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Minor Elements Utility in Paleo-lake Evolvement and Signification of Lower Tertiary Fning Formation，Gaoyou Sag, Subei Basin[1]

FU Qiang[2]

Abstract: According to the study vertical variations of trace elements: Boron(B) and Strontium(Sr) contents testing in clay rock of tertiary Funing Formation(from bottom to up :E_1f^1、 E_1f^2、 E_1f^3、 E_1f^4), Gaoyou sag, Subei Basin of China., the water of palaeolake in Gaoyou sag of Subei Basin changed from freshwater(E_1f^1、 E_1f^3) gradually to salt water(E_1f^2、 E_1f^4). The calcareous cement is formed in early diagenesis. It also means that Gaoyou palaeolake was twice opened to the sea from the first section of Fning Formation to the fourth (E_1f^1-E_1f^4). During the second and fourth of Funing Formation (E_1f^2、 E_1f^4）, the Gaoyou palaeolake was the deepest and the area was largest. Comprehensive analysis of trace elements indicates that palaeo-salinity and depth fluctuated during different sedimentary periods. The sedimentary periods of Funing Formation can be divided into 9 intermediate cycles with relative lake level change. The paleolake level was relative rising quickly in the second and fourth of Funing Formation (E_1f^4) and relative descending quickly in the first Funing Formation (E_1f^1).

Key words: palaeolake; trace elements; lower tertiary Fning Formation; Gaoyou sag

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[2] Born in 1964 Hebei Tangshan, male, professor, PHD. Eng, State Key Laboratory of Marine Geology,Tongji University, Shanghai ,200092, China.
Email: fuqiang@tongji.edu.cn

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The depositional geochemical behaviors have the distinctive functions in exact tracing and HR calibrating. The variation of minor elements reflects the salinity of palao lacus and the fluctuation evolution of the water body. The variation of minor elements of B, Sr, Ga which has a close relationship with the lake water, indicates how the lake water had varied, and has a inner connection with the water body and the salinity variation.[3] The ratio of V/Ni not only correlated with the luxuriant growth of biology, but has a connection with the fluctuation of water body, oxidate and oxygen-free environment.[4] So, the over time changes of the minor elements existed in the sediments can be used for the study of revolution of palao-lacustrine salinity during the geological periods and the fluctuation of the lacus water level which can be used for the further inquiry of the revolution of the palao lacus.

As the salinity of the water body and the lake water level took control of the formation of reservoirs and the growth of the sedimental organic materials, also dominated the formation and distribution of the source rocks directly.[5] So, through the test analysis of minor elements of the cores, the study the paleo lacustrine sedimental revolution of tertiary Funing Formation of Gaoyou sag in Subei Basin has a significance for the study of both development of the source rock and reservoirs development, and the exactly dividing the stratigraphic sequences of tertiary Funing formation of Gaoyou sag.

1. GENERAL GEOLOGY

Petroleum in Gaoyou sag mainly lies in the tertiary formation of Subei basin(Fig.1),the sedimental environment of Funing Formation was lacustrine deposit, from bottom to top: from bottom to up :E_1f^1、E_1f^2、E_1f^3、E_1f^4. The sandstones in E_1f^1、E_1f^3 are the oil-bearing formation, and E_1f^2、E_1f^4 are the source rocks formation. The E_1f^1 is about 500~600m thick with vary thick alternate layers of light grey and light brown sandstones, siltstones and silty mudstones. The silty mudstones and mudstones have flat beddings which reflects the oxidate brink meare lake environment. E_1f^2 is about 200~300m thick with dark grey, grey-dark mudstones, lime-mudstones, the lake water deepened apparently, and the lacus of Gaoyou widened. E_1f^3 is about 240~330m thick, dark grey, grey-black mudstones and light grey, grey siltstones, fine sandstones alternate layers, are the main oil-bearing series. The mudstones which indicates the relative shallow water body of meare lacus intrafacies are between fine sandstones and siltstones. E_1f^4 is about 190~400m thick, the thick lime-mudstones are mingled in the dark grey, grey-black mudstones. The mudstones have three types: black pure mudstones, lime-mudstones, grey-mudstones, lime-mudstones, oil shales etc which reflects the semi-deep lacus-dark deep lacus intrafacies.

