Mineral Composition and Sedimentary Environment Analysis of Wulalike Formation in the Western Margin of Ordos Basin

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Abstract. Based on petrographic research, organic geochemistry and elemental geochemistry are applied to analyze the sedimentary environment of the Ordovician Wulalike Formation in the Ordos Basin, and explore its impact on organic matter enrichment. The research results indicate that the shale of the Wulalike Formation is mainly composed of quartz and clay minerals, and there is a certain degree of positive correlation between the accumulation of organic matter and the content of quartz and clay minerals. The content of quartz and clay minerals has a positive promoting effect on the accumulation of organic matter in the Wulalike Formation. The sedimentary environment is a reducing environment with weak water stratification, and during the sedimentation period, the water is relatively deep and stable. There is a certain positive correlation between organic matter accumulation and redox conditions in the study area, but a poor correlation with ancient water depth and climate indicators, indicating that the reducing environment may be the influencing factor of organic matter accumulation. In contrast, the warm and humid climate has little effect on improving the paleo-productivity of the Wulalike Formation.

Keywords: Ordos Basin; Wulalike Formation; Sedimentary Environment; Total Organic Carbon.

1 Introduction

Shale gas, as an unconventional natural gas resource, is formed from organic matter in shale and undergoes a complex process of biological and/or thermal origin. In this process, shale not only plays the role of a source rock but also serves as a reservoir and caprock [1]. Organic matter is not only the material basis for oil and gas generation and accumulation but also an important carrier for adsorbed gas in shale. The formation of

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oil and gas depends on the living environment and preservation conditions of the hydrocarbon parent material. Only by restoring the sedimentary environment during shale development can the enrichment mechanism of organic matter be clarified. Organic matter enrichment is a complex physical and chemical process, and there has always been a debate between two perspectives. Some scholars believe that the enrichment of organic matter is mainly controlled by primary productivity during the formation of source rocks [2], while others believe that preservation conditions are the main controlling factor affecting organic matter enrichment [3]. Due to the multiple factors involved in organic matter enrichment and the complexity of the process, the formation and preservation of organic matter are not caused by a single factor. Therefore, it is necessary to reconstruct the sedimentary environment during the development of source rocks from multiple perspectives.

Previous studies have shown that the enrichment of shale gas in the Wulalike Formation of Ordovician Wulalike Formation in Ordos Basin is controlled by factors such as sedimentary environment, reservoir development degree, preservation conditions, and formation pressure [4].

2 Geological Background

The Ordos Basin is the second largest oil-bearing basin in China, contains multiple layers and types of energy mineral resources such as oil, gas, coal, and uranium ore, with extremely rich reserves. At present, the Ordos Basin has developed into one of the most important energy production bases in China [5]. The basin is mainly composed of sedimentary rocks from the Cambrian to Paleogene, with geological structures dominated by faults and folds. The organic matter enrichment within the basin is mainly concentrated in source rocks, which are mainly distributed in the Paleozoic and Mesozoic stratum, including the Carboniferous, Permian, and Jurassic strata. The shale argillaceous shale and coal seams in these strata are rich in organic matter and are important sources of oil and gas formation [6].

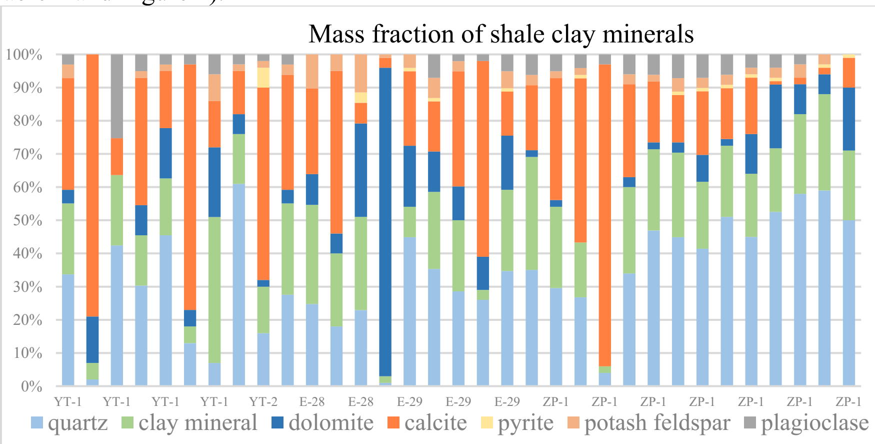
The Wulalike Formation is an important stratigraphic unit in the Ordos Basin, mainly distributed in the western edge of the basin. The formation is mainly composed of argillaceous shale and coal seams with a large thickness and a wide distribution range [7]. The Wulalike Formation is one of the important source rocks in the western margin of the basin. These organic-rich strata provide an important material basis for the formation and enrichment of oil and gas [8].

