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Application of Evaporite Minerals in Identification of Marine Carbonate Sedimentary Environment: A Case Study of Ma 5_4 in the Central-East Ordos Basin

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Abstract:

Based on the lithological analysis and regional distribution, the genesis of gypsum-salt rock in Ma 5_4 in central-east Ordos Basin was studied, and then the reflected migration and evolution of the gypsum-salt rock and their sedimentary environment significance were discussed. The Ma 5_4 gypsum-salt rock was formed in the underwater concentration environment. The available drilling and coring data in the basin reveal that the Ma 5_4 gypsum-salt rock generally shows a trend of gradual thickening from west to east, and the occurrence and content of anhydrite show regular changes, which reflects the sedimentary environment information. Ma 5_4 belongs to the evaporation shelf environment with low sea level. According to the occurrence, content and distribution range of halite and anhydrite minerals, the evaporation shelf can be further divided into five kinds of microfacies. The evolution of sedimentary microfacies is controlled by sedimentary geomorphology features, ancient climate and relative sea level changes. In vertical direction, the sedimentary microfacies distribution has certain inheritance. However, as the slow transgression from Ma 5_4^3 to Ma 5_4^2 and then to Ma 5_4^1, sea water recharge rate and quantity increased, evaporation decreased, and sea water salinity gradually reduced, leading to regular changes of the development and distribution of the microfacies.

Keywords*: Ma 5_4, Evaporite mineral, Sedimentary microfacies, Evolution of sedimentary environment, Ordos Basin.*

I. INTRODUCTION

Evaporite is mainly composed of gypsum-salt minerals, different from common clastic rocks and carbonate rocks. Its genesis is attractive and controversial[1-10]. Some scholars have classified it into two types: supratidal Sabkha and underwater concentrated precipitation[11]. The supratidal Sabkha type is developed in supratidal sedimentary environment under semi-arid to arid climate conditions. Due to strong

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evaporation, the concentration of intergranular water in supratidal sediments increases to allow evaporate minerals to precipitate. Evaporite is often associated with exposure signs, which is mainly characterized by the development of ptygmatic and nodular gypsum and dispersed salt rock, with poor stratification. It is relatively developed on the landside on the plane and distributed in a belt form parallel to the coastline[5]. The underwater concentrated precipitation type is developed in lagoon, basin and other impoundment bodies which are relatively stable under semi-arid to arid climate conditions. The salinity of water body increases with the enhancement of evaporation, and the heavy brine in hollow zone is refluxed and deposited. Gypsum-salt rock is generally lack of exposure signs, distributing in stable horizons. On the plane, it is distributed in a ring form, transiting in a succession of mudstone and limestone–dolomite–gypsum rock–salt rock, from edge to center[12].

The deposition of evaporite minerals, regardless of the genesis, is often controlled by arid and hot climate conditions[13]. Strong evaporation forms high-density brine, and the reflux and accumulation of the brine on the plane is controlled by the topography of the sedimentary period, forming gypsum-salt deposits with varying types and occurrences from region to region. Therefore, evaporite minerals are of good environmental significance, that is, their types, occurrences and contents can reflect different sedimentary environments, which has important geological indication significance.

Through observation of cores from the fourth submember of the fifth member the Ordovician Majiagou Formation (hereinafter referred to as Ma 5_4) in central-east Ordos Basin, several rock types such as micritic-silty crystal dolomite, gypsum-bearing dolomite, fine-coarse crystal dolomite and karst formation rock are identified. Due to weathering and denudation for more than 150 million years, Ma 5_4 has been strongly affected by multi-stage karst superposition and recrystallization, which destroyed the macro and micro characteristics of lithologies and the original sedimentary information to varying degrees, so it is far from enough to characterize the sedimentary environment only by rock microfacies. In order to further determine the sedimentary environment, this paper discusses how evaporite is indicatively significant to the identification of sedimentary environment based on the previous studies, so as to provide new reference information for regional and similar studies.

II. GEOLOGIC SETTING

The study area is located in the central-north part of the current Yishan slope of the Ordos Basin (Fig 1). The Mizhi Paleo-sag in the east and "L"-shaped Central Paleo-uplift in the southwest, which are respectively positive and negative structural units, constitute a paleotopographic transition[14]. The Ordos Basin was generally in the basin margin flat environment of a (internal) shelf basin with better sealing conditions during the deposition of Ma 5_4 [14-15], only connected with open sea in the east to a certain extent. The basin environment was deeper in the east and shallower in the west, showing a closed to semi-closed state. Under the arid and hot climate conditions, Ma 5_4 was characterized by the symbiosis of multicycle marine carbonate rocks and evaporites. On the plane, the middle and west sides of the study area mainly contain silty-crystal dolomite, silty-crystal dolomite (containing) anhydrite (nodule) and a small amount of

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anhydrite, which constitute the main accumulation space in Ma 5_4. The salinity increases gradually from west to east in the sedimentary environment. Dolomitic anhydrite and anhydrite are relatively developed in the east of the study area; eastward, the gypsum basin appears in the Zizhou-Qingjian region. Longitudinally, it is characterized by interbedding of marine silty-crystal dolomite, gypsum-bearing dolomite and gypsum with unequal thicknesses, which is in conformable contact with the underlying Ma 5_5 (Table I).