[3] Zhou Yongqing, Relationship between the sedimentary elements distribution and environment of Yellow River Estuary area. Marine Geology&Quaternary Geology[J]，1987，29(7)：123-129
[4] Li Rongxi, Wei Jiayog, Yang Weidong, Guo Qingjun, Comparison between the marine water level variation and worldwide using SS. Advances in Earth Science[J], 2000，15（6）：729-734
[5] Zhang Zhihuan, Yang Fan, Li Dongming, Biomarker Assemblage Characteristics of Source Rocks and Associated Crude Oils in Saline Lake Facies of Cenozoic in China, Acta Sedimentologica Sinica, 1998，16（3）：119-123

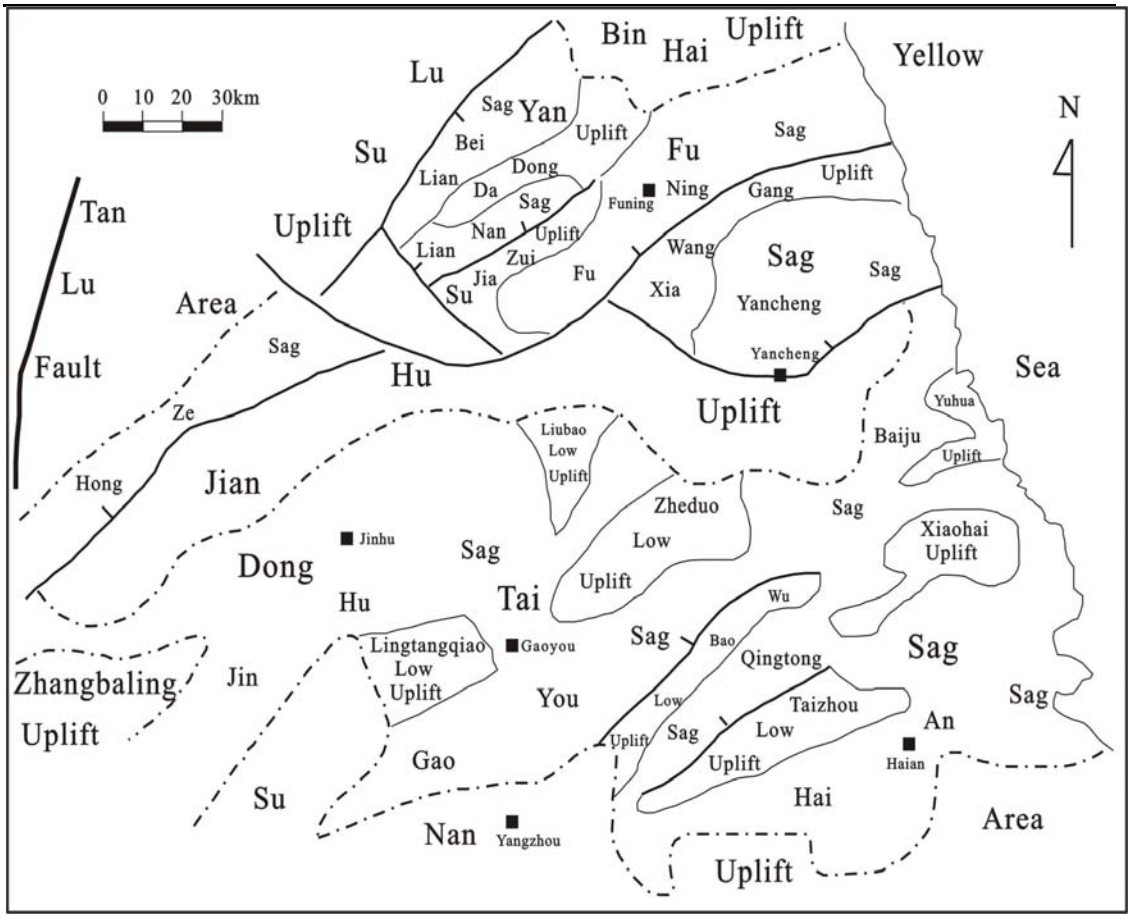

Fig.1. Tectonic units and research area of Subei basin

In the lacustrian and delta sedimental system, when the sediments reach the certain ratio, the ascent of the lacus water level will lead to the deepen upwards of the sedimentary facies sequences and the thin of the sedimentary grain. In the other side, the decent of lacus will lead to shallow upwards of the sedimentary environment and thicken of the sedimentary grain. The associate condition of the mudstones reflects better of the sedimentary environment.[6]

