1	206.5
Mi104	204.2	286.7	366.8
Fu5	203.7	282.4	370.5
Tao112	232.9	277.0	302.2
Jin14	172.6	219.9	263.7
Mitan2	213.2	322.0	422.7
Zhaotan1	176.8	205.5	240.5
Tao107	406.9	442.0	483.7
Jingtan1	199.5	251.2	308.7
Tao108	421.9	453.5	499.5
Jingtan2	219.9	266.7	311.9
Shan476	270.3	310.8	353.8
Huo3	152.7	188.4	220.0
Tao93	202.4	241.5	271.4
Futan1	121.5	159.2	184.6
Shan139	144.4	225.2	313.3
Lian124	95.9	112.5	140.0
Long3	19.0	37.7	53.0
Yitan1	104.5	144.4	180.2

Scholars hold different views on the compaction rate of evaporite. Luo Quansheng (2000) [18] believed that in the gypsum salt development area, due to the rapid deposition rate (30m / Ma), it is not balanced with its compaction drainage, and in the process of compaction, gypsum will produce metamorphism, so it will form an undercompacted mudstone zone under the gypsum salt layer. NB Vysotsky (1979) believed that when the buried depth was below 1000m (Boscht believed that it was below 2000m), gypsum would be dehydrated into anhydrite. It is estimated that 0.486 m3 of water will be released per cubic meter of gypsum dewatering, which is a large value. It is well known that the water in gypsum is the water in the crystal lattice, and the crystal water will be converted into free water during the metamorphic process. These water into the adjacent formation pores, will increase the fluid pressure in the rock. As mentioned above, the gypsum-salt rock in the study area often forms multiple rhythms with mudstone. Therefore, the water released from gypsum metamorphic anhydrite will enter the pores of mudstone due to volume expansion, which will increase the pore pressure of mudstone. At the same time, the volume of gypsum will also be partially contracted, and the corresponding formation thickness will also be compressed to about half.

Gypsum salt rock has a very close relationship with oil and gas. Because of its strong plasticity, easy flow and compactness, it is often used as the cap rock of oil and gas reservoirs and has been widely studied and analyzed by scholars (Wang, 2018 [19]). At the same time, the thickness will also change greatly in the process of buried depth. Gu Zhixiang (2019 [20]) After extensive literature research, scholars believe that gypsum is converted into anhydrite with the increase of burial depth (generally 500-2500m), and its solid volume is reduced by about 39 %. Limestone and dolomite have crystallized and consolidated in the early stage of deposition, and their own compressive strength is strong. Although there are structures such as pressure solution and suture line, the overall compaction range is not large.

Based on the above research results, this study focuses on the compaction correction of mudstone and gypsum salt rock. Through the calculation of lithology and thickness of logging data, the compaction degree of mudstone (compaction loss thickness) is 65 %, the compaction degree of gypsum salt rock (compaction loss thickness) is 39 %, and the compaction degree of carbonate rock is zero.

4.1.2. Restoration of Ancient Landform by Impression Method

On the basis of fully analyzing the tectonic evolution and sedimentary strata characteristics of the Lower Paleozoic in the Ordos Basin, combined with the current paleogeomorphology restoration technology, the valuable experience and the latest data of the predecessors in the restoration of paleogeomorphology, the impression method is fully used to realize the restoration of the pre-sedimentary landform of the third member of the Mashan Formation in the eastern part of the basin. Taking the bottom of Ma5 or the top of Ma4 as the isochronous marker layer, and the thickness index from the marker layer to Ma3 as the reference basis, the compaction rate is calculated, and on this basis, the paleohydrodynamic and paleogeographic environment are analyzed. The paleogeomorphology before the deposition of Ma3 can be framed in the first-level geomorphic unit of carbonate platform, and three second-level geomorphic units such as platform interior, denudation ancient land area and platform margin area are developed in the carbonate platform. The interior of the platform is the main body of the eastern part of the basin, and the macroscopic restoration of paleogeomorphology before the deposition of Ma3 is further completed according to the thickness of the impression.