Table I. Division of Ma 54 in central-east Ordos Basin

Strata				**Lithology**	**Contact relationship**
Majiagou Formation	Ma 5 Member	Ma 5_3		Gray muddy dolomite, dolomitic breccia intercalated with laminated dolomite	
		Ma 5_4	Ma 5_4^1	Light gray silty-crystal dolomite, breccia dolomite and gypsum dolomite	Conformity
			Ma 5_4^2	Intercalated thin gray silty-crystal dolomite, gypsum dolomite and gypsum-salt layers	
			Ma 5_4^3	Intercalated thin gray silty-crystal dolomite, gypsum dolomite and gypsum-salt layers	
		Ma 5_5		Gray-dark micrite intercalated with dolomite	

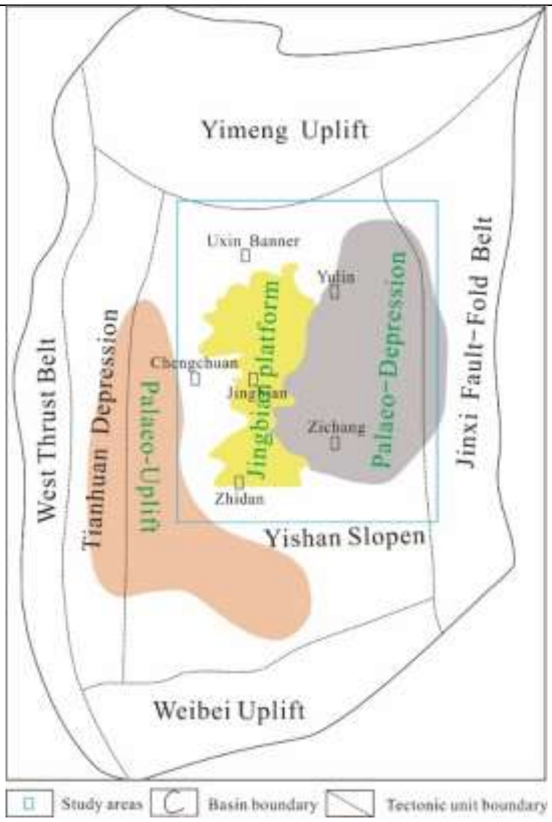

Fig 1: Structure distribution in the Ordos Basin

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III. DISTRIBUTION CHARACTERISTICS OF GYPSUM-SALT ROCKS

Available drilling data show that the gypsum-salt rocks of Ma 5_4 in the Ordos Basin are distributed in zonal form along sag center. In the sedimentary period of Ma 5_4, the gypsum depocenter was located in the Zizhou-Qingjian region, with a maximum thickness of more than 30 m, gradually thinning around until disappearing, which is more consistent with the sedimentary characteristics of underwater concentrated precipitation type gypsum rocks.

3.1 Petrological Characteristics of Gypsum-Salt Rocks

A: Silty-crystal dolomite containing anhydrite nodules. After anhydrite nodules are dissolved, the lower part is filled with dolomite, and the upper part retains residual pores; single polarization, cast slice, Well Shaan 199, Ma 5_4^1, 3066.47 m.

B. Silty-crystal dolomite containing anhydrite nodules. After anhydrite nodules are dissolved, the lower part is filled with dolomite, and the upper residual pores are filled with calcite; single polarization, cast slice, Well Su 23, Ma 5_4^1, 3599.6 m.

C. Silty-crystal dolomite containing anhydrite nodules. After anhydrite nodules are dissolved, they are filled with dolomite, calcite and quartz; single polarization, cast slice, Well Lian 23, Ma 5_4^1, 3944.57 m.

D: Chick-like dolomitic anhydrite, Well Shaan 149, Ma 5_4^1, 3184.5 m.

E: Stratified anhydrite, Well Shaan 81, Ma 5_4^1, 4070 m.

F: White-colorless transparent massive salt rock, Well Yu 87, Ma 5_4^3, 2725.77 m.

The gypsum-salt rock of Ma 5_4 is mainly anhydrite, and halilyte locally in Ma 5_4^3. The anhydrite occurs as: (1) anhydrite nodules or columnar crystals in silty-crystal dolomite, with the content and diameter varying greatly in different wells in the study area – the nodule content changes in the range of about 5%–30% and the nodule diameter is about 1–5 mm, while the content of columnar crystals changes in the range of 1%–5%, which were corroded during the epigenetic stage to form moldic pores that were filled and precipitated by multi-stage diagenetic minerals in the process of burial diagenesis (Fig 2A, B, C) [14, 16]; (2) chick-like dolomitic anhydrite mixed with gray-white massive anhydrite and dark-gray micritic dolomite (Fig 2D); and (3) gray-white pure stratified anhydrite (Fig 2E). The halilyte is white–colorless transparent massive potassium salt rock and sodium salt rock (Fig 2F).