2. THE MINOR ELEMENTS ANALYSIS OF THE PALEOSALINITY OF THE LACUS IN GAOYOU

305 samples of mudstones and muddy limestones of Funing formation of tertiary in this study revolves fifteen wells including Well Chen 2, Well Sha 20, Well Lian 24, Well Zhou 31, Well Yong 16, Well Zhuang 2 etc.

[6] Morey G B & Setterholm D R. Rare earth elements in weathering profiles and sediments of Minnesota:implications for provenance studies[J]. J of Sedi Petrol,1997,67:105-115.

2.1 The minor element B in the sediments

The palaeosalinity of the palaelacus is wavy which reflects the relative variable of the lacus water level.[7] The mass fraction and the ratio of m(B)/m(Ga) of B in the sedimentary rocks have the close relationship with the salinity of the palaelacus water medium. The study documents of the land facies salted lacus indicate that the ratio of B mass fraction can not tell whether the lacus were salted and the marine deposit. The mass fraction of B can only be treated as an indicator of the palaesalinity. The relationship between mass fraction of B and the salinity in the water body is linear, that is, higher the salinity of the water body, bigger the mass fraction of B(Tab 1). Different clay minerals have different ability in absorbing B, that is, illites have the strongest absorptive capacity, and kaolinites have the weakest capacity.

Tab.1. Salinity fingerprint of the elemental geochemistry

environment	w(B) ($mg\cdot kg^{-1}$)	m(B)/m(Ga)	m(Sr)/m(Ba)
salinity	>100	>4	>1
Half-salinity	60-100	3-4	>1
fresh	<60	<3	<1

According to the X diffraction of mudstones of Funing formation of tertiary in Gaoyou sag, illites are the main clay mineral, while clayites are very rare. So, the mass fraction of B in the sedimentary rocks mainly relies on the illites. From the 200 analytical samples, the distribution of mass fraction of B: 95 samples are <60×10-6, 100 samples are between <60×10-6 and <100×10-6, 5 samples are >100×10-6. According to the average mass fraction of B element from the layering statistics (tab 2), the average mass fraction of B declines from 67×10-6 to 56×10-6 which means that, during the sedimentary periods from E1f1 to E1f4, the palaeosalinity declined gradually.

Tab.2. Rare elements in clayrock analysis of Tertiary Funing group ,Subei basin

Formation	w(Ba)	w(Sr)	w(B)	w(Ga)	m(B)/m(Ga)	sample
Ef^4	372 240 – 520	690 212 – 1140	56 50 – 68	17.7 12.4 – 30	3.57 2.03 – 5.32	80
Ef^3	405 144 – 650	239 84 – 490	59 29.8 – 82	22.8 17.2 – 26.8	2.64 1.21 – 4.13	65
Ef^2	290 150 – 430	670 140 – 1560	67.5 47 – 102	14.5 10.8 – 22	4.8 2.57 – 6.73	85
Ef^1	317 154 – 480	390 320 – 460	72 62 – 82	18.3 17.2 – 19.4	3.91 3.6 – 4.22	10

($\frac{\text{everage}}{\text{min-max}}$)

According to tab 1 and 2, the ratio of m (B)/ m (Ga) of sediments in Gaoyou sag lies between fresh water and brackish water, and decreased from 3.91 to 3.57 which indicates that during E_1f^1 to E_1f^4 sedimental periods, the palaeosalinity. This conclusion conformed the variation of B element.

