Sedimentary environment and reservoir characteristics of microbial carbonate rocks in Leikoupo Formation of Jiangyoutongkou Section

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Abstract. As an important part of carbonate rocks, microbial rock is a good reservoir rock type, and its type characteristics and reservoir formation mechanism are different in different environments. By selecting Jiangyou Tongkou section in western Sichuan, the development environment and reservoir physical characteristics of typical microbial rock are analyzed, and the formation conditions of high-quality microbial rock reservoir are discussed. The results show that: The types of microbial rocks in the Leikoupo Formation of Jiangyou Tongkou Section are mainly tubbers and stromatolites, among which the second and fourth members of Leikoupo Formation are typical. They are developed in relatively warm and high salinity seawater, and their sedimentary environment is anaerobic environment with strong reductive property. The reservoir space types of microbial rocks are mostly intra (intergrain) void and grainy pore. In terms of reservoir physical properties, microbiolites are superior to non-microbiolites, and the 4th member of Lei Formation is the dominant reservoir of microbiolites.

Keywords: Microbial carbonate rocks; Sedimentary environment; Reservoir analysis.

Introduction

The term microbiolites was first proposed by Burne R.V in 1987, which is a general term for the rocks formed by microorganisms or related to microorganisms [1], among which the most important is microbial carbonate rocks, which usually refer to the benthic microbial community through capturing and bonding carbonate particles or the mineral precipitation caused by them [2-4]. According to the growth structure and macro characteristics, our predecessors roughly divided the microbial rocks into seven categories: stromatolite, dendritic stone, thrombolite, homogenous stone, nucleate stone, textured stone, and foamlite [5-7]. In general, there are corresponding sedimentary types of microbial rocks developed in different sedimentary environments, and different microbial rocks also have certain differences in reservoir physical properties. At present, many microbial carbonate oil and gas fields have been found in the world, among which the development of microbial rock reservoir has been found in Bohai Bay Basin, Sichuan Basin, Tarim Basin and North China. Microbial rock reservoir has become a very important type of reservoir and can be used as a high quality oil and gas reservoir.

Exploration of Leikoupo Formation in Sichuan Basin began in the 1970s. Zhongba gas field was discovered in western Sichuan in 1978, Moxi gas field was discovered in central Sichuan in 1980, and high-yield gas was found in Chuanke 1, Xinshen 1 and Pengzhou 1 Wells in western Sichuan in recent years, which also indicates that Marine strata of Leikoupo Formation in western Sichuan have good oil and gas exploration potential. Compared with Dengying microbiolites in Sichuan Basin, Lekoupo microbiolites are only developed in western Sichuan. In the early exploration process, the progress of the Lekoupo Formation in western Sichuan was slow. In 2008, a major breakthrough was made in the dolomite of the upper submember of the fourth member of the Lekoupo Formation, which revealed the huge exploration potential of the fourth member of the Lekoupo Formation [8]. Because the reservoir of the fourth member of the Lekoupo Formation is dominated by microbial carbonate rocks and the thickness of local microbial carbonate rocks can reach 70m [9], Therefore, the study on microbial carbonate reservoir of Leikoupo Formation in Sichuan Basin has been widely concerned.

Although the Leikoupo Formation gas reservoir has been found to be characterized by multi-layer multi-point distribution and local enrichment, no large-scale contiguous oil and gas field groups have been found, one of the important reasons is the lack of integrated and systematic research and correct understanding of reservoir formation mechanism [10]. Therefore, the present study on the microbial rock reservoir of Leikoupo Formation in northwest Sichuan area needs to be further studied. Based on the field records, thin sections of rock samples, carbon and oxygen isotopes, trace elements and rock reservoir property analysis of the stratigraphic section of Lekoupo Formation in Jiangyou Tongkou area, and combining with the knowledge of carbonate sedimentology and reservoir science, this paper discusses the characteristics of microbial carbonate rocks, sedimentary environment and reservoir space in Jiangyou Tongkou. It is a more detailed reference for the follow-up exploration and further study of Leikoupo Formation

