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岩屑总化学成分的统计学方法在白垩纪松辽盆地分析中的应用

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石油钻探中通常取心很少，因此主要用物探测井资料划分地层和分析沉积层序的韵律旋回性。然而另一方面，大量的岩屑资料又经常不能被充分利用，除用于气测、萤光等有关储层评价方面的研究外，很少被用于沉积学研究。本文试图用岩屑（包括岩心）的化学成分分析结果，经多元统计学方法处理后用于沉积盆地分析研究——划分地层、分析沉积韵律和沉积旋回。

1　地质背景与基本研究资料

松辽盆地位于中国东北部（北纬 42°—49°，东经 120°—128°），是中新生代的近海陆相沉积盆地。盆地呈北北东向展布，面积约 260000km^2。盆地基底主要由前侏罗纪的变质岩、岩浆岩和火山岩组成，盖层为晚侏罗世的火石岭组（j_3h），下白垩统沙河子组（k_2s）、营城组（k_1l）、登娄库组（k_1d）、泉头组（k_1q），上白垩统青山口组（k_2q）、姚家组（k_2y）、嫩江组（k_2n）、四方台-明水组（k_2sm）和第三系，总沉积厚度大于 10000m。白垩系地层可分划为十个沉积相类型：①冲积扇相；②冲泛平原相；③扇三角洲相；④三角洲相；⑤滨浅湖相；⑥湖岸盐坪相；⑦半深—深湖相；⑧水下沉积物重力流相；⑨沼泽相；⑩火山-沉积岩相。J_3—K_2 构成完整的一级水进—水退沉积旋回，其中可划分出五个二级旋回（即 J_3h—K_1y，K_1d，K_1q—K_1qn；K_2y—K_2n 以及 K_2sm）。半咸水似海相夹层常见于 K_1q—K_2n 层序中。

本文以松辽盆地东南隆起的 W_3 井（44.6N，125.4E）与 SN—15 井（43.8N，124.3E）为研究靶区，系统采集了三百余块泥岩样品进行全岩化学成分分析，选取其中 11 个常量元素（Si、Al、Fe^{2+}、Fe^{3+}、Ti、Mn、Ca、Mg、Na、K、P），16 种微量元素（Ba、Be、Cd、Co、Cr、Cu、La、Mo、Ni、Pb、Sr、V、Y、Zn、S、C）和 7 个比值参数（Mn/Fe、Ti/V、Ni/Co、Sr/Ba、Mg/Al、Ca/Mg、Mg/Fe）等 34 个参数作为多元统计计算的基本变量。

2　原理与方法

石油钻探中的地层分层和旋回划分实质上是基于沉积层序的岩性物性（视电阻率、自然电位、自然伽玛等）。岩石的化学成分不仅可以反映岩性而且可以反映沉积环境。与物探资料相比，化学成分能更直接地反映地下地质信息。因此，恰当地选取元素地化参数来划分地层和分析沉积旋回，应比单一的岩性法或测井曲线法所得结果更合理、更客观。

本文采用变量筛选法选择分层及划分沉积旋回的指标。具体做法是：在取心段选取 50 个已知岩性和沉积环境（应用已有研究成果）的样品，用上述 34 个参数的各种组合形式（变换剔除部分变量）进行样品间的 Q 型聚类分析，选取其中与实际情况吻合最好的一组参数

作为分层和划分沉积旋回的指标（此时相同岩性、相同沉积环境的样品聚到一类），最后确定用 Al、Fe、Ca、Mg、Mn、P、Ti、Ba、Co、Cr、Cu、Ni、Sr、Y、Zn、S、C、及 Mn/Fe、Ti/V、Ni/Co、Sr/Ba、Mg/Al 等 23 个参数作为层和划分沉积旋回的指标。