3 Sample Testing and Results

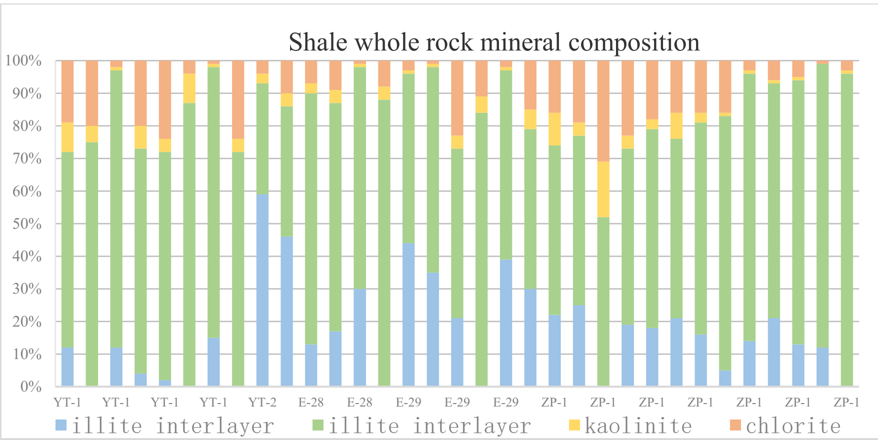
This article investigates the petrology and geochemistry of the Wulalike Formation [9], including mineral composition and total organic carbon (TOC), and provides a detailed analysis of the relationship between organic matter and mineral composition, as well as the sedimentary environment of the Wulalike Formation. Among them, PW1730 X-ray diffractometer was used for mineral content analysis of the sample, TOC analysis uses the LecoCS-744 carbon-sulfur analyzer to measure CO2 volume to estimate TOC content, and the trace elements were determined by inductively coupled plasma mass spectrometry (ICP-MS).

3.1 Mineral Composition of Shale

The shale minerals of the Wulalike Formation are mainly quartz and clay (Table 1 and Figure 1), with the highest quartz mass fraction ranging from 1.0% to 61.0%, with an average of 32.7%. The mass fraction of clay minerals is 2.0%~44.0%, with an average of 19.6%, mainly composed of illite interlayer and illite. The average mass fraction of dolomite is 12.3%, and the average mass fraction of calcite is 27.8%. The average mass fraction of pyrite is 1.5%, while the mass fractions of other minerals are all below 5% (Table 1 and Figure 1).



(a)Mineral composition of shale whole rock



(b)Mineral composition of shale clay

Fig. 1. Mineral composition of shale and clay in the Wulalike Formation

Table 1. Mineral composition analysis results of shale samples from the Wulalike Formation

Well name	Depth/m	Mass fraction of clay minerals/%				Mass fraction of whole rock minerals/%						
		Illite interlayer	Illite	Kaolinite	Chlorite	Quartz	clay mineral	Dolomite	Calcite	Pyrite	Potassium feldspar	Plagioclase
YT-1	3885.06	12	60	9	19	33	21	4	33		4	3
YT-1	3892.06		75	5	20	2	5	14	79			
YT-1	3964.20	12	85	1	2	42	21		11			25
YT-1	3966.05	4	69	7	20	30	15	9	38		2	5
YT-1	3967.60	2	70	4	24	45	17	15	17		2	3
YT-1	3968.10		87	9	4	13	5	5	74			3
YT-1	3969.30	15	83	1	1	7	44	21	14		8	6
YT-1	3970.10		72	4	24	61	15	6	13		2	3
YT-2	3908.10	59	34	3	4	16	14	2	58	6	2	2
YT-2	3915.70	46	40	4	10	27	27	4	34		3	3
E-28	3942.75	13	77	3	7	24	29	9	25		10	
E-28	3942.95	17	70	4	9	18	22	6	49		5	
E-28	4010.90	30	68	1	1	22	27	27	6	3	11	
E-28	4015.42		88	4	8	1	2	93	3		1	
E-29	3966.50	44	52	1	3	44	9	18	22	1	4	
E-29	4046.80	35	63	1	1	35	23	12	15	1	6	7
E-29	4049.10	21	52	4	23	28	21	10	34		3	2
E-29	4054.30		84	5	11	26	3	10	59			2
E-29	4108.65	39	58	1	2	34	24	16	13	1	5	5
ZP-1	4185.22	30	49	6	15	34	33	2	19		3	6
ZP-1	4190.28	22	52	10	16	29	24	2	36		2	5
ZP-1	4191.44	25	52	4	19	26	16		48	1	2	4
ZP-1	4191.84		52	17	31	4	2		91			3
ZP-1	4196.94	19	54	4	23	34	26	3	28		3	6
ZP-1	4226.58	18	61	3	18	46	24	2	18		2	6
ZP-1	4237.75	21	55	8	16	44	25	3	14	1	4	7
ZP-1	4240.73	16	65	3	16	41	20	8	19	1	3	7
ZP-1	4241.00	5	78	1	16	50	21	2	15	1	3	6
ZP-1	4249.53	14	82	1	3	45	19	12	17	1	2	4
ZP-1	4250.70	21	72	1	6	52	19	19	1	1	3	4
ZP-1	4255.85	13	81	1	5	58	24	9	2		4	3
ZP-1	4259.29	12	87		1	59	29	6	2	1	3	
ZP-1	4264.70		96	1	3	50	21	19	9	1		