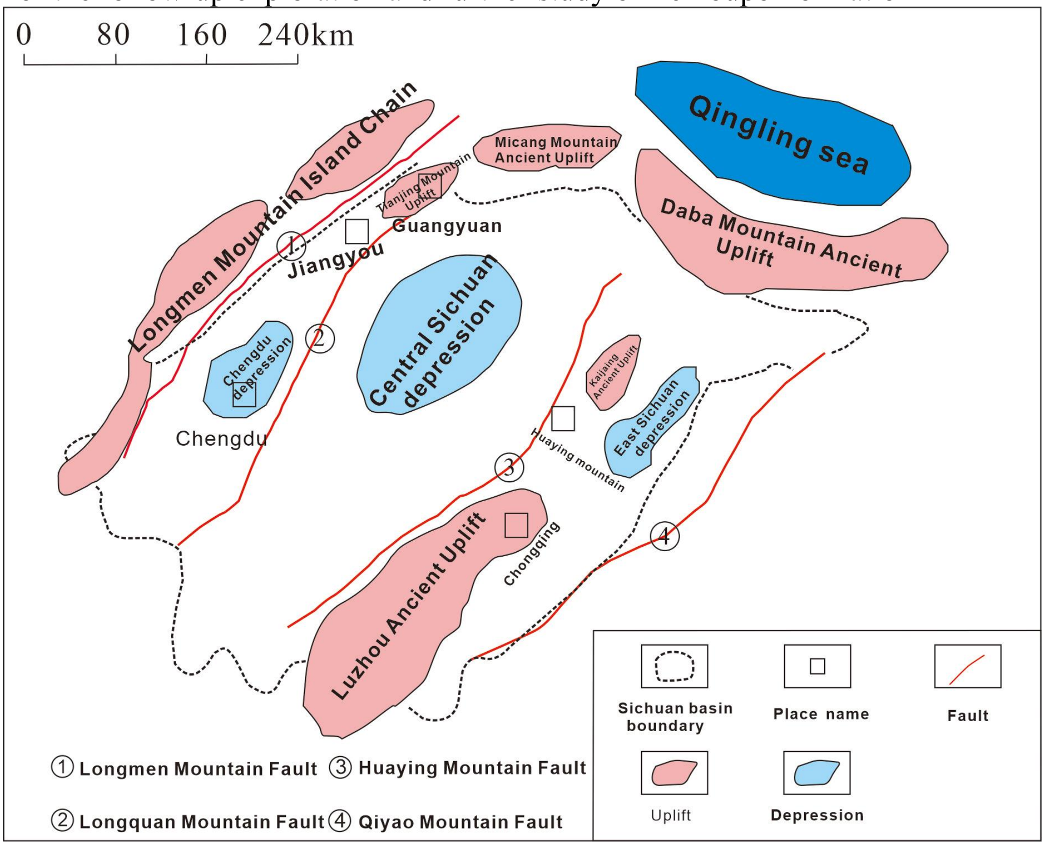

Figure 1.1 Structural Location Map of Jiangyou Tongkou Section (Modified according to [11])

1. Regional geological background

The Sichuan Basin is located in the northwest side of the Yangtze quasi-platform and belongs to a second-order tectonic unit of the Yangtze quasi-platform [11, 12]. Its overall contour is approximately rectangular and inclined to the right in the central and southern parts of the Asian continent. The Middle Triassic Leikoupo Formation was part of the Yangtze Craton Basin during its depositional period [11, 13]. Influenced by the Indosinian movement, Yanshan movement and Himalayan orogeny, the overall geographical pattern of Sichuan Basin is characterized by the development of ancient lands and uplifts around, and the development of central depression [14, 15]. In the southwest, Kangdian ancient land is developed, Jiangnan ancient land is developed in the southeast, and northern Qinling ancient land is developed in the northeast. In the northwest, it faces the Yunnan-Qinghai-Tibet ancient ocean along the Longmen Mountain Island chain; in the north, Tianjingshan Uplift, Micang Mountain Palaeouplift and Daba Mountain Palaeouplift are developed, and they face the Qinling Sea; in the southwest, there is Luzhou Palaeouplift [15-18]. The central depression consists of Chengdu Depression, central Sichuan Depression and eastern Sichuan depression from west to east. In addition, four faults developed in the Sichuan Basin from west to east, namely Longmen Shan fault, Longquanshan fault, Huaying Mountain fault and Qiyashan fault, as shown in Figure 1.1. Sichuan Basin as a whole presents a relatively gentle sedimentary paleo-geomorphic pattern with low west and high east, shallow sea water in the basin, relatively closed sedimentary environment, limited sea water circulation, and weak hydrodynamic conditions, presenting a relatively closed carbonate platform sedimentary environment [15].

The research section is located in the northwest of Sichuan Basin, and the administrative region belongs to Tongkou Town, Jiangyou City, Mianyang City, Sichuan Province. The measured Leiguopo Formation is about 634.1m thick, and it is obviously observed in the field that there is integration contact with the underlying Jialingjiang Formation. The lithology of the section is mainly granular dolomite and argillite crystal dolomite, and paste dolomite, argillite, calcareous dolomite and granular limestone can be seen in local intervals. The main microbial rock types are stromatolites and thrombolites (Figure 1.2). The thickness of the first member of Lei is about 118.2m, and the development of mung bean rock can be seen at the bottom. The overall rock types are mainly argillite crystal dolomite and sand clastic dolomite, and the local argillite dolomite, thrombolite dolomite and oolitic dolomite. The thickness of the second member is about 239.8m. The lithology of the second member is mainly endoclastic dolomite, oolitic dolomite, micrite dolomite, thrombolite dolomite, and sand clastic dolomite and breccia dolomite. The thickness of the third member of the Lei Formation is about 151.9m, and the lithology is mainly thrombolite dolomite and argillite dolomite. The fourth member of the Lei Formation is about 124.2m thick and mainly composed of paste dolomite, micrite dolomite and thrombolite dolomite. Stromatolites are well developed in this formation, but large karst caves are often developed near the middle and upper part of the fourth member of the Lei Formation, and gypsum and other substances are often found in the samples, so it is significantly affected by karstification.