3 地层划分与对比

现以 W_3 井为实例加以说明，沿该井整个钻探剖面自上而下系统采样（等距离加密采样，样距在 5m 以内），测算各样品的上述 23 个分层指标，用计算机对这 23 个参数变量进行 Q 型聚类分析，统计计算后得到 8 种基本（岩石）类型，它们分别为：A. 半深湖相灰绿色泥（页）岩；B. 深湖相灰黑色泥岩、油页岩；C. 滨浅湖相斑杂色粉砂质泥岩；D. 浅湖泥坪相紫红—灰绿色泥岩；E. 滨湖相紫灰、灰紫色泥质粉砂岩；F. 冲泛平原相紫红色粉砂岩；G. 滨浅湖相绿色粉砂质泥岩；H. 滨浅湖相杂色泥岩。

根据这 8 种岩性在地层剖面中的叠置关系可计算出马尔柯夫链式转移矩阵。该矩阵中的小概率值代表地质历史中出现的小概率事件。以此作为分层界线分别得到下列九种转移关系：A→D，A→F，C→G，D→F，E→D，G→A，G→E，C→B，H→A。它们分别对应于 K_1q—K_2n^2 的九个组段间分层界线，与岩心录井及测井分层界线相吻合。

4 沉积韵律与沉积旋回分析

根据聚类分析的计算结果，依照沉积层序自下而上各种基本（岩石）类型的叠置关系，建立可能概率矩阵 Eig 和转称概率矩阵 Pij，二者相减相差数数值矩阵。该矩阵表示沉积层序中实际出现的概率值与理论上应出现的概率值之差。负值表示实际出现的频率小于理论值。正值表示实际频率大于理论值，说明这种地层转移关系是该沉积层序中经常出现的事件、地层出现了有规律的重复，即具有韵律性或旋回性特征。本文选取差数数值矩阵中概率值＞0.1 的差减数值作马尔柯夫式相关结构图，得到该层序中的主要沉积韵律为 A⇆B 型，它相当于暗色泥岩的频繁互层；主要沉积旋回为 F→G→A⇆B→C→E 型，相当相于红色→暗色→红色的粉砂及泥质岩旋回。W_3 井钻探层位为 K_1q^3—K_2n^2，相当于盆地坳陷期的两个最大的二级复合水进—水退旋回。上述沉积旋回的分析结果正反映了这种沉积特征：即下部紫红色粉砂质泥岩为旋回下部的水进沉积层序，其上的暗色泥岩韵律互层为最大水进期的稳定沉积，顶部以红色调为主的粉砂质岩石相当于二级复合旋回上部水退过程的沉积产物。由此说明，用元素地化-数理统计法分析沉积层序的韵律层序的韵律旋回性可以得到符合客观实际的结果。

THE APPLICATION OF DEBRIS BULK CHEMICAL COMPOSITION STATISTICS METHOD TO THE SONGLIAO BASIN ANALYSIS (CRETACEOUS, NORTHEAST CHINA)

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Debris samples are easy to get and inexpensive in petroleum exploration drilling. But in addition to gas and fluorescent determinations, few of them have been used for stratigraphic and sedimentary cycle studies. On the other hand, the sedimentologic studies of oil basins are mainly based on the indirect geologic information-loggings. The authors of this paper try to use the chemical compositions of debris/core samples to basin analysis, stratigraphic classification and correlation, as well as sedimentary rhythm and cycle studies.