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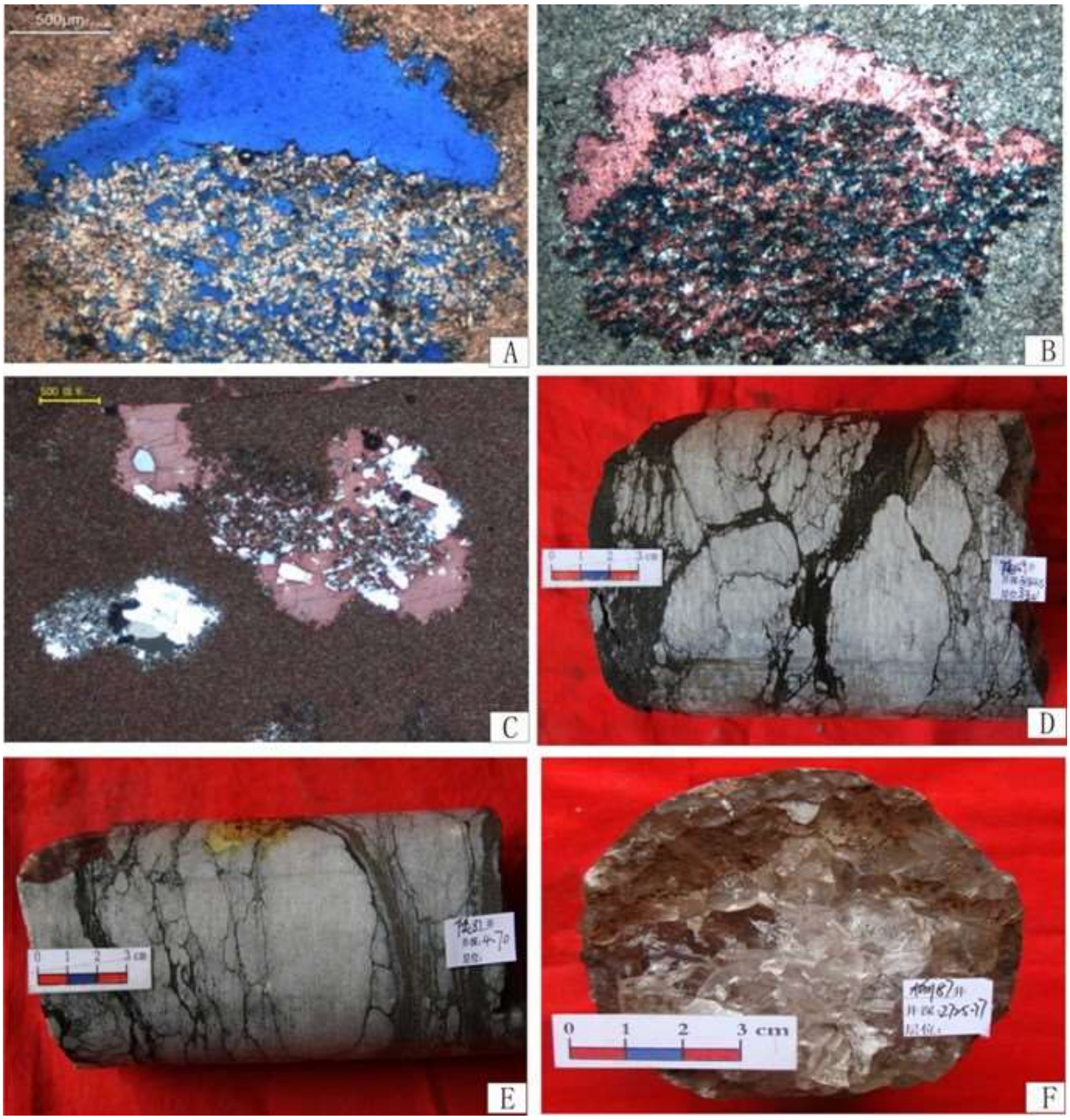

Fig 2: Occurrence types of gypsum-salt rocks in Ma 5_4

3.2 Vertical and Horizontal Distribution of Gypsum-Salt Rocks

Gypsum-salt rocks are relatively developed in three sublayers (Ma 5_4^1, Ma 5_4^2, Ma 5_4^3) of Ma 5_4, but they are very different vertically. During the deposition of Ma 5_4^3, anhydrite was generally thin, laminated and massive, with the cumulative thickness $\leq$30 m, but it was distributed in a large range in the plane. Gypsum rocks were continuously distributed to the east of the Uxin banner-Jingbian-Gaoqiao belt, with the cumulative thickness of 10–25 m which gradually increased eastward. A salt rock subsidence center appeared in the Zizhou-Qingjian region, with the maximum thickness more than 40 m (Fig 3). This shows that during the deposition, the bedform in the basin tilted to the east, the evaporation and concentration of seawater were strengthened from west to east, and the salinity increased gradually. During the deposition

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of Ma 5_4^2–Ma 5_4^1, the development and distribution of gypsum-salt rocks showed certain inheritance from and also differences with Ma 5_4^3. First, salt rock was developed only in Ma 5_4^3, and the thickness and distribution scope of anhydrite decreased from Ma 5_4^3→Ma 5_4^2→Ma 5_4^1. Second, in the Ma 5_4^2 period, the anhydrite was mainly laminar and massive, but with smaller bed thickness and cumulative thickness (<20 m). In the Ma 5_4^1 period, the anhydrite was mainly distributed in massive or nodule shape, forming dolomitic anhydrite with chicken-cage and iron-wire structure and dolomite with anhydrite nodules, followed by laminar and massive gypsum rocks that were only locally developed in the east of the study area. Third, gypsum rocks were still continuous in the east of the study area, but narrower in horizontal distribution range, showing an obvious characteristics of shrinking eastward (Fig 4 and Fig 5).