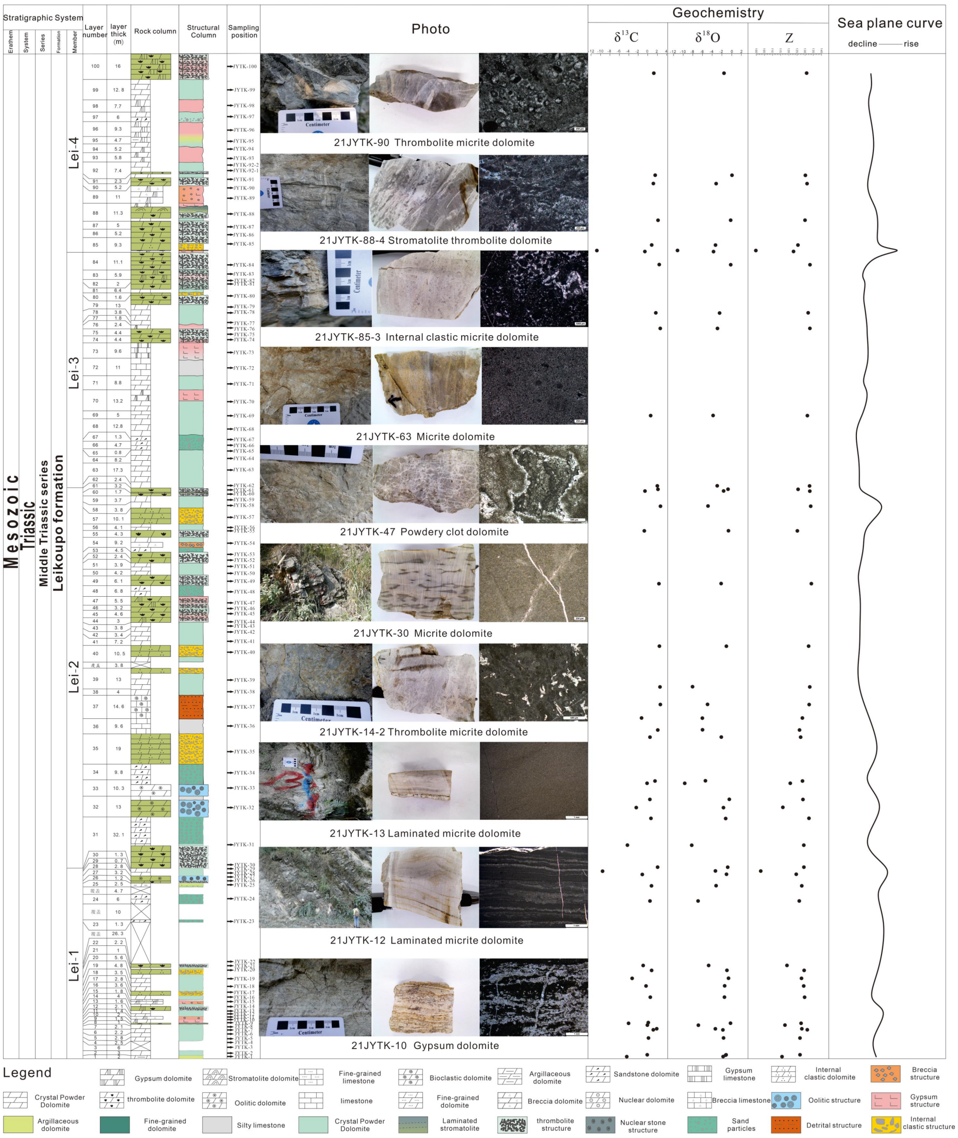

Figure 1.2 Comprehensive histogram of Leikoupo Formation in Tongkou area of Jiangyou Tongkou

2. Sample and method

The samples used in this study were collected from the Leiguopo Formation in Tongkou area of Jiangyou, all of which were taken from fresh outcrops. The samples were observed after grinding glass slides. According to the observation results, the samples in the study area were sampled by dental drill and grinding.

General slide observation was done in the professional laboratory of School of Earth Science and Engineering, Shandong University of Science and Technology. After local staining with alizarin red, pictures were taken under DM4P + Leica polarizing microscope and photographic system. Carbon and oxygen isotopes were tested in the professional laboratory of College of Earth Science and Engineering, Shandong University of Science and Technology. The powder samples were ground to 200 purpose, weighed into the test tube with 0.00030 ~ 0.00035 grams, and reacted with phosphoric acid at a concentration of 98g/mol and 50 degrees Celsius for 2 hours. The released co2 was extracted by Mat 253 plus equipment. Carbon and oxygen isotopes were tested. The data of carbon and oxygen isotopes were all PDB standard. The main and trace elements were tested in Wuhan Upper Spectrum Analysis Technology Co., LTD., the main elements were tested by wavelength dispersive X-ray fluorescence spectrometer (ZSXPrimusII), the use of wavelength dispersive X-ray fluorescence spectrometry "silicate rock chemical analysis method Part 28: Determination of 16 primary and secondary components (GB/T 14506.28-2010) "Rock and mineral analysis" silicate rock analysis, trace element test through the inductively coupled plasma mass spectrometer (Agilent 7700e), Method for Chemical Analysis of Silicate Rocks (GB/T14506.30-2010) was used for analysis.

3. Sedimentological characteristics of microbial carbonate

3.1 Petrological characteristics of microbial carbonate rocks

Due to the influence of tectonic movement and transgressive and regressive activities, the sedimentary environment in the Sichuan Basin changed constantly in different sedimentary periods. The Jiangyou Tongkou area was affected by the overall environmental changes in the basin, and there were some differences in the rock types developed in different sedimentary periods. As a whole, the rock types of Leikou slope in Jiangyou Tongkou area mainly include carbonate rocks, evaporative rocks and clastic rocks. The clastic rocks are mainly mudstone with low development frequency. The local strata of Guangyuan Northwest Township section can be seen, and the argillous components of Jiangyou Tongkou section are mostly produced in the form of argillous cloud rock. The evaporative rocks are mainly gypsum rock. Since the Leikoupo Formation is mainly platform facies deposition, evaporation platform and restricted platform are widely developed, so gypsum rock components are more commonly developed in carbonate rocks. Carbonate rocks can be divided into two parts: non-microbial rock and microbial rock. The non-microbial rock mainly includes micrite dolomite, fine crystalline dolomite, sand clastic dolomite, breccia dolomite, paste dolomite, oolitic dolomite, calcareous dolomite, micrite limestone, oolitic limestone, fine and mesocrystalline limestone, paste limestone, argillaceous dolomite. According to their respective growth structure characteristics and petrological characteristics, microbial rocks can be divided into two categories, namely stromatolite and thrombolite. The overall microbial rock lithology is dominated by cloud rock, mostly filled with paste. The lithologic classification scheme is shown in Table 3.1.