3.2 Geochemical Characteristics

3.2.1 Organic Geochemical Characteristics

The organic matter abundance is an important indicator in shale gas evaluation [10], which serves as the material basis for shale gas generation and determines the hydrocarbon generation intensity of shale. The overall TOC mass fraction of the samples in the study area is relatively high, ranging from 0.30% to 1.16%, with an average value of 0.79% (Table 2).

Table 2. TOC Mass Fractions of Shale Samples

Number	Sample Number	Depth/m	TOC/%
1	zp-1	4240.73	0.86
2	zp-2	4241.00	0.33
3	zp-3	4243.94	0.62
4	zp-4	4249.53	0.46
5	zp-5	4250.70	0.82
6	zp-6	4253.71	0.80
7	zp-7	4255.85	0.29
8	zp-8	4259.29	0.88
9	zp-9	4260.75	0.97
10	zp-10	4262.19	0.84
11	zp-11	4263.72	0.93
12	zp-12	4264.28	0.67
13	zp-13	4264.70	0.56
14	zp-14	4268.10	0.61
15	zp-15	4268.59	0.33
16	zp-16	4269.15	0.80
17	zp-17	4269.53	0.96
18	zp-18	4271.00	0.22
19	zp-19	4274.95	1.24
20	zp-20	4277.11	0.81

3.2.2 Sedimentary Geochemistry

Inorganic parameters such as trace elements are important indicators in sedimentary environment research. By deeply analyzing the content, distribution, and ratio changes of these elements, we can obtain more accurate primitive geochemical information. The selected trace element content is shown in Table 3.

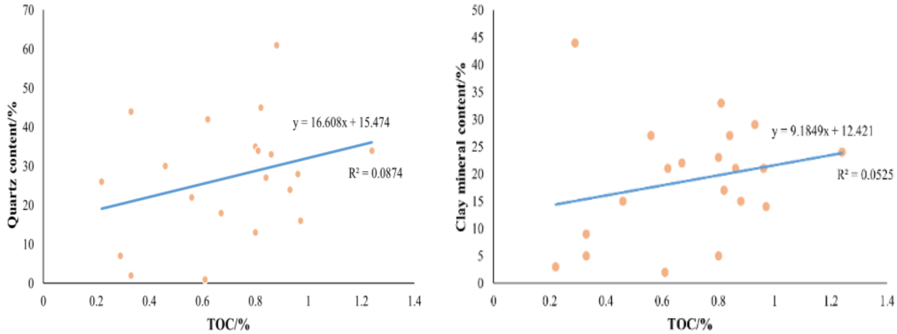
Table 3. Analysis results of trace elements (ppm) and some rare earth elements (ppm) in shale