Table 2. Standard for the division of paleogeomorphic units by impression method

Geomorphologic unit Class	I landform	carbonate platform is divided			
	II landform	platform internal area		erosion ancient land area	platform margin area
	III landform	within the platform micro uplift area	within the platform low-lying area	around the continental slope area	platform margin uplift area
Impression thickness after decompaction Hc (m)	$Ma3_1$	≤180m	≥240m	≤90m	≤120m
	$Ma3_2$	≤200m	≥270m	≤105m	≤140m
	$Ma3_3$	≤250m	≥340m	≤130m	≤175m

According to the above classification criteria of paleogeomorphic units and the thickness data of deep impression, the paleogeomorphic map before the deposition of the third member of the Mashan Formation was compiled. It can be seen from the restored three-dimensional map of paleogeomorphology that the paleogeomorphology before the deposition of the third member of the Mashan Formation is generally a gentle platform with high on the west side and low on the east side. The high part is located in the Qingyang paleo-uplift area in the southwest and the southern and northern areas of the basin. The low-lying area in the sedimentary front platform is located in the north and northeast of the study area. The two low-lying areas are separated by low-amplitude uplifts. The Masan section uplift is relatively small, distributed in the southern and central regions.

On the whole, the internal area of the Ma3 sedimentary front platform is relatively flat, accounting for about 70 % of the area, of which the low-lying area in the eastern platform accounts for about 45 % of the area. The southern platform margin area and the western denudation ancient land slope area account for about 30 % of the area.

During the deposition period of the third member of the Madian Formation (Fig.3 ~ Fig.5), the paleogeomorphology became smaller, the platform tended to be flat as a whole, the gap between the low-lying area and the micro-uplift area in the platform was small, and the low-lying area was large. In addition, the whole basin of the third member of the Madian Formation is dominated by regression, the water body is shallow and the evaporation is large, forming a large and shallow platform lagoon evaporation environment conducive to gypsum salt crystallization.

There is a certain inheritance of paleogeomorphology before the deposition of each small layer in the third member of the Maxian Formation, and the structural amplitude in the layer is also affected by sedimentary filling, showing a gradual weakening trend.

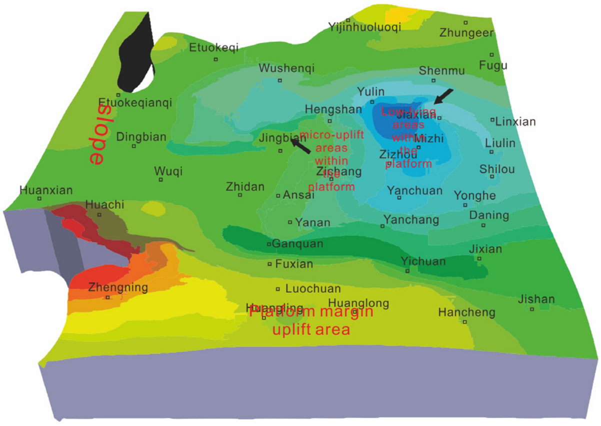

Fig 3. Three-dimensional map of paleogeomorphology before deposition of $Ma3_3$ after impression compaction correction by impression method

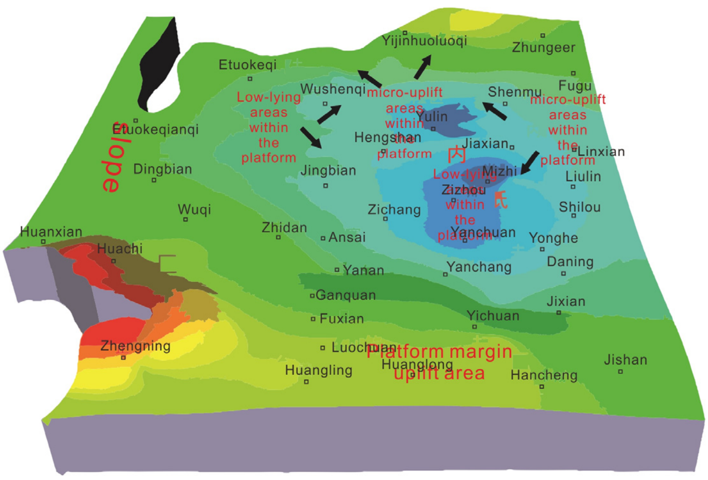

Fig 4. Three-dimensional map of paleogeomorphology before deposition of $Ma3_2$ after compaction correction by impression method