Table 3.1 Lithologic classification table of carbonate rocks in Jiangyou Tongkou section

main type	subtype	Microclass
clasolite	Terrigenousclastic rocks	mudstone
carbonatite	Nonmicrobial rock	Mud powder dolomite, Fine grained dolomite, Sand dolomite, Horny dolomite, Gypsum dolomite, Oolitic dolomite, Lime dolomite, Powder limestone, Fine-mesomorphic limestone, Muddy dolomite
	Microbial rock	Stromatolite，Thrombolite

3.1.1 Stromatolite dolomite

As for the naming of stromatolites, Kalkowsky first named them as stromatolites in 1908, and believed that stromatolites were sedimentary structures generated during the process of sediment capture, bonding and bonding, and were products of microbial growth and metabolism [19]. Walcott first discovered cyanobacteriate-like microfossils in the laminae of a Proterozoic siliceous stromatolite in 1914, and proposed that the stromatolites were precipitated by cyanobacteria [20]. Awramik proposed in 1974 that stromatolites are biosedimentary structures formed by cyanobacteria-dominated microorganisms adhering to and capturing mineral particles in the process of growth and metabolic activities, which has been widely recognized by geologists [21, 22]. According to field profile observation of Jiangyou Tongkou Section stromatolites and observations of microscopic and hand specimens, it is mainly composed of light and dark laminae, and the composition of light and dark laminae is different (Figure.3.1.1A, Figure.3.1.1B). On the whole, the stromatolite dolomites are well developed and produced in the first and fourth member of the Lei Formation. The light and dark laminae of the stromatolite in the first member of the Lei Formation have little undulation and good transverse continuity. The bright laminae are mainly micritic dolomites, and the calcified cyanobacteria near the ellipsoid can be seen in the dark laminae (Figure.3.1.1C). The upper layer of the stromatolites is paste micrite dolomite, and the lower layer is micrite dolomite, which indicates that the stromatolites developed in the relatively weak evaporative tidal flat environment. The stromatolites of the fourth member of Lei Formation are relatively developed, and the common stromatolites tubs coexist in the mirror. Tubs grow along the layers between the bright and dark laminae of the stromatolites, and the stromatolites laminae are mostly undulating, with little overall undulation and columnar growth in some cases (Figure. 3.1.1D). Due to the relative development of paste in the strata of the fourth member of Lei Formation, Sometimes gypsum filling or dissolution pores are relatively developed between stromatolite lamellar structures (Figure.3.1.1D). Therefore, according to lithology characteristics, growth structure and lithology of upper and lower strata, stromatolite dolomites are mostly formed in evaporating lagoons with relatively weak hydrodynamics and in platform algal dome environment with medium-low energy hydrodynamics.

3.1.2 Thrombolite dolomite

The concept of thrombolite was first introduced by Aitken in 1967, referring to deposits formed by non-calcifying algae (cryptoalgae) through caking or secretion [23]. In Jiangyou Tongkou section, tufferite is more developed than other microbial rocks, and the tufferite dolomite development is the most typical in Haolei 2nd Member and Lei-4th Member, but less so in Lei-1st Member and Lei-3rd Member. Field observation shows that tufferite dolomite formation develops more frequently near the hill. Obvious porphyritic structures can be seen in the sampling sites of individual strata of the thrombolite dolomite of the Lekoupo Formation, which are mostly grayish white in visual observation (Figure.3.1.2A, 3.1.2B and 3.1.2C). On the whole, most features are not obvious in the scale of hand specimens. Combined with the microscopic observation, the microscopic characteristics of thrombolite dolomite are more obvious, and obvious gray-black clot structure can be seen, with different shapes of clots, mostly in the shape of patches or near-ellipsoid as a whole, mostly filled with bright dolomite between clots, and locally paste filling and dissolved pore development (Figure.3.1.2D, Figure.3.1.2E, Figure.3.1.2F). The size of clot structure varies. On the whole, the upper and lower lithologies are mostly argillite dolomite, and some of them are associated with paste dolomite and stromatolite, indicating that the clot dolomite in this section is mostly formed in low and medium energy hydrodynamic environment.

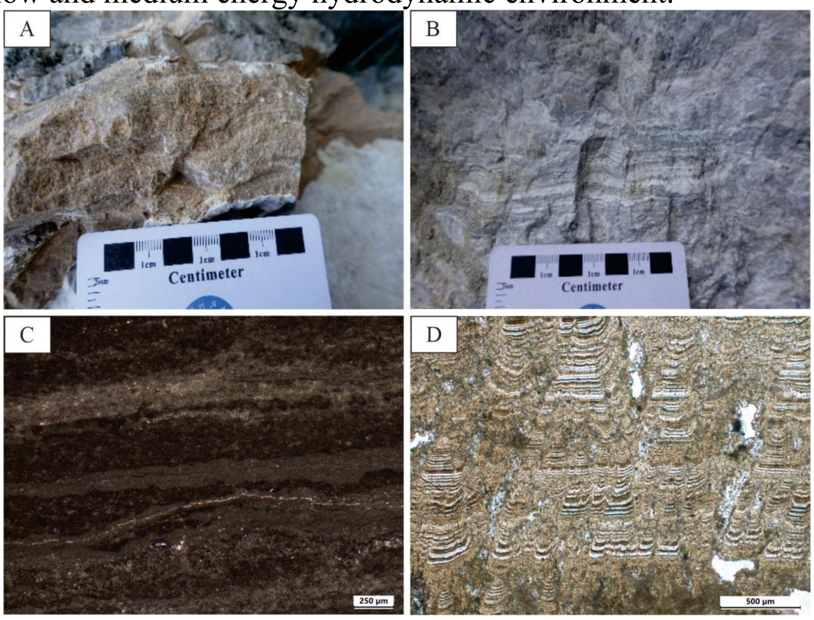

Figure 3.1.1 Petrology characteristics of stromatolite in Jiangyou Tongkou

(A) lamellar stromatolites, Lei 4th Member, outcrop; (B) lamellar stromatolites, seen alternating light and dark laminae in laminar fabric, Lei 4th Member, outcrop; (C) Stromatolites, mixed laminae, calcified cyanobacteria near the ellipsoid in the dark layer, monopolarized light, Lei-Member, JYTK-9-1; (D) Lamellar stromatolites, columnar growth structure and alternating distribution of dense and fine light and dark laminae, dissolved pore development, single polarized light, the fourth member of the Thunder Formation, JYTK-85-2