Number	sample number	Th	U	Zr	Sr	Rb	Cu	Mn	V	Mo	Ni
1	zp-1	8.652	2.164	70.39	91.19	111.5	37.56	66.67	107.4	0.3958	23.56
2	zp-2	7.158	1.591	56.72	128.1	111.6	32.4	154.2	80.93	0.4797	32.65
3	zp-3	10.180	2.066	78.8	86.85	143.8	49.96	103	117.6	0.6449	25.67
4	zp-4	5.989	2.557	45.77	84.52	84.44	25.74	186.3	128.1	3.84	27.6
5	zp-5	7.827	1.968	61.09	76.08	116.7	32.19	69.41	99.16	0.7214	28.03
6	zp-6	6.642	1.904	50.43	88.07	98.98	31.96	197.7	133.3	1.204	35.4
7	zp-7	8.822	3.471	78.59	92.73	130.4	42.63	106.8	119.5	1.492	27.84
8	zp-8	4.957	3.142	40.14	167.5	68.51	14.48	358.4	79.23	0.8809	22.17
9	zp-9	10.150	2.957	87.31	115.3	131	29.79	203.2	153.3	1.734	27.31
10	zp-10	7.181	2.802	68.71	76.46	112.1	37.94	90.41	115.3	0.6644	21.63
11	zp-11	7.087	1.853	54.43	86.32	108.1	34.5	178.7	99.67	0.9476	34.7
12	zp-12	8.671	3.047	58.25	139.2	116.6	29.68	325.4	136.2	2.022	39.21
13	zp-13	8.085	1.698	62.67	87.21	120.1	27.85	163.4	107.1	0.3378	28.71
14	zp-14	10.020	2.29	78.61	102.8	149.6	41.66	134.8	169.4	0.6402	38.63
15	zp-15	5.919	2.189	52.88	120.8	93.54	16.53	189.5	91.27	0.6564	17.32
16	zp-16	2.389	1.693	20.94	203.3	39.66	9.715	346.7	44.9	0.3189	24.5
17	zp-17	1.966	1.603	14.98	312.3	27.56	7.591	672.7	27.16	0.2876	25.45
18	zp-18	6.301	4.7	93.41	141.3	93.1	39.65	237.8	152.9	1.793	38.85
19	zp-19	6.739	1.913	53.32	71.27	104.4	22.76	120.1	143.5	0.5081	27.69
20	zp-20	6.644	1.933	50.15	121.4	97.06	28.14	173.8	86.09	1.031	32.61

4 Discussion

4.1 Analysis of the Relationship between Mineral Composition and Organic Matter

The mineral composition is closely related to organic matter and occupies an important position in crustal materials [11]. The composition of minerals affects the formation and distribution of organic matter, and organic matter also participates in and influences mineral evolution. After in-depth analysis of the relationship between TOC and quartz and clay minerals, it was found that there is a certain degree of positive correlation between TOC and quartz content and clay mineral content [Figure 2 (a), (b)]. This discovery indicates that the quartz content and clay mineral content have a positive promoting effect on the enrichment of organic matter in the Wulalike Formation.



(a)The relationship between quartz content and TOC

(b)Relationship between clay mineral content and TOC

Fig. 2. Correlation analysis between TOC and mineral composition content

4.2 Sedimentary Environment Analysis

The sedimentary environment is one of the main factors controlling the development of source rocks [12]. Among them, inorganic parameters such as trace elements are more stable in reflecting the ancient environment and evolutionary information than organic matter, and have the ability to preserve original geochemical information, which can provide a basis for the inversion of the development environment of source rocks [13]. Previous studies [14] [15] have established elemental geochemical indicators for evaluating sedimentary paleoenvironments, including paleoclimate, redox environment, and depth of ancient water bodies.

4.2.1 Analysis of Redox Characteristics.

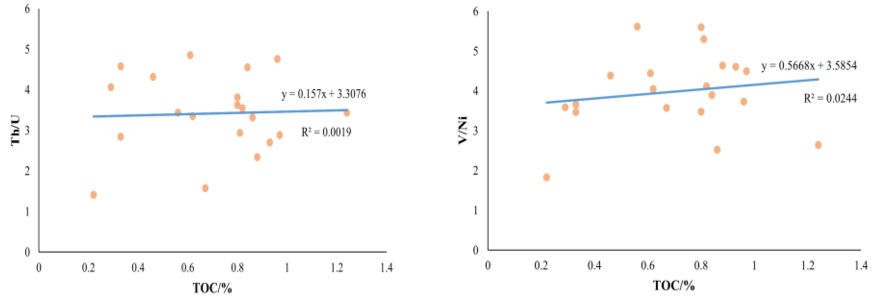
Th/U, V/(V+Ni), The ratios of V/Cr, Ni/Co and other element ratio can be used to restore the redox properties of ancient environments. In general, Th / U value less than 4 indicates the reducing environment, and greater than 4 indicates the oxidizing environment [16]. The value of V / (V + Ni) less than 0.5 indicates the oxidation environment, and greater than 0.5 indicates the reduction environment. Some scholars have also shown [17] [18] that high V/(V+Ni) values (>0.84) reflect the anaerobic environment of water stratification and the presence of H2S in the bottom layer of water; The moderate value (0.6-0.82) reflects the anaerobic environment with weak water stratification; The low value (0.46-0.6) reflects a weakly stratified oxygen poor environment in the water body. The V / Ni value greater than 1 reflects the reduction environment, and less than 1 reflects the oxidation environment. [19].