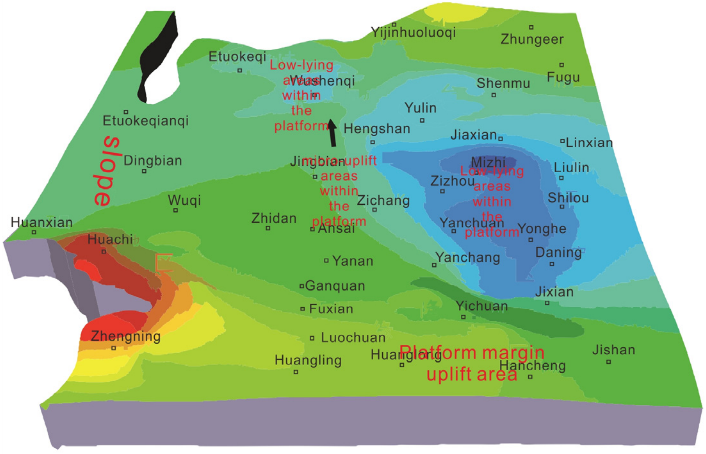

Fig 5. Three-dimensional map of paleogeomorphology before deposition of Ma3$_1$ after compaction correction by impression method

4.2. Single Factor Analysis Comprehensive Mapping to Restore Lithofacies Paleogeography

In this paper, in the lithofacies paleogeographic text and mapping, not only the qualitative analysis method is adopted, that is, in the field work and the analysis of the previous data and the analysis of the sedimentary facies of the section, the theory and analysis method of sedimentology and paleogeography are used to analyze the sedimentary environment according to the lithology characteristics and sedimentary facies signs of the strata. Moreover, in the process of lithofacies paleogeographic mapping, quantitative paleogeographic analysis and mapping methods are adopted, that is, the ' single factor analysis and multi-factor comprehensive mapping method ' advocated by Professor Feng Zengzhao is used.

The core of this methodology is quantitative, that is, based on the quantitative single-factor data of each single section, starting from the analysis of various quantitative single-factor basic maps, and then through the superposition and comprehensive analysis and judgment of various single-factor basic maps, the quantitative lithofacies paleogeographic map is finally made. In the paleogeographic maps made by this method, the determination of each paleogeographic unit is based on accurate quantitative data. Therefore, such a paleogeographic map is no longer indicative, nor is it qualitative, but quantitative. Feng Zengzhao used the single factor comprehensive mapping method to study the lithofacies paleogeography. The single factor is a factor that can independently reflect some characteristics of the sedimentary environment of a sedimentary section in a certain geological period in a certain area. Its presence or absence or its content can independently reflect some characteristics of the sedimentary environment of the sedimentary section in the area. The thickness of a sedimentary section, specific rock type, structural composition, mineral composition, chemical composition, fossils and their combinations, color, etc., can be used as a single factor. The single factor analysis and multi-factor comprehensive mapping method can be divided into three steps: First, carry out careful stratigraphic and quantitative petrological studies on each section, especially the main sections, and obtain various first-hand qualitative and quantitative data, especially quantitative data, to understand the sedimentary environment characteristics of each sedimentary section of each section.

Secondly, in the obtained quantitative data of each section, according to the required mapping units, the factors that can independently reflect the characteristics of its sedimentary environment are selected, that is, single factors, and the percentage of various single factors of each mapping unit of each section in the whole area is counted out, and various corresponding single factor maps are made, mainly isoline maps. These single factor maps can quantitatively reflect the sedimentary environment of the area and the layer from different sides. This is the single factor analysis.