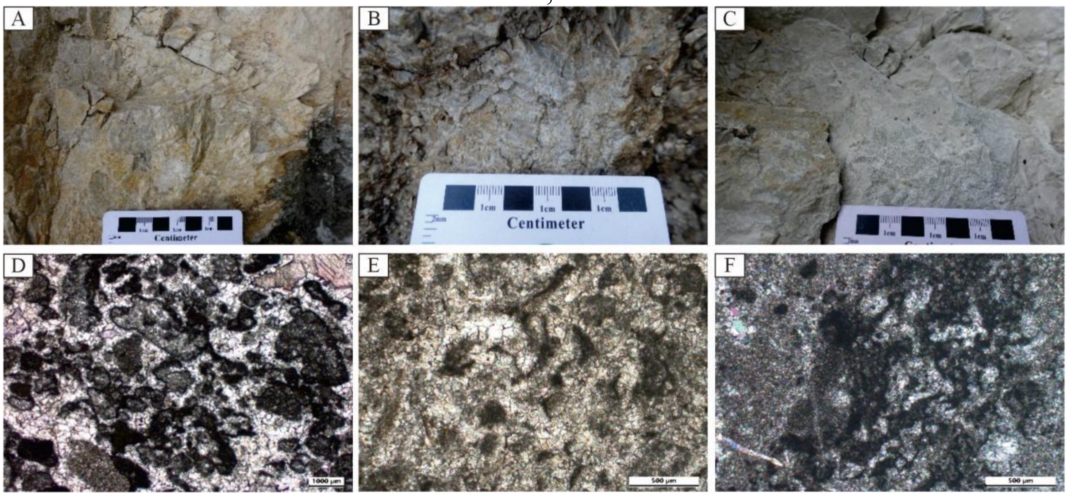

Figure 3.1.2 Petrology characteristics of thrombolites in Jiangyou Tongkou

(A) thrombolite dolomite, with distinct gray-white porphyritic structure, second member Lei, outcrop; (B) thrombolite dolostone, with distinct gray-white porphyritic texture, chromdolomite grain, second member of the Lei Formation, outcrop; (C) Thrombolite dolomite with grayish-white porphyritic structure, Lei 4th Member, outcrop; (D) The thrombolite dolomite has obvious gray-black clot structure, which is mainly composed of micrite organic matter components, and the overall shape is mostly in strip shape. There are more sparry dolomite filling between the clots, single polarized light, the second member of the Lei Formation, JYTK-44; (E) The thrombolite dolomite has obvious gray-black clot structure, which is mostly composed of micrite organic matter components, and the whole is mostly patch-like, with sparry dolomite and gypsum filling between the clots, unipolarized light, the third member of the Lei Formation, JYTK-79-3; (F) The thrombolite dolomite showed obvious gray-black clot structure, and the clot shape was more or less elliptic combined into patch-like structure, with sparite dolomite and gypsum filling between the clots, unipolarized, the fourth member of the Ray Formation, JYTK-85-4

3.2 Analysis of microbial carbonate paleoenvironment

The development characteristics of microbiolites are closely related to the sedimentary environment, and the production characteristics of microbiolites are usually different in different environments. While the paleoenvironment affects the development of microbiolites, it also has a certain influence on the formation of reservoirs. Therefore, in this paper, carbon and oxygen isotopes and trace elements of some samples are used to describe the sedimentary environment characteristics of major rock types in this section, as shown in Table 3.2. Combined with petrological and geochemical characteristics and the comparison between microbial rocks and non-microbial rocks, the formation environment of typical microbial rocks is analyzed.

Figure 3.2 Analysis results of trace elements and isotopes of carbonate rocks in Jiangyou Tongkou

Sample number	rock character	microelement10-6（ug/g）			δ 13C	δ 18O	Z	T/℃
		V	Cr	Ni	（VPDB)/‰			
JYTK-1-2	Mudstone dolomite	64.15	25.63	14.21	-4.41	-0.75	117.89	15.35
JYTK-8	Mudstone dolomite	69.12	25.65	13.50	-3.64	-6.62	116.54	43.91
JYTK-16-	Mudstone dolomite	24.34	3.70	4.13	0.35	-0.43	127.81	14.05

2								
JYTK-24	Mudstone dolomite	8.98	2.20	3.23	-0.29	-2.48	125.47	22.83
JYTK-32	Oolitic dolomite	20.06	2.14	3.82	2.13	0.71	132.01	9.63
JYTK-36	Powder limestone	12.93	1.61	2.99	-0.23	-4.47	124.60	32.41
JYTK-40-2-3	Thrombolite dolomite	20.14	1.13	3.15	2.79	0.18	133.10	11.64
JYTK-55	Thrombolite dolomite	11.06	2.81	3.47	2.20	-1.76	130.93	19.62
JYTK-58-1	Mudstone dolomite	21.43	14.30	10.74	1.76	-0.64	130.58	14.90
JYTK-61-1	Stromatolite dolomite	29.22	2.39	3.54	0.75	-2.82	127.44	24.40
JYTK-69	Thrombolite dolomite	8.05	1.89	3.67	2.61	1.25	133.26	7.66
JYTK-76	Gypsum dolomite	19.42	4.75	5.13	2.38	-2.08	131.13	21.03
JYTK-79-1	Mudstone dolomite	14.04	4.66	4.50	2.30	0.15	132.08	11.76
JYTK-85-2	Stromatolite dolomite	12.24	6.85	8.48	-10.66	-11.53	99.73	74.68
JYTK-91	Mudstone dolomite	40.23	32.18	16.43	1.21	-0.27	129.65	13.41