2.2 Minor element B in the sediments

According to the sedimentary facies and petrology, the mass fraction in southern steep of palaeolacus in

[7] Li Y H, Teraoka H, Young T S et al. The elemental composition of suapended particles from the Yello and Yangtze Rivers[J].Geochim Cosmochim Acta,1984,48:1561-1564

Gaoyou is high in detrital mineral, moderate in the clay mineral, and low in carbonate mineral, and the mass fraction of Si, Fe is high, Al, V is moderate, Ca, Sr, Ba is low. The mass fraction of shallow water area in the northern slope is moderate in the detrital mineral, high in clay mineral, and moderate in carbonate mineral and the mass fraction of Al, V is high, Ca, Sr, Si, Fe is moderate.[8] The mass fraction of Sr increased from the shallow water area to deep water areas which indicates the variation of water level. From tab 2, the mass fraction of Sr in E_1f^2 and E_1f^4 of -670×10^{-6} and 690×10^{-6} exceeds that in the E_1f^1 and E_1f^3 of 390×10^{-6} and 239×10^{-6} which indicates the water in E_1f^2 and E_1f^4 is deeper than in E_1f^1 and E_1f^3.

3. THE ANALYSIS OF WATER LEVEL VARIATION IN FUNING FORMATION AND THE DIVISION OF THE HR SEQUENCES

3.1 E_1f^1

The records of sedimentary rockets show sequences of shallower and coarser upwards. It can be presumed that the lacustrian water level is relatively low order which turns out to ascend quickly and descend gradually. But the changes aren't obviously:

1st.The lithologic association in E_1f^1 is dark brown, yellow-grey mudstones, silty mudstones and brown, yellow-grey silty sandstones with alternate combination of light grey mudstones. This indicates the relative shallower water level of the sediments in E_1f^1 and the oxidate and weak oxygen free environment.

2nd. The mass fraction of minor element of B is relative high- 62×10^{-6}~82×10^{-6} ， and m(B)／m(Ga)is 3.6~4.22(Tab 2) which indicates the brackish water-dilute water.

3rd. The mass fraction of Sr in the sedimentary rockes is relatively low with the average level of 390×10^{-6} which is far beneath that in E_1f^3. in sum, the water body of palaelacus in Gaoyou sag is relative shallower in the sedimentary periods in E_1f^1 and E_1f^3. and the water level in $E_1f^1$is even shallower than that in E_1f^3. the water level in E_1f^2 and E_1f^4 are relative high in sedimentary period. And water level in E_1f^4 is even deeper.

4th. The record of sedimentary rocks grains turns out to be hemicycle with lighter and coarser upwards. The maximum capacity lies in mudstones with relative deep water level that turns out to be meare lacustrain sedimentary facies.

3.2 E_1f^2

The palaolacustrain water level in Gaoyou sag in this period is the first relative fastigum. And the water level has several fluctuations. According to the continuous samples of cores from the dark mudstones (from small to big, representative the formations from deep to shallow) and the curves of minor element Sr, there are 3～4 times fluctuations of lacustrain water level in E_1f^2(Tab 2). More details above:

1st. The tectonic descent of Subei basin results the augment of the acceptable spaces and the sediment supply. Under this strong background, in the early E_1f^2,the sedimentary environment is meare beach-jetty, then turns into mearelacus-half deep lacus-deep lacus sediment. The sedimentary rocks indicate oxygen free-strong oxygen free environment with the combination of dark grey, grey-black,black

[8] Bhatia M R.& Crook K A W. Trace element characteristics of graywacks and tectonic setting discrimination of sedimentary basins[J]. Contrib Mineral Petrol,1986,92:181-193
Garver,J.I.,Royce,P.R.and Smick,T.A. Chromium and Nickel in shale of the Taconic Foreland:A case study for the provenance of fine-grained sediments with an ultramafic source[J],J of Sedi Res,1996,66:100-106
Hay W W. Detrital sediment fluxes from continents to oceans[J]. Chem Geol,1998,145:287-323

lime-mudstones containing silt belts and rhyme lamina mudstones and pure mudstones. The thickness of dark pure mudstones section is steady with broad distribution representative the half deep lake-deep lake intrafacies sedimentation which is also the result of the extension of the lacustrain water level.