The test data shows that, the main body of Th/U values is 1.41~4.85, The average Th/U value is 3.42. The V/(V+Ni) value ranges from 0.65 to 0.85, with an average value of 0.79. The V/Cr value is 1.57-4.21, with an average of 2.37. The V/Ni value ranges from 1.83 to 5.60, with an average of 3.98. The test results indicate that the sedimentary environment in the study area is a reducing environment and the water layer is not strong anaerobic environment. The redox conditions directly determine whether organic carbon can be preserved and are also an important control factor for organic matter enrichment. Generally, reducing conditions are more conducive to the preservation of organic carbon. The correlation between TOC content in the study area and Th/U and V/Ni is weak [Figures 3 (a) and (b)], and the reducing environment may not be a factor affecting organic matter enrichment.

4.2.2 Analysis of Ancient Climate and Ancient Water Depth

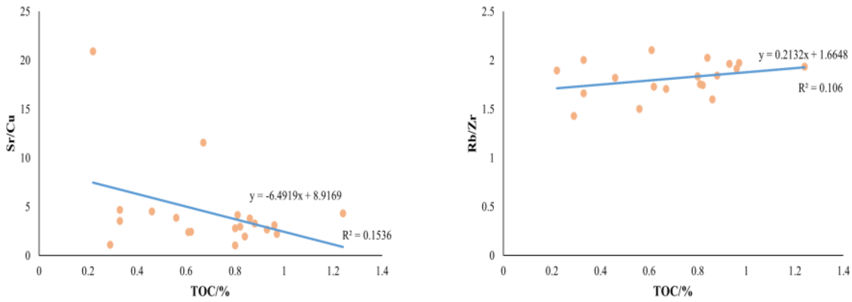
The relative content of P, the content of Co, Sr/Cu, Mg/Sr, A12O3/MgO and other indicators reflect the ancient climate and water depth conditions in sedimentary environments [20]. Usually, the Sr / Cu value of 1.3 ~ 5 indicates a warm and humid paleoclimate, 5 ~ 10 indicates a semi-humid to semi-arid paleoclimate, and more than 10 indicates a dry and hot climate. The Fe / Mn value of sedimentary rocks is higher in humid climate and lower in arid climate. Meanwhile, the high value of Mg / Ca can indicate the arid climate, and the low value reflects the humid climate. Zr is mainly enriched in shore-shallow sea sandstone in the form of heavy minerals such as zircon, and the argillaceous sedimentary area is the low value area of Zr [21]. Therefore, Zr can be used as an indicator of heavy minerals or coarse-grained components, which can be used to indicate the degree of terrestrial material addition in deep cement shale. Rb is an alkaline earth element, which is chemically active and easy to migrate. It is easy to be adsorbed and enriched by fine or light minerals such as clay minerals and mica in a low-energy environment, and has a tendency to increase with the deepening of water body. Therefore, the Rb / Zr value can be used as a qualitative discriminant index of water depth. The higher the value, the deeper the water body [22] [23].

Actual measurement data shows that, the Sr/Cu value is 1.04~20.93, with an average of 4.37. The analysis results indicate that the sedimentary period in the study area mainly developed a warm and humid ancient climate. The Rb/Zr values range from 1.43 to 2.10, with an average of 1.81, indicating that the water in the study area was deep and stable during the sedimentation period. There is a weak negative correlation between TOC and paleoclimate indicators in the study area [Figure 3 (c)], and a weak positive correlation between TOC and paleowater depth indicators in the study area [Figure 3 (d)], indicating that the warm and humid climate has a weak impact on the enrichment of organic matter in the Wulalike Formation.



(a) Relationship between Th/U and organic matter enrichment

(b) Relationship between V/Ni and organic matter enrichment



(c) Relationship between Sr/Cu and organic matter enrichment

(d) Relationship between Rb/Zr and organic matter enrichment

Fig. 3. Parameter diagram of influencing factors of organic matter enrichment

5 Conclusion

1)The shale minerals are mainly quartz and clay, with the highest content of quartz. The clay minerals are mainly composed of illite-montmorillonite interlayer and illite. There is a certain degree of positive correlation between TOC and the content of quartz and clay minerals in the research area. The content of quartz and clay minerals has a positive promoting effect on the enrichment of organic matter in the Wulalike Formation.

2)The sedimentary environment of the study area is a reducing environment with weak water stratification, and the water body is deep and stable during the sedimentary period. During the sedimentary period, the warm and humid paleoclimate is mainly developed. The TOC content in the study area has a certain positive correlation with redox conditions, but a weak correlation with ancient water depth and climate indicators, indicating that the reducing environment may be a factor affecting organic matter enrichment, while the warm and humid climate has a negligible effect on the organic matter enrichment of the Wulalike Formation.

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