3.2.1 Paleosalinity

The salinity of sedimentary environment is an important factor affecting the formation of dolomite, especially the development of microbial carbonate rocks. Keith et al. used the combination of $\delta^{13}C$ and $\delta^{18}O$ to indicate the paleosalinity [24], and derived the following equation: $Z=2.048(\delta^{13}C+50)+0.498(\delta^{18}O+50)$. According to the experimental statistical results in Table 3.2 and Table 3.2.1, the microbial salinity index of the Lekoupo Formation is relatively high on the whole, and the Z value range of the thrombolites in Jiangyou Tongkou profile is all greater than 120, with an average value of 132.43. Compared with thrombolites, the development of stromatolites in the Leikou slope floor is slightly lower, with a minimum Z value of 99.73 and a maximum Z value of 127.44. However, the δ13C and $\delta^{18}O$ values of one of the stromatolites (JYTK-85-2) are significantly negative, with $\delta^{18}O$ <-10‰, suggesting that it may be affected by diagenetic alteration. Therefore, the measured values of carbon and oxygen isotopes are not taken into account. However, the Z value of JYTK-61-1 is 127.44, which is significantly higher than 120. It indicates that the sedimentary environment of the stromatolites and thrombolites in Jiangyou Tongkou section of Lekoupo Formation is Marine sedimentary environment with high salinity. In non-microbial rocks, the minimum Z value is 116.54, the maximum is 132.08, and the mean is 126.78. On the whole, the salinity of paleoseawater in microbiolites is slightly higher than that of non-microbiolites.

Table 3.2.1 Statistics of Paleosalinity Z value of carbonate rocks in Jiangyou Tongkou

region	rock character	Z value		
		minimum value	maximum	average value
Jiangyou tongkou	thrombolite	130.93	133.26	132.43
	stromatolite	99.73	127.44	113.59
	Nonmicrobial rock	116.54	132.08	126.78

3.2.2 Ancient seawater temperature

The temperature of sedimentary environment is also an important factor affecting the formation of dolomite. The formula for calculating the paleo-temperature of δ18O was summarized by predecessors [25] : T(℃)=16.9-4.2(δ18O+0.22)+0.13(δ18O+0.22)2. According to the experimental statistical results in Table 3.2 and Table 3.2.2, the T values of the three coagulative stones in Jiangyou Tongkou section experiment range from 7.66℃ to 19.62℃, with an average value of 12.98℃. The minimum and maximum values of stromatolites' T values are 24.40℃ and 74.68℃, respectively. Without considering the influence of diagenesis, the T values of stromatolites' ancient seawater temperature samples should be close to the measured values of JYTK-61-1 at 24.40℃. The T values of non-microbial rocks range from 9.63℃ to 43.91℃, with an average value of 27.81℃. This indicates that the thrombolites and stromatolites in Lekoupo are in a relatively warm seawater environment and are lower than non-microbial rocks.

Table 3.2.2 Statistics of Paleotemperature T value of carbonate rocks in Jiangyou Tongkou

region	rock character	T/℃		
		minimum value	maximum	average value
Jiangyou tongkou	thrombolite	7.66	19.62	12.98
	stromatolite	24.40	74.68	49.54
	Nonmicrobial rock	9.63	43.91	27.18

3.2.3 REDOX conditions

The REDOX condition of sedimentary environment is not only conducive to the preservation of organic matter, but also an important factor affecting the development of microbiolites. According to V/Cr, V/(V+Ni) and other indicators, the REDOX conditions of the sedimentary environment can be judged.2 < V/Cr < 4.25 represents the oxygen-poor environment, and V/Cr > 4.25 represents the anaerobic environment. 0.45 <V/(V+Ni) < 0.6 represents anaerobic environment, and V/(V+Ni) > 0.6 represents anaerobic environment [26]. The roots are shown in Table 3.2.3. In the coagulative stone samples, V/Cr ranges from 3.93 to 17.82, with an average value of 8.67. The value of V/(V+Ni) ranged from 0.69 to 0.862, with an average value of 0.77. In stromatolite samples, V/Cr values ranged from 1.79 to 12.23, with an average value of 7.01; The value of V/(V+Ni) is between 0.59 and 0.89, with an average value of 0.74. In non-microbial rock samples, V/Cr values ranged from 1.50 to 9.39, with an average value of 4.31. The value of V/(V+Ni) is between 0.67 and 0.85, with an average value of 0.78. According to the statistical results in Table 3.2.3, the test samples are in an anaerobic environment under reducing conditions as a whole, and the sedimentary environment of stromatolites in sample JYTK-61-1 is significantly more reductive without considering diagenesis.

Table 3.2.3 Trace element characteristics of Jiangyou Tongkou carbonate rock

Microbial rock	element	minimum value	maximum	average value
thrombolite	V/Cr	3.93	17.82	8.67
	V/(V+Ni)	0.69	0.86	0.77
stromatolite	V/Cr	1.79	12.23	7.01
	V/(V+Ni)	0.59	0.89	0.74
Nonmicrobial rock	V/Cr	1.50	9.39	4.31
	V/(V+Ni)	0.67	0.85	0.78

4. Characteristics of microbial carbonate reservoir

4.1 Characteristics of microbial carbonate reservoir space

The characteristics of reservoir space is one of the important indicators affecting the evaluation of microbial carbonate reservoir characteristics. The characteristics of reservoir space are usually different in different sedimentary environments and different rock types. According to field observation, microscopic analysis and geochemical data indication, the dolomite of Jiangyou Tongkou section was developed in the evaporation environment of high salinity seawater as a whole, and the paste and salt materials were widely developed, which was easily affected by late dissolution. In the field, large karst caves were found in many places of the fourth member of Lei Formation. According to the microscope observation of the samples, the types of microbial rocks in Jiangyou Tongkou area are mainly thrombolite and stromatolite. The main pore types in thrombolite are intergranular (intergranular) void and lattice pore, while the main pore types in stromatolite are lattice pore. Intra granular (intergranular) pores can be roughly divided into intra granular dissolution pores and intergranular dissolution pores. Intra granular dissolution pores are mainly represented by dissolution filling inside clot particles, while intergranular dissolution pores are represented by residual pores between clot particles, which have not been completely filled in the later stage and can retain more effective pores (Figure. 4.1.1A and 4.1.1B). In stromatolites, lattice pores are mainly developed between laminae and retain relatively good pore structure after dissolution (Figure. 4.1.1C). Lattice pores in coagulated stones are mainly the residual pores between the clot lattice, which are mostly filled by sparry minerals in the later period (Figure 4.1.1D).