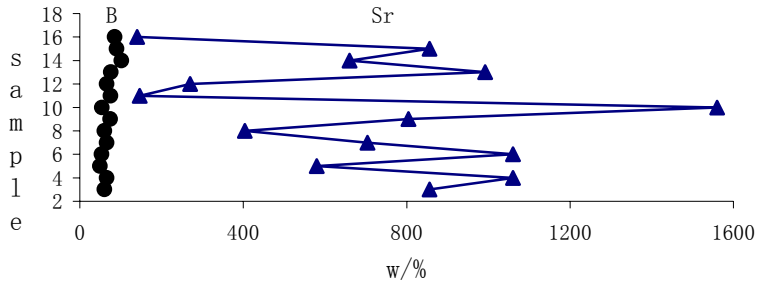

Fig.2. Minor elements in clayrock vertical variety of Funing formation(Ef^2), Subei basin

2nd. The variation of minor elements B and Sr is the synthetical reflection of the palaeosalinity and the relative variation of the lacustrain water level. According to the core analytical data, the changes of mass fraction of minor element B which between 50 $\times 10^{-6}$ and 100 $\times 10^{-6}$ in the sediments in E_1f^2 is not obvious vertically indicates the salinity of the water body is mainly brackish water. The minor element Sr varies greatly which confirms the variation course from shallow to deep, then shallow again of the brackish water body in E_1f^2.

3.3 E_1f^3

The water level of the Gaoyou palaolacus descent in E_1f^3, but there are also several secondary fluctuation cycles(Fig 3). More details above:

1st. The sedimentary environment is meare lacustrain-predelta intrafacies which involved from the half deep lacus in E_1f^2. The dark grey mudstones, silt mudstones with thin siltstones formed shallower sedimentary sequences upwards. The underwater branch channel folded many erosion periods formed several sedimentary rhymes which turns lighter and coarser upwards including light grey, dark grey, black mudstones and grey sandstones.

2nd. Vertically, the mass fraction of minor element B behaves three cycles from small to big which indicates the course of the lake water level from ascension to declination. While the course from big to small of minor element Sr indicates the course of the water body change from shallow to deep, then to shallow again.

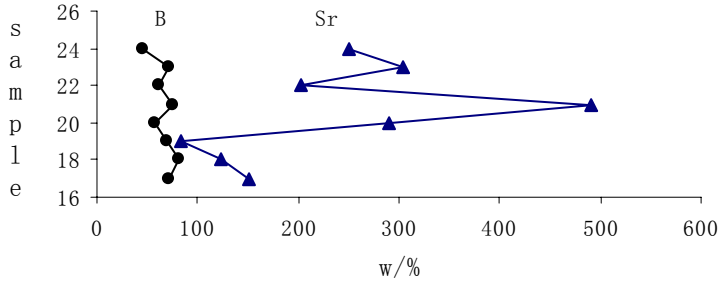

Fig. 3. Minor elements in clayrock vertical variety of Funing formation(Ef^3)，Subei basin

3.4 E_1f^4

The dark grey pure mudstones,lime-mudstones lithologic characters indicate another relative high water level of the palaolacus in Gaoyou. The average mass fraction of B in the mudstones is the lowest of 56×10^{-6}，which indicates the brackish water with partial fresh character of the palaolacustrain water body in Gaoyou. The mass fraction of minor element Sr changed greatly which indicates the four times salinity changes of the lacus waater body in E_1f^4(Fig 4). The total mass fraction of minor element Sr is relative high with average 690×10^{-6} indicates the deep water body of the palaolacus.