Fig 3: Gypsum-salt thickness map of Ma 5_4^3

Fig 4: Gypsum-salt thickness map of Ma 5_4^2

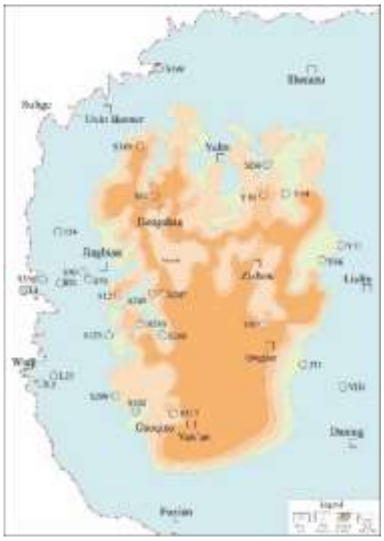

Fig 5: Gypsum-salt thickness map of Ma 5_4^1

IV. SEDIMENTARY MIGRATION OF EVAPORITE MINERALS AND ITS ENVIRONMENTAL SIGNIFICANCE

The statistics of 41 cores samples from the study area show that the matrix micritic-silty crystal dolomite has $\delta^{13}C$ (PDB) value of -0.863‰ and $\delta^{18}O$ (PDB) value of -7.819‰, with the order degree of 0.64–0.68 (Table II). The characteristics of petrology, carbon isotopes, oxygen isotopes and crystal texture all show that the sedimentation took place in the dry and hot evaporative environment. The subtle changes of the sedimentary environment controlled the sedimentary migration and range of evaporite minerals. Therefore, the evaporite minerals are of good environmental significance, and their lithology types, contents, occurrences and sedimentary structures can reflect different sedimentary environments. According to the type, occurrence and content of halite and anhydrite, this study applied single factor analysis method to divide the sedimentary microfacies of Ma 5_4 into dolomite flat, dolomite flat (containing) anhydrite nodules, gypsiferous dolomite flat, gypsum dolomite flat and gypsum-salt basin.

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Table II. Division of sedimentary microfacies of Ma 54 in central-east Ordos Basin

Microfacies type	Lithology	Anhydrite (salt rock) content	Anhydrite (salt rock) occurrence	Sedimentary structure	Geochemical feature		
					C and O isotopes (PDB‰)		Order degree
					$\delta^{13}C$ (matrix)	$\delta^{18}O$ (matrix)	
Dolomite flat	Fine-silty crystal dolomite	Anhydrite nodule content: <5%	Sporadic distribution	Horizontal beddings are common			0.64
Dolomite flat containing anhydrite nodules	Dolomite containing anhydrite nodules	Anhydrite nodule content: 5-15%	Nodule and lamina	Continuous or discontinuous horizontal lamina and wavy lamina	-0.863	-7.819	0.68 (matrix)
Dolomite flat with anhydrite nodules	Dolomite with anhydrite nodules	Anhydrite nodule content: 15-30%					
Gypsiferous dolomite flat	Lenticular anhydrite, algal-laminated dolomite	Anhydrite nodule content: 25-50%	Distributed in lamellar, banded, lenticular and beaded aggregates	Plastic deformation is common			
Gypsum dolomite flat	Layered and nodular anhydrite, algal-laminated dolomite	Anhydrite nodule content: 50-75%	Lamellar or chick-like nodule layer	Horizontal and massive beddings are common			
Gypsum-salt basin	Halite and muddy dolomite	Gypsum-salt content >75%	Interbedding anhydrite and halite with unequal thicknesses	Massive and deformed beddings			

4.1 Characteristics of Main Sedimentary Microfacies

4.1.1 Dolomite flat

The salinity of seawater is close to or slightly higher than that of normal seawater. Main deposits include gray and light gray thin laminar or thick massive micro–fine-silty crystal dolomite, with

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micritic-silty crystal structure and mosaic contact. When the silty crystal dolomite occurs in thick massive alone, its crystal diameter is generally finer and there are relatively few intercrystal pores. It is often interbedded with dolomite (containing) anhydrite nodules in thin–middle layered with unequal thicknesses, or the two kinds of lithologies transit gradually, then the silty-crystal dolomite also shows coarser crystal diameter with well-developed intercrystal pores. Moreover, there is argillaceous micritic-silty crystal dolomite sometimes, and its argillaceous content is generally 5%–30%. Silty-crystal clastic dolomite and sandy-silty clastic dolomite are occasionally seen. The latter contains columnar and acicular gypsum pseudocrystals. Vertically, they are relatively developed at the bottom of Ma 5_4^3 and the top of Ma 5_4^1 (Fig 6).