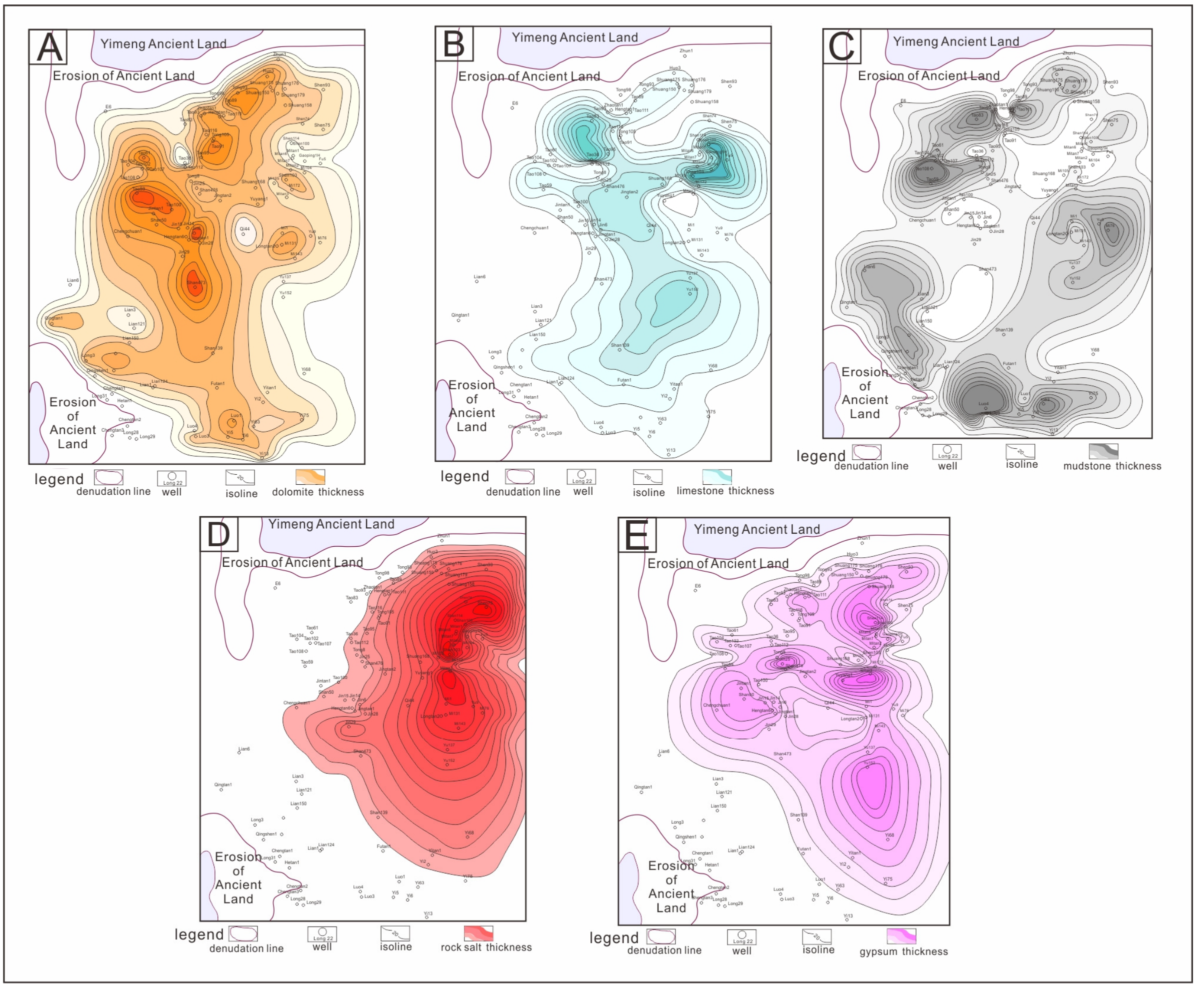

Fig 6. Thickness distribution map of each single factor

Thirdly, these quantitative single factor maps are superimposed, and combined with other quantitative and qualitative data of the region and the layer, the quantitative lithofacies paleogeographic map of the region and the layer can be compiled by removing the rough and selecting the fine, removing the false and retaining the true, comprehensive analysis and comprehensive judgment. This is the multi-factor comprehensive mapping.