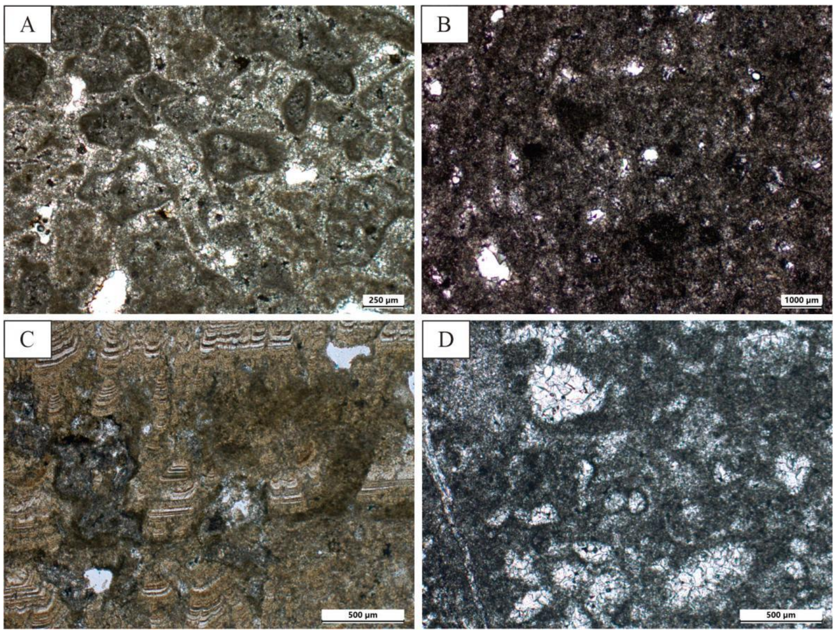

Figure 4.1.1 Spatial characteristics of microbial carbonate reservoir in Jiangyou Tongkou area

(A) Thrombolite, second stage of thunder, intergranular pores, Single polarized light, JYTK-40-2-3; (B) Thrombolite, third member of Thunder, inner pore, Single polarized light, JYTK-84-2; (C) Stromatolite, Lei 4th Member, lattice pore, Single polarized light, JYTK-85-2; (D) Thrombolite, Thunder Section 4, lattice hole, single polarized light, JYTK-88-3

4.2 Physical characteristics of microbial carbonate reservoir

In this study, 21 samples of Jiangyou Tongkou Section of Leikoupo Formation were selected, mainly microbial rocks and non-microbial rocks in the second member of Leikoupo Formation, the third member of Leikoupo Formation and the fourth member of Leikoupo Formation. According to the results, the porosity of the second member of Leikoupo Formation is generally concentrated between 1 and 2%, and the porosity of A few samples can reach more than 4% (Figure 4.2.1A), and the permeability is mainly concentrated between 0.1 and 1mD. The average permeability was 0.74mD (Figure. 3.2.1B). The physical condition of the 3rd member of Lei formation is slightly higher than that of the 2nd member of Lei formation, and the overall porosity value is between 1 and 3%, and the proportion of high porosity value is significantly higher than that of the 2nd member of Lei formation (Figure. 4.2.1C). The permeability is mainly between 0.1 and 1mD, with an average value of 0.23mD, slightly lower than that of the 2nd member of Lei Formation (Figure. 4.2.1D). The physical property conditions of the fourth member of Lei are worse than those of the third member of Lei, and the porosity value of the third member is mainly between 0 and 2%. The high porosity value of the third member is lower than that of the third member, but it is significantly higher than that of the second member (Figure 4.2.1E). The permeability characteristics of the second member of Lei and the third member of Lei are roughly the same, mainly distributed between 0.1 and 1mD, with an average value of 1.1mD. However, the permeability difference of the fourth member of Lei Formation is large, with both low and high permeability accounting for a certain proportion. Combined with the comprehensive consideration of porosity and permeability, the physical property condition of the fourth member of Lei Formation is obviously better than that of other strata without distinguishing lithology.

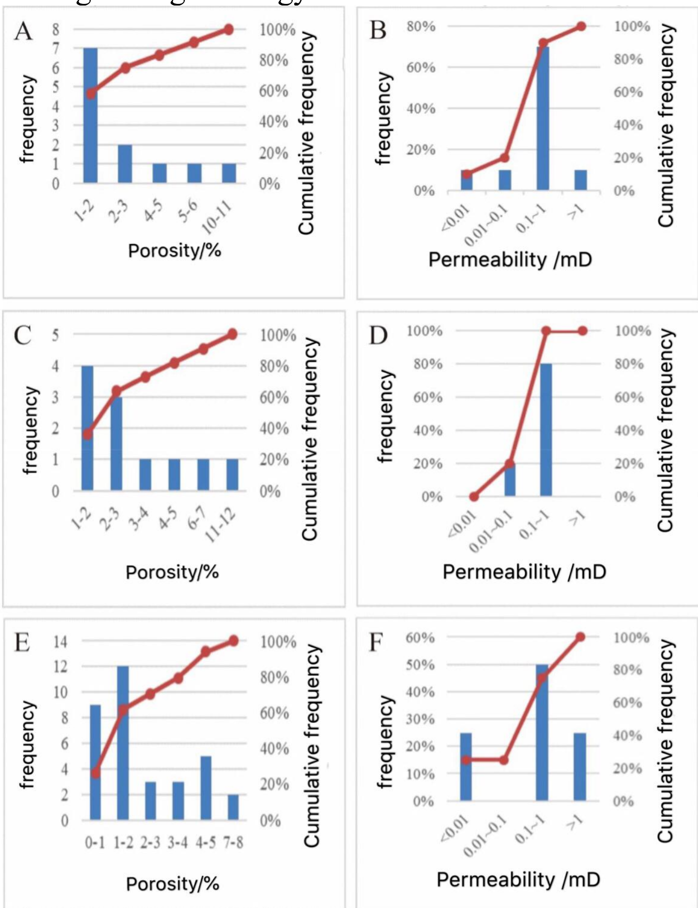

Figure 4.2.1 Histogram of physical properties of the second, third and fourth sections of Leikoupo Formation in Jiangyou Tongkou