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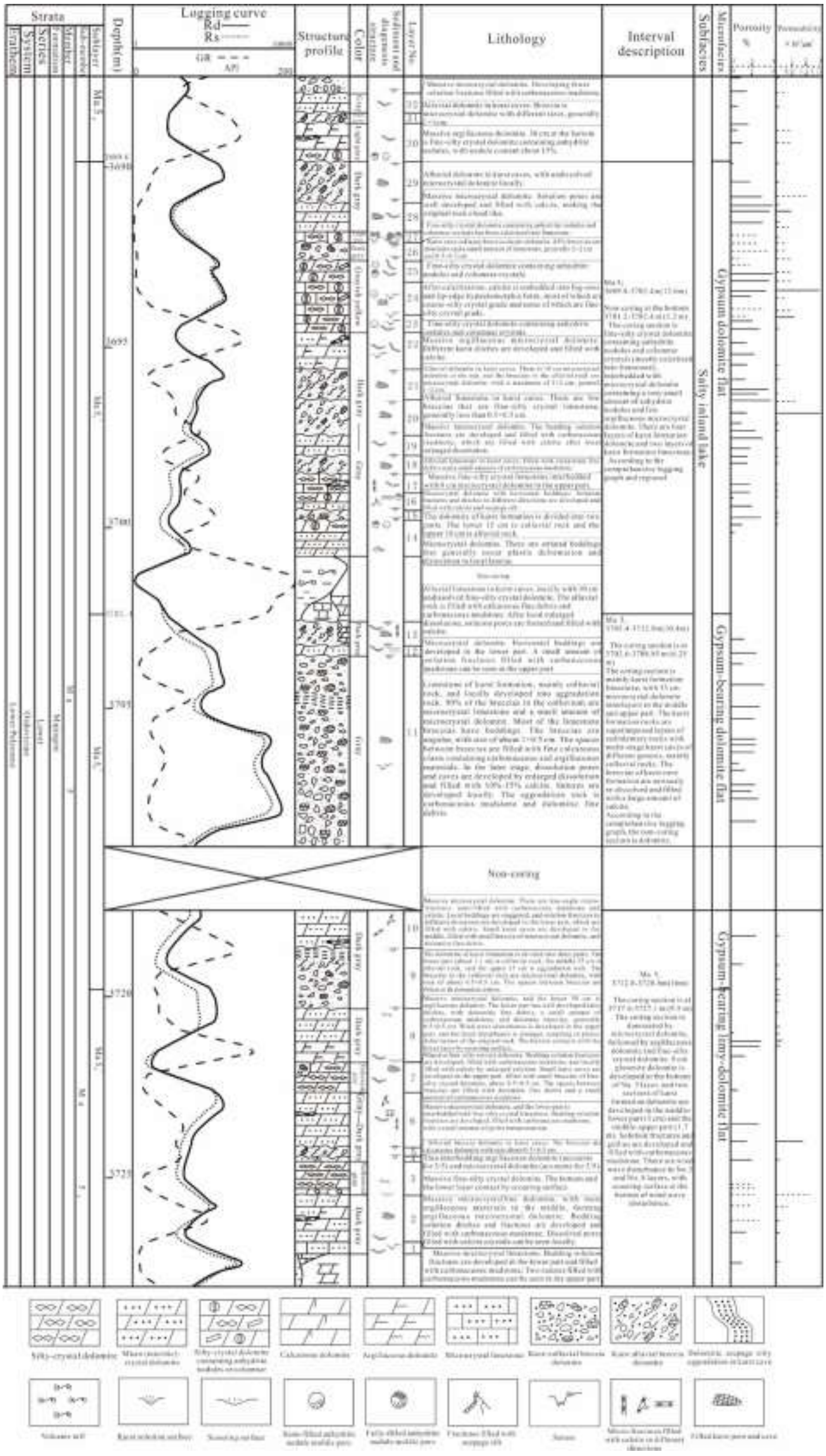

Fig 6: Comprehensive analysis of stratigraphy and sedimentary facies of Ma 5_4 in Well Shaan 51

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4.1.2 Dolomite flat microfacies (containing) anhydrite nodules

Seawater continues to evaporate and concentrate. When the salt concentration reaches more than 15–17%, anhydrite begins to precipitate and is distributed in nodular form in dolomite, forming gray or brownish gray medium–thick layered fine-silty crystal dolomite (containing) anhydrite nodules. The anhydrite nodule content varies from 5%–30%, and the nodule diameter is generally about 1–5 mm. Generally, the dolomite containing anhydrite nodules has high nodule content and large nodule diameter, and the crystal diameter of bedrock dolomite is also relatively coarse, up to 0.03–0.04 mm, with more intercrystal pores and good reservoir physical properties. According to the content of anhydrite nodules, it can be further divided into the dolomite flat containing anhydrite nodules. The overall characteristics of the two are basically the same. Longitudinally, they are mainly developed in the middle and upper parts of Ma 5_4^1 (Fig 6), and can be seen at local single wells of Ma 5_4^2 and Ma 5_4^3. On the side near the Central Paleo-uplift, the density of anhydrite nodules is large (up to 20%–30%), and gradually decreases to the east to the Jiaxian-Suide-Yan'an-Yichuan belt. There is fine-silty crystal dolomite with horizontal lamina or wavy lamina structure that is interbedded with fine-silty crystal dolomite (containing) anhydrite nodules with unequal thicknesses.

4.1.3 Gypsiferous dolomite flat

Seawater continues to concentrate, and anhydrite precipitation increases. Main deposits include thin–medium layered anhydrite microcrystal dolomite. The anhydrite is distributed in laminar, banded, lenticular and beaded aggregates, and horizontal bedding and massive bedding can be seen. The matrix is dark gray argillaceous microcrystal dolomite, often intercalated or interbedded with micro-silty crystal dolomite, with significant bedding deformation. It is relatively developed in Ma 5_4^3 and Ma 5_4^2, and also developed in lower Ma 5_4^1 (Fig 6).

4.1.4 Gypsum dolomite flat

Layered anhydrite and dolomitic anhydrite with chick-like nodules are dominant, intercalated with micro-silty crystal dolomite and a small amount of microcrystal limestone. The layered anhydrite has horizontal and micro wavy beddings, and can be intercalated with micro-silty crystal dolomite lamina, developing plastic deformation beddings. The chick-like and nodular nodules in anhydrite are generally in centimeter scale, relatively developed in Ma 5_4^3 and Ma 5_4^2 (Fig 6), but only in eastern wells in Ma 5_4^1.