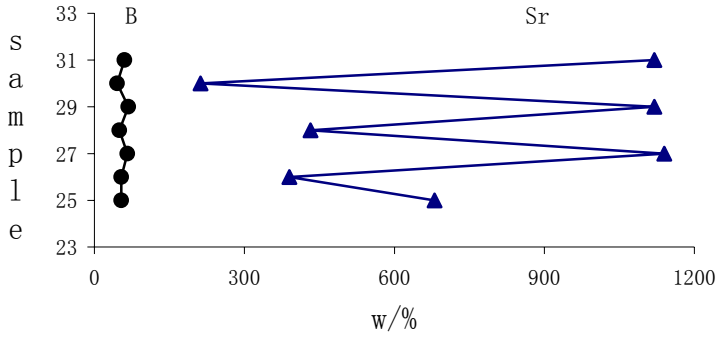

Fig. 4. Minor elements in clayrock vertical variety of Funing formation(E_1f^4)， Subei basin

To sum up, aimed for the great suit of dim mudstones developed in E_1f^2 and E_1f^4, using the minor element analysis, considering the rhyme changes of the vertical lithologic characteristics, the Funing formation is divided into nine middle period basal level cycles(tab 4). The division of the HR sequences of Funing formation in Gaoyou sag will help the division and the comparison of the source rocks， reservoir rocks and the roof rocks.

Tab. 4. High-resolution sequence stratigraphy division of Lower Tertiary, Fning Formation,Gaoyou Sag

Strata			Datum plane cycle		Sedimentary facies and environment	Well to refer
Group	Section	Sand formation	Intermediate stage cycle	Code number		
E_1f	E_1f_4	$E_1f_4^1$	Maximum lake flooding surface	MSC9	Mud of the half deep lake clamps the gray matter, muddy limestone and dolomite In the middle part , mud shale of deep lake In lower part , mudstone and muddy limestone of half bathymetric	Zhen14well Xu2well Su137well Sha20welll
		$E_1f_4^2$				
	E_1f_3	$E_1f_3^1$		MSC8	Delta front, the water depth changes shallowly	Zhang2well
		$E_1f_3^2$		MSC7	Mudstone of Delta front and prodelta	Sha20well
		$E_1f_3^3$		MSC6	$E1f_2^{2-1}$ is mudstone and lime-mudstone of half deep lake and deep lake E1f3 is mudstone of prodelta anddelta fornt , water changes from shallow to deep , to shallow again	Dong43well Dong53well
	E_1f_2	$E_1f_2^1$	Maximum lake flooding surface			
		$E_1f_2^2$				
		$E_1f_2^3$		MSC5	Lake beach, Delta front	Zhuang2well Sha20well
	E_1f_1	$E_1f_1^1$		MSC4	Delta front, Roof get shallow	Su137well
		$E_1f_1^2$		MSC3	Delta plain, Delta front upward	Sha8well
		$E_1f_1^3$		MSC2	Flood plain of river	Sha20well
		$E_1f_1^4$		MSC1	Flood plain of river	Dong56well

5. CONCLUSION

1st. The minor element analysis indicates that, the palaosalinity turned lighter gradually from E_1f^1 to E_1f^4 of Gaoyou palaolacus in Subei basin. The depth of the water body in E_1f^2 and E_1f^4 is the deepest.

2nd. The carbon-oxygen isotopes of the carbonate rocks of formations T_3 in Gaoyou sag indicates that, the environment of the palaolacustrain sedimentary periods in E_1f^1 and E_1f^3 is dilute, while that in E_1f^2 and E_1f^4 is saline affected by the sea invasion.

3rd. According to the variation of the mass fraction of Sr of the whole sedimentary periods in Funing formation is divided into six middle periodic cycles of relative bigger alternations. E_1f^2 and E_1f^4 sedimentary periods are the relative ascend of the palaolacustrain water level, E_1f^1 is the maximal period of the relative lowest period.

4th. From the minor elements analysis, the lacustrain fluctuation is the smallest in E_1f^1, but more frequent, while the fluctuations in E_1f^2 and E_1f^4 are small.

5th. The characters of the palaolacustrain salinity and fluctuation changes of the water body of Funing formation in T_3 benefit the beneficial association of source rocks，reservoir rocks, roof rocks and became the main exploratory formation in Gaoyou sag of Subei basin. While, according to the study of minor elements variation vertically, the fluctuations of the palaolacustrain water level can be learned from the great suit of dark mudstones in E_1f^2 and E_1f^4 of Gaoyou sag which offers the practical technology clues for exact division of HR formation sequences.