The core of this methodology is quantitative, that is, based on the quantitative single-factor data of each single section, starting from the analysis of various quantitative single-factor basic maps, and then through the superposition and comprehensive analysis and judgment of various single-factor basic maps, the quantitative lithofacies paleogeographic map is finally made. In the paleogeographic maps made by this method, the determination of each paleogeographic unit is based on accurate quantitative data. Therefore, such a paleogeographic map is no longer indicative, nor is it qualitative, but quantitative.

The essence of this methodology is to analyze and understand something from different aspects, and then comprehensively analyze and judge these aspects, so as to achieve the purpose of understanding the essence of things.

Combined with the paleogeomorphology, sedimentary facies and lithofacies characteristics of the Ma3 Member in the eastern Ordos Basin during the sedimentary period, this paper selects the five elements of dolomite thickness DOLO, limestone thickness LIME, mudstone thickness

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SH, gypsum thickness ANHY and salt rock thickness SALT, and draws them in combination with the plane distribution characteristics of formation thickness. Before drawing the single factor map, the logging parameters of more than 120 wells were classified and summarized and the single factor parameters were calculated.

Through the quantitative analysis of the thickness of each single factor of dolomite thickness DOLO, limestone thickness LIME, mudstone thickness SH, gypsum rock thickness ANHY, salt rock thickness SALT and mudstone thickness, combined with the sedimentary facies type and evolution law of the third member of the Mashan Formation in the eastern part of the Ordos Basin, the differences in rock composition and sedimentary microenvironment in different facies areas, the single factor mapping method is used to quantitatively classify them (Figure 6 Single factor thickness distribution map).

4.3. Microscopic Experiments Assist in the Calibration of Microphase Types

Sedimentary facies is the material expression of rock sedimentary environment, which is the sum of all sedimentary characteristics in a sedimentary environment, including rock types, associated minerals, sedimentary structures and paleontology. Therefore, the identification of sedimentary facies needs to be proved by the symbolic characteristics that best reflect the sedimentary environment. Generally, the identifiable sedimentary facies markers of carbonate rocks include: color and lithologic characteristics, rock and particle structure of coring wells, sedimentary structure markers, paleontological markers, etc. In this paper, through the observation of wild rocks, sampling, microscopic observation and combined with longitudinal stratigraphic section and microscopic comparison (figure 7), the evidence of identifying sedimentary microfacies is extracted.

The development of the regional sedimentary system is restricted by the background of the North China epicontinental sea. The paleo-uplift in the Ordos Basin and the development and evolution of the Qinqi trough and the Helan aulacogen in the southwestern margin also have a significant impact on the development of the sedimentary system. According to the observation of Ordovician drilling cores and field outcrops, combined with the above paleogeomorphological restoration results, petrological characteristics, paleontology, profile structure, logging characteristics and seismic interpretation results, and considering the regional sedimentary tectonic background, the sedimentary system of the Ma3 member in the eastern Ordos Basin is divided into open platform facies and evaporation platform facies (Table 3).

Table 3. Sedimentary facies division table of Ma3 member in eastern Ordos Basin

stratum	sedimentary facies	Microscopic reservoir / pore type	sedimentary micro
Ma3	evaporate platform	Plaster mold hole, with dissolved hole	(gypsum) salt rock lagoon
		Intercrystalline pores, intergranular dissolved pores	Huiyunping, Baiyunping, Niyunping, Gaoyunping, Taineitan
		Particle hole	granular beach

The Ma3 member is dominated by the evaporative platform facies under the regression system, mainly developing the intra-platform lagoon and the evaporative tidal flat subfacies. The intra-platform lagoon is mainly the salt rock lagoon microfacies, and the evaporative tidal flat subfacies is further divided into ash dolomite flat, dolomite flat, mud dolomite flat, gypsum dolomite flat and other microfacies.