4.1.5 Gypsum-salt basin

It was developed in the dry and hot low water-level period with stronger evaporation than the fresh water supply, mainly forming anhydrite, and developing massive, medium–thin layered beddings and deformed beddings. Anhydrite often develops halite crystals and crystal colonies, and plastic deformation

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is common. Sometimes it is interbedded with argillaceous dolomite and dolomitic mudstone laminae, occasionally interbedded with anhydrite and halite with equal or unequal thicknesses. It is relatively developed in Ma 5_4^3 and Ma 5_4^2 (Fig 6), but rarely in Ma 5_4^1.

4.2 Plane Distribution of Ma 5_4 Sedimentary Microfacies

The basin was generally in a basin margin flat environment in the (inner) continental shelf gently inclined to it on the north, west and south sides during the deposition of Ma 5_4 [14]. Under the control of this paleogeographic pattern, the salinity in the sea area was high, and the heavy brine with large specific gravity must converge to the central-east part of the basin, that is, the direction of the compensation depression basin-gypsum-bearing basin. On the other hand, in local time, especially when the climate was relatively humid, atmospheric precipitation would desalinate the salinity of seawater at the edge of the basin[16]. Although the study area was slight away from the margin of the basin, its west, followed by the north and south, would also be affected to some extent. In other words, on the plane, the salinity of seawater is different from well to well, being more greatly variable in the east-west direction than the north-south direction. Taking Ma 5_4^1 as an example to conduct horizontal sedimentary and reservoir correlation (Fig 7). From the lithology comparison of coring sections (the lithology of non-coring sections can only be roughly calibrated according to the comprehensive logging graph and core map, and cannot be accurately compared), Well Lian 4, located in the westernmost part, has a residual thickness of 5.9 m (further to west, Ma 5_4^1 has been denuded). Only the lower karst formation rock was cored, and the breccia debris is microcrystal dolomite and fine-silty crystal dolomite. There is no dolomite breccia debris containing anhydrite nodules. Eastward, for Well Shaan 51, only 1.7 m from the bottom was not cored. Except for karst formation rock, the lower part is microcrystal dolomite interbedded with fine-silty crystal dolomite containing anhydrite nodules, and the upper part is interbedding micro-silty crystal dolomite and silty crystal dolomite containing anhydrite nodules, or silty crystal dolomite containing anhydrite nodules, columnar crystals and nodules. Further eastward to Well Shaan 70, in which Ma 5_4^1 is completely cored, except that the middle and lower parts are intercalated with karst formation rock, the lower part is micro-silty crystal dolomite intercalated with silty crystal dolomite containing anhydrite nodules, and the upper part is mainly silty crystal dolomite containing anhydrite nodules. Compared with Well Shaan 51, the thickness of silty crystal dolomite containing anhydrite nodules increases, the content of nodules increases, and the nodule diameter also increases. Further eastward to Well Shaan 12, only the middle and upper parts were cored. In the middle of Ma 5_4^1, argillaceous anhydrite rock with chick-cage and iron-wire structure and argillaceous dolomitic anhydrite rock with chick-like nodules (chick-like anhydrite nodules of different sizes and contents are unevenly distributed in argillaceous microcrystal dolomite), interbedded with silty-crystal dolomite containing anhydrite nodules. The upper part is silty-crystal dolomite and silty dolomite containing anhydrite nodules. There are many anhydrite nodules with large nodule diameter. Then eastward to Well Shaan 247, which was only cored in the middle section, and more than 1/2 of the coring section is argillaceous anhydrite with chick-cage and iron-wire structure.

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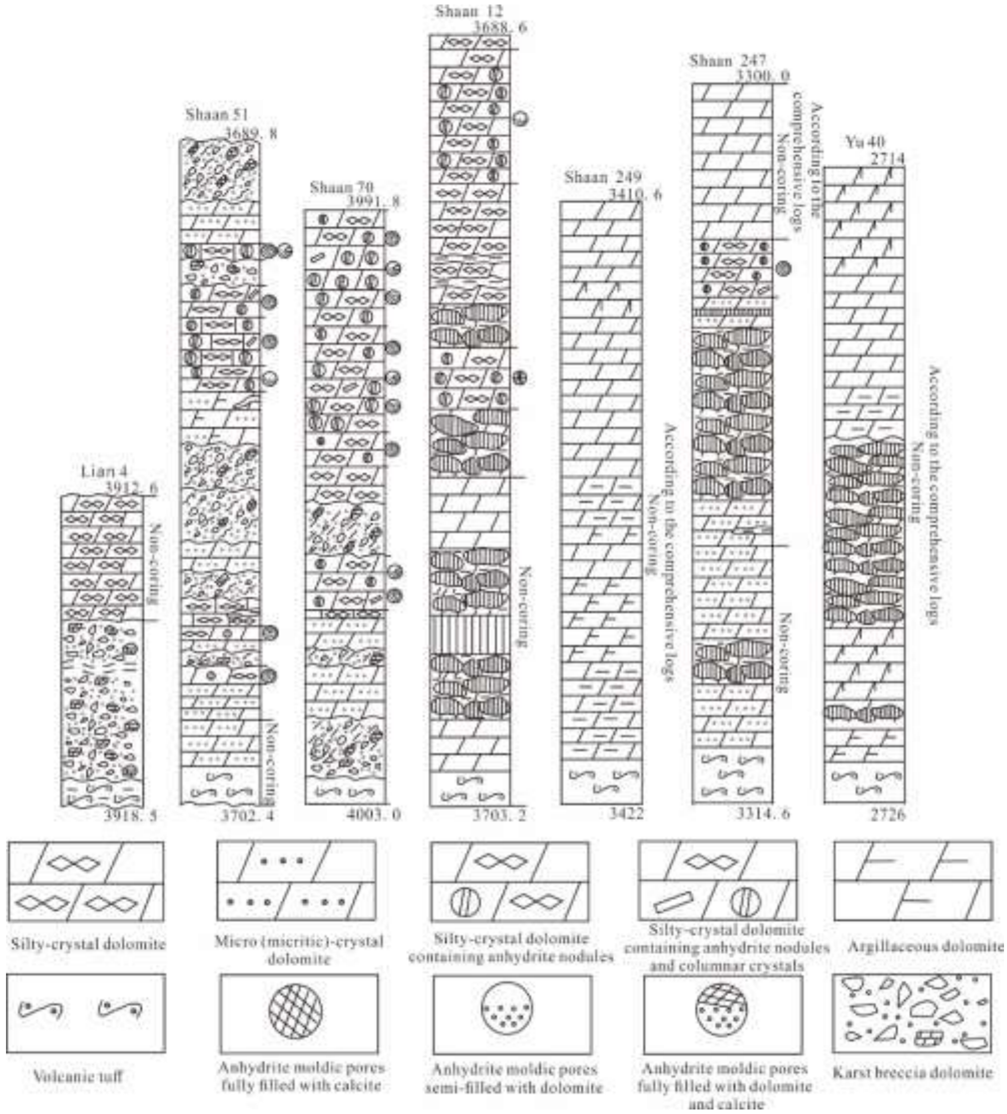