(A) Histogram of porosity distribution of the second member of Lei Formation; (B) Histogram of permeability distribution in the second member of Lei Formation; (C) Histogram of porosity distribution of the third member of Lei Formation; (D) Histogram of permeability distribution in the third member of Lei Formation; (E) Histogram of porosity distribution of Member 4 of Lei Formation; (F) Permeability distribution histogram of the fourth member of Lei Formation

On the basis of the original porosity, lithology correlation is further carried out. The second member of Lei formation is mainly composed of thrombolite dolomite, stromatolite dolomite, oolitic dolomite and sand clastic dolomite. The average porosity of thrombolite is 4.1%, the average permeability is 0.8mD, and the average porosity of stromatolite dolomite is 1.4%. The average permeability is 0.7mD, the average porosity and permeability of oolitic dolomite are 1.4% and 1.0mD, and the average porosity and permeability of sand-clastic (internal clastic) dolomite are 2.3% and 0.4mD, respectively. It can be seen that thrombolite dolomite belongs to the rock type with good reservoir property in the second member of Lei formation (Figure. 4.2.2E). The third member of Lei Formation is mainly composed of micrite dolomite, powdery dolomite and thrombolite dolomite. The average porosity of micrite dolomite is 1.9% and the average permeability is 0.1mD; the average porosity of powdery dolomite is 0.9% and the average permeability is 0.03mD; the average porosity of thrombolite is 5.5% and the average permeability is 0.3mD. The thrombolite dolostones show relatively high porosity and permeability values (Figure 4.2.2B). The types of microbial rocks developed in the fourth member of Lei Formation are mainly thrombolite dolomite and stromatolite dolomite, as shown in Figure 4.2.2C. The average porosity of stromatolite dolomite is 8.0%, the average permeability is 4.2mD, the average porosity of thrombolite dolomite is 2.8%, and the average permeability is 0.1mD, among which the stromatolite dolomite has the best porosity conditions. Therefore, the results show that the microbial rocks show high porosity in each interval, and tubs develop in multiple intervals with high porosity. From the second member of Lei Formation to the fourth member of Lei Formation, the development of stromatolites tends to be limited, while the stromatolite dolomites in the fourth member of Lei Formation have high porosity and permeability.

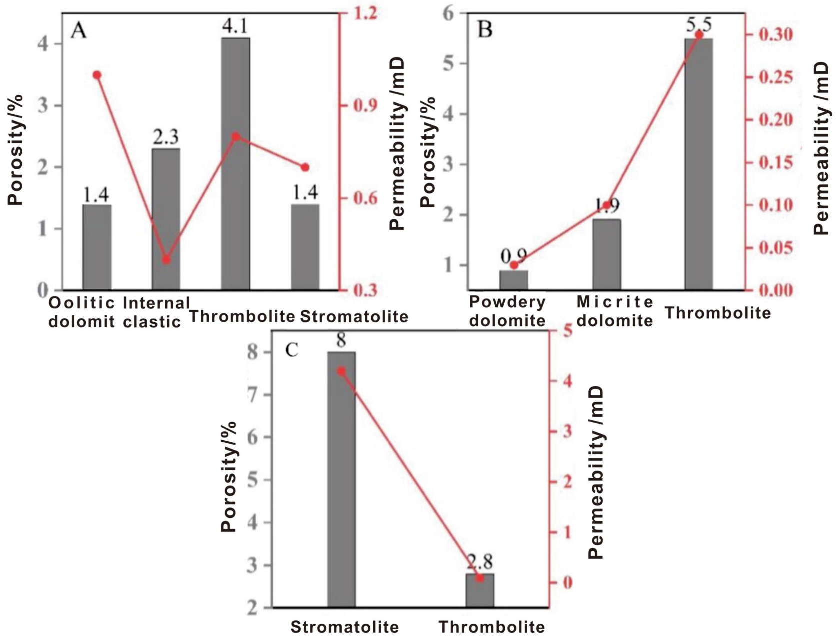

Figure 4.2.2 Lithologic and physical characteristics of different layers of Leikoupo Formation in Tongkou, Jiangyou

(A) Different lithology and physical properties of the second member of Lei Formation; (B) Different lithology and physical properties of the third member of Lei Formation; (C) Different lithology and physical properties of the fourth member of Lei Formation

Conclusion

(1) The reservoir rocks in the microbiolites of the Lekoupo Formation in Jiangyou Tongkou Section are mainly stromatolites and thrombolites, mainly distributed in the second and fourth member of Lei, and the development frequency of thrombolites is higher than that of stromatolites.

(2) The salinity and temperature of the sea water during the deposition of Leikoupo Formation in Jiangyou Tongkou section were generally suitable for the development of microbial rock. The reduction environment under the condition of high salinity sea water at the same time under the anaerobic condition was very conducive to the development of microbial rock, which provided a good material basis for the formation of microbial rock reservoir.

(3) The reservoir physical property of the second member of Lei Formation to the fourth member of Lei Formation shows an overall increasing trend. The reservoir physical property of microbial rock is better than that of non-microbial rock on the whole. The thrombolites and stromatolites show higher porosity, indicating that the microbial rock of the fourth member of Lei formation is the dominant formation for reservoir development.

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