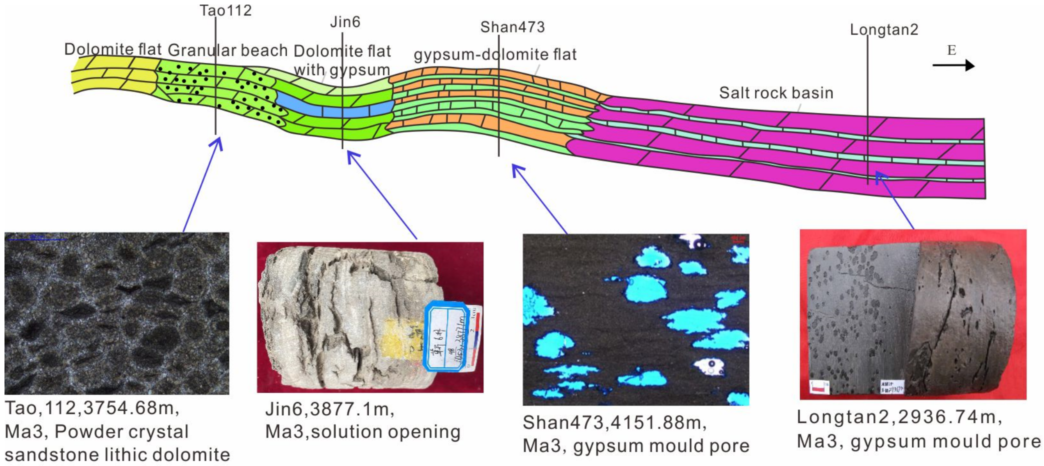

Fig 7. The corresponding pattern of longitudinal section and microscopic photo

5. Lithofacies Paleogeographic Evolution Characteristics

During the sedimentary period of the third member of Ma 'an Formation, the eastern Ordos Basin belongs to the transgressive system tract of the second stage of Ma 'an Formation to the regressive system tract of the third stage of Ma 'an Formation, and the depth of seawater becomes shallow. However, the low-lying area along the Shenmu area-Yichuan area still exists. In addition to the paleoclimate conditions of strong evaporation, the low-lying area has become a sulfate, which is a favorable place for gypsum salt rock deposition. Therefore, a relatively closed intra-platform lagoon environment has been formed, and the lagoon area is very large. From Shuang 176 well-Shen 74-Mi 1 in Shenmu area to Yu 152-Yi 68 well in the south, it has become a salt rock deposition area. In addition, due to the influence of pre-depositional paleogeomorphology, the Shaan 476-Jin 15 well area in the Ma 3 period was in a relatively low-lying area, while the northwestern part of the basin was at a relatively high position at this time, which provided conditions for the formation of intra-platform beaches. The intra-platform beach deposits such as E 6 well area, Tao 61-Tao 108 well area, Tao 93-Tao 116 well area, Tao 112 well area and Tao 59 well area were formed, and the intra-platform beach deposits were also formed in the central Shaan 473 well area and the southern Yitan 1-Yi 2 well area. Due to the relative decline of the central paleo-uplift in the Ma-3 period, the sea water reconnected the Qilian Sea with the North China Sea, forming a large area of relatively gentle tidal flat sedimentary area, forming a dolomite flat-Niyunping-Gaoyunping-Yanyan lagoon sedimentary area with zonal distribution characteristics.

From the lithofacies paleogeographic distribution map of each sub-layer of Masan Member (Fig.8 ~ Fig.10), the favorable microfacies intra-platform shoal is mainly distributed in Masan 1 and Masan 2, and Masan 3 is limited.

Since 2000, with the continuous improvement of the exploration degree of the lower combination of the Majiagou Formation (Ma1 ~ Ma4) in the Ordos Basin, there has been a more mature understanding of the dolomite belt along the stratigraphic denudation line. In contrast, the exploration and geological understanding of the central areas such as Wushenqi-Hengshan-Jingbian on the east side is relatively weak. In the past two years, with the discovery of Hengshan highland, the favorable exploration area of the lower combination has been broadened to the central region, and the key exploration problem of what geological factors control the reservoir development in the study area has been extended.