Fig 7: Distribution and horizontal correlation of Ma $5_4{}^1$ across Wells Lian 4-Shaan 12-Yu 40

It can be clearly seen from Fig 7 that the salinity of sedimentary environment is increasing from west to east, which means that the sedimentary microfacies salinity is increasing. As the stratum to the west of Well Lian 4 has been denuded, according to this sedimentary law, microcrystal dolomite and calcareous dolomite might have been deposited in Ma $5_4{}^1$ to the west of Well Lian 4. That is, dolomite could be deposited in the west of the study area at the same time (interval), while silty-crystal dolomite containing anhydrite nodules could be deposited to the east, and then dolomite, dolomitic anhydrite with chick-cage and iron-wire structure and layered anhydrite could be deposited to further east close to the depression basin. This trend should also exist in the north-south direction of the study area, but it is less obvious than that in the east-west direction. Therefore, the sedimentary microfacies are distributed in a zonal form on the plane. With the gradual increase of seawater salinity from west to east, the circum-continental dolomite flat, dolomite flat containing anhydrite nodules, gypsiferous dolomite flat, gypsum dolomite flat and

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gypsum-salt basin are developed successively (Figs 8, 9 and 10).

Fig 8: Distribution of sedimentary facies in Ma 5_4^3

Fig 9: Distribution of sedimentary facies in Ma 5_4^2

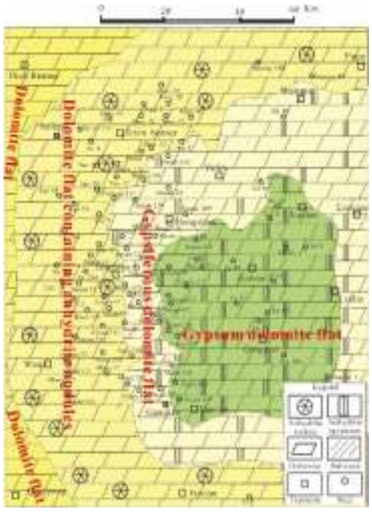

Fig 10: Distribution of sedimentary facies in Ma 5_4^1

V. SEDIMENTARY EVOLUTION OF MA 5_4

The sedimentary microfacies of Ma 5_4^3 are characterized by nearly EW-striking zonal distribution. The areas from the south of Jiaxian to Qingjian and the east of Zizhou to Liulin mainly contain salt basin microfacies. The salt rock deposits are the largest near Qingjian and thin towards the edge. Gypsum dolomite flat, gypsiferous dolomite flat, dolomite flat containing anhydrite nodules and dolomite flat microfacies are developed successively from the salt basin to its outer edge (Fig 8). The development and distribution of sedimentary microfacies of Ma 5_4^2 inherited the pattern of Ma 5_4^3. However, affected by the slow transgression, the seawater supply speed and quantity increased, the salinity gradually decreased, and the salt basin deposit was missing. The gypsum dolomite flat microfacies also shrunk to the center of the basin, mainly distributed in the Shaan 210-Mi 36-Liulin-Daning belt in the middle of the study area. The sedimentary range of gypsiferous dolomite flat, dolomite flat containing anhydrite nodules and dolomite flat microfacies at the outer edge shifted and expanded to the center (Fig 9). The sedimentary microfacies of Ma 5_4^1 remained the characteristics of nearly EW-striking zonal distribution. Under the influence of continuous transgression, the salinity of seawater further decreased, the microfacies of gypsum dolomite flat further shrunk to the area of Shaan 260-Yu 14-YH 1-Shaan 317 belt in the middle of the study area, and the dolomite flat containing anhydrite nodules expanded eastward to the Shaan 162-Shaan 123-Shaan 299 belt (Fig 10).

VI. CONCLUSIONS

(1) The gypsum-salt rocks of Ma 5^4 in the Ordos Basin were formed in underwater concentration environment. Anhydrite rocks with different occurrences were formed in different sedimentary

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microenvironments. They mainly include anhydrite nodules or columnar crystals in silt-crystal dolomite, with nodule content about 5%–30% and the nodules about 1–5 mm, chick-like dolomitic anhydrite mixed with gray-white massive anhydrite and dark-gray micritic dolomite, gray-white pure layered anhydrite, and white-colorless transparent massive salt rock.

(2) According to the type, occurrence, content and sedimentary structure of halite and anhydrite, the change of seawater salinity during the sedimentary period was analyzed, the development law of sedimentary rocks under different sedimentary microenvironments was summarized, and then the sedimentary microfacies of Ma 5_4 were divide into dolomite flat, dolomite flat (containing) anhydrite nodules, gypsiferous dolomite flat, gypsum dolomite flat and gypsum-salt basin.

(3) During the deposition of Ma 5_4, the Ordos Basin had a paleogeographic pattern of gently dipping from the north, west and south to the central-east part. The salinity of the seawater at wells on the plane showed greater variation in EW direction than in SN direction. The sedimentary microfacies on the plane are obviously distributed in zonal form. With the gradual increase of seawater salinity from west to east, the circum-continental dolomite flat, dolomite flat containing anhydrite nodules, gypsiferous dolomite flat, gypsum dolomite flat and gypsum-salt basin are developed successively. Vertically, with the slow transgression from Ma 5_4^3 to Ma 5_4^2 and then to Ma 5_4^1, the speed and quantity of seawater recharge increased, the evaporation decreased, and the salinity gradually decreased. The distribution of sedimentary microfacies has a certain inheritance, which is manifested in the shrinkage of anhydrite-salt basin, the retreat of gypsum dolomite flat and gypsiferous dolomite flat to the east, and the transition and expansion of dolomite flat containing anhydrite nodules and dolomite flat.

REFERENCE

[1] Kinsman J J. 1969. Modes of formation, sedimentary associations, and diagnostic features of shallow-water and supratidal evaporites. AAPG Bulletin, 53(4): 830-840.
[2] Schmalz R F. 1969. Deep-water evaporate deposition agenetic model. AAPG Bulletin. 53(4): 798-823.
[3] Hardie L A, Eugster H P. 1971. The depositional enviromment ofmarine evaporates-a case for shallow clastic accumulation. Sedimentology, 16(3-4): 187-220.
[4] Hsu K J. 1972. Origin of saline giants: a critical review after the discovery of meditterance. Earth Science Review, 8(4): 371-386.
[5] Treesh MI, Friedman GM. 1974. Sabkha deposition of the salina group (upper silurian) of new york state. In: Coogan A H, ed. General Geology of Salt and Other Evaporites. United States: American Geological Institute, 35-46.
[6] Hermann Borchert and Richard O. Muir. Salt deposits: genesis, metamorphism and deformation of evaporative rocks. Translated by Jianqi Yuan. Beijing: Geological Publishing House, 1976.
[7] Jianqi Yuan, Chengyu Huo and Keqin Cai. The high mountain-deep basin saline environment – a new genetic model of salt deposits. Geological Review. 29(2): 63-69.
[8] Hongfa Zhu and Cuizhang Liu. Prospectivenes of main salt-bea ring formations in China. Journal of Mineralogy and Petrology. 1985 (03): 51-59.
[9] Ping Xue. Origin of evaporites in a vast epicontinental platform sea. Geological Review. 1986 (01): 59-66.

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[10] Babel M. 2007. Depositional environments of a salina-type evaporate basin recorded in the Badenian gypsum facies in the northern Carpathian Foredeep. Geological Society, London, Special Special Publications, 285(1): 107-142.

[11] Ling Li, Xiucheng Tan, Chun Zou et al. Origin of the Leikoupo Formation Gypsum-Salt and Migration Evolution of the Gypsum-Salt Pot in the Sichuan Basin, and Their Structural Significance. Acta Geologica Sinica. 2012 (02): 316-324.

[12] Hongping Bao, Chengyun Yang, Jiansong Huang. "Evaporation drying" and "reinfluxing and redissolving" – a new hypothesis concerning formation of the Ordovician evaporites in eastern Ordos Basin. Journal of Palaeogeography. 2004 (03): 279-288.

[13] Yaoting Lin, Jinquan He. Study on Palaeomagnetism and Salt Formation Conditions of the Stratum of Lower-Middle Trias Series (T_1j-T_2j) of Sichuan Basin. Journal of Salt Lake Research. 2005, 13(04): 1-4.

[14] Qiao Lin, Shen Zhaoguo, Fang Shaoxian,et al. The Main Controlled Factors of Heterogeneity of Middle Ordovician Majiagou 5_{1-4} Reservoir in Jingbian Buried Platform and Its Periphery Area,Ordos Basin. Marine Origin Petroleum Geology. 2007 (01):12-20.

[15] Fanghao Hou, Shaoxian Fang, Zhaoxing Dong, et al. The Developmental Characters of Sedimentary Environments and Lithofacies of Middle Ordovician Majiagou Formation in Ordos Basin. Acta Sedimentologica Sinica. 2003, 7(01): 106-112.

[16] Shaoxian Fang, Jiang He, Fanghao Hou, et al. Reservoirs pore space types and evolution in $M_5^5$to M_5^1 submembers of Majiagou Formation of Middle Ordovidan in central gasfleld area of Ordos basin. Acta Petrologica Sinica. 2009, 25(10): 2425-2441.