Underwater highlands are often conducive to the development of high-energy sedimentary facies such as grain beaches and microbial mounds. At the same time, taking into account the high construction rate, it is easy to expose the top of the mound and beach, so the platform beach subfacies has always been the most favorable exploration target for marine carbonate rocks. Based on the study of the restoration of the paleogeographic pattern of the Masan Member, two underwater bulges developed in the study area were identified, and the development of granular beaches (mainly sandy beaches) was characterized. This study believes that the intra-platform shoal subfacies controlled by the concave-convex geomorphological pattern is the root cause of the north-south distribution of the reservoir rock development zones in the second and third members of Ma 'an Formation.At the same time, many industrial gas wells have been drilled in the favorable areas of Taolimiao underwater highland and Hengshan highland, which have the potential for continuous exploration.

In addition, from the perspective of the whole pre-salt deep layer, there are great differences in reservoir genesis and favorable zone distribution between pre-salt and pre-salt strata. Through the study of paleogeographic pattern, gypsum-salt rock-carbonate rock symbiosis law and tectonic genesis, it is considered that the development of Ma3 reservoir under salt is controlled by the inheritance of paleogeomorphic units.

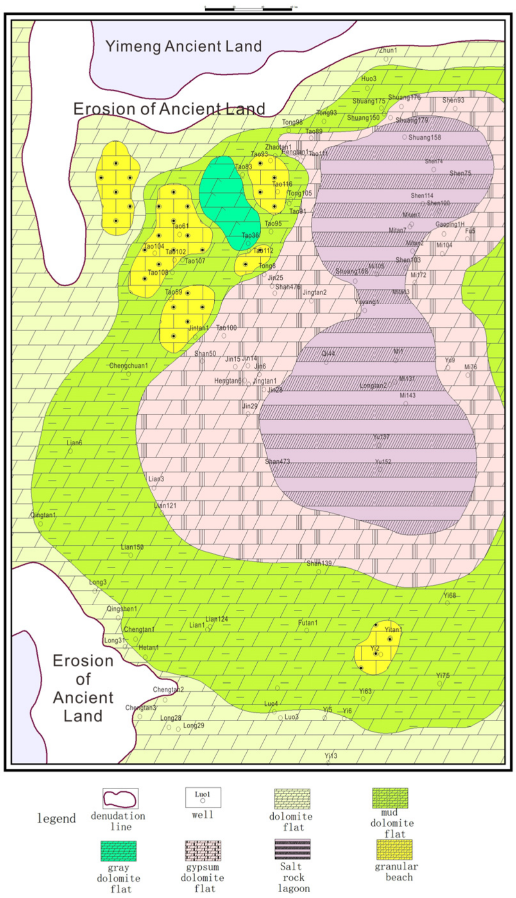

Fig 8. Lithofacies paleogeographic distribution map of $Ma3_1$ member in eastern Ordos Basin

6. Conclusion

In this paper, the recovery of lithofacies and paleogeography of the Ma3 member in the eastern Ordos Basin is taken as the main research goal. Based on the comprehensive geological, logging and seismic data, the recovery of paleogeomorphology and lithofacies and paleogeography of deep sedimentary facies under salt is systematically carried out, and the relationship between lithofacies and reservoir distribution is discussed. The main conclusions are as follows :

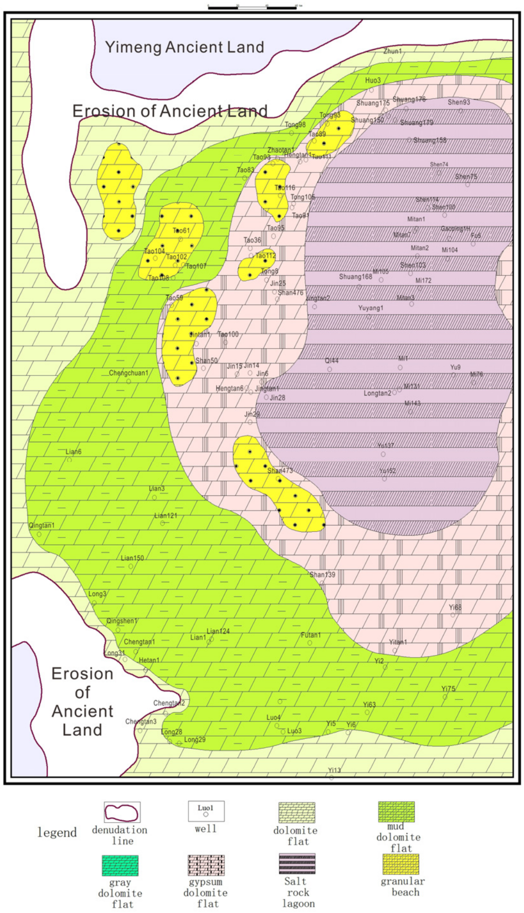

Fig 9. Lithofacies paleogeographic distribution map of $Ma3_2$ member in eastern Ordos Basin

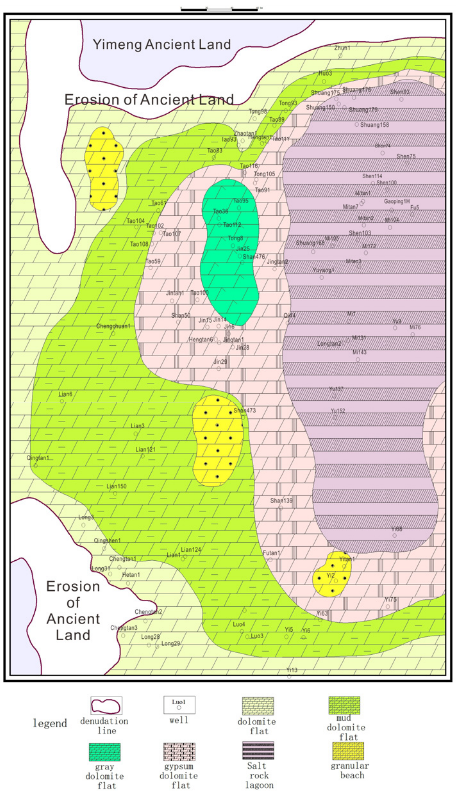

Fig 10. Lithofacies paleogeographic distribution map of $Ma3_3$ member in eastern Ordos Basin

(1) The paleogeomorphology before the deposition of Ma3 member is generally high in the west and low in the east. The high part is located in the Qingyang paleo-uplift area in the southwest and the south and north of the basin. The low-lying area in the sedimentary front is located in the north and northeast of the study area, and the two low-lying areas are separated by low-amplitude uplift. Masan section uplift is relatively small, distributed in the southern and central regions of a small amount. On the whole, the internal area of the platform is relatively flat and occupies the main body, accounting for about 70 % of the area, of which the low-lying area in the eastern platform accounts for about 45 % of the area. The southern platform margin area and the western denudation ancient land slope area account for about 30 % of the area.

(2) The Ma3 member is dominated by the evaporation platform facies under the regression system, mainly developing the intra-platform lagoon and the evaporation tidal flat subfacies. The intra-platform lagoon is mainly the salt rock lagoon microfacies, and the evaporation tidal flat subfacies is further divided into the gray dolomite flat, dolomite flat, mud dolomite flat, gypsum dolomite flat and other microfacies.

(3) During the sedimentary period of Masan member, the eastern part of Ordos Basin belongs to the regression system tract of Masan period from the transgressive system tract of Masan period, and the depth of seawater becomes shallow. However, the low-lying area of Shenmu area-Yichuan area still exists. In addition to the ancient climate conditions of strong evaporation, the low-lying area has become a favorable place for sulfate, that is, gypsum salt rock deposition. Therefore, a relatively closed intra-platform lagoon environment has been formed, and the lagoon area is very large. From Shuang 176 well-Shen 74-Mi 1 in Shenmu area to Yu 152-Yi 68 well in the south, it has become a salt rock sedimentary area. According to the lithofacies paleogeographic distribution map of each layer of the third member of the Mashan Formation, the favorable microfacies platform inner beach is mainly distributed in the third member of the Mashan Formation 1 and the third member of the Mashan Formation 2, and the third member of the Mashan Formation 3 is limited.

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