GEOLOGICAL SETTING AND THE WORKED WELLS

Situated in the Northeast of China (42°—49°N, 120°—128°E), the Songliao Basin is a Meso — Cenozoic nearshore continental sedimentary basin of NNE direction with about 260000km^2. The basement of the basin is mainly composed of pre-Jurassic metamorphic rocks, intrusive and volcanic rocks, which are covered by the sequence of up to 10,000 m thick: the late Jurassic Huoshiling Formation (J_2h), the Early Cretaceous Shahezi (K_1s), Yingcheng (K_1y), Denglouku (K_1d) and Quantou (K_1q) Formations; then the Late Cretaceous Qingshankou (K_2qn), Yaojia (K_2y), Nenjiang (K_2n) and Sifangtai-Mingshui (K_2sm) Formations and with the Tertiary on the top. Ten types of sedimentary facies have been recognized by the authors, which are ①alluvial fan; ②fluvial plain; ③fan delta; ④delta; ⑤shore—shallow lacustrine; ⑥beach salty flat; ⑦half deep — deeplacustrine; ⑧subaqueous gravity flow deposits; ⑨lacustrine swamp and ⑩pyroclastic facies. The whole sequence is a giant cycle with complete lake transgression-regression, which can be divided into 5 secondary cycles: J_3h—K_1y, K_1d, K_1q—K_2qn, K_2y—K_2n and K_2sm (Wang Pujun and Du Xiaodi, 1992; Liu Zhaojun *et al.*, 1993; Wang Pujun *et al.*, 1992).

After systematic sampling in the drills of W_3 (44°36'N, 125°24'E) and SN15 (43°48'N, 124°18'E), which are all in the southeast uplift of the Songliao Basin (Fig. 1), the authors analyzed over 300 debris/core samples for 11 major elements (Si, Al, Fe^{2+}, Fe^{3+}, Ti, Mn,

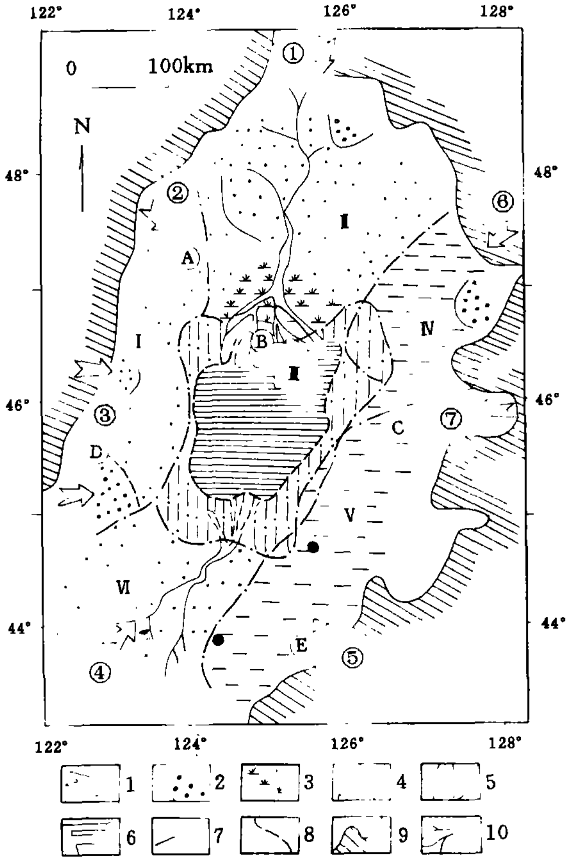

Fig. 1 Geographical coordinates, structural division and depositional systems in the Songlian basin

1 = source direction; 2 = alluvial fan; 3 = fluvial plain; 4 = beach flat; 5 = shore facies; 6 = deep lacustrine facies; 7 = structural division/depositional system boundary; 8 = facies boundary; 9 = present basin boundary; 10 = stream Ⓐ = Qiqihaer; Ⓑ = Daqing; Ⓒ = Haerbin; Ⓓ Baicheng; Ⓔ = Changchun; I — VI structural divisions: I = west slops, II = north downdip, III = central downwarp, IV = NE uplift, V = SE uplift, VI = SW uplift; ①—⑦ depositional systems: ① = North Bei'an—Nenjiang system; ② = West Qiqihaer system; ③ = West Ying—Baicheng system; ④ = SW Baokang—Tongyu system; ⑤ = SE Huaide—Jiutai system; ⑥ = NE Shuihua—Qinggong system; ⑦ = East Binxian—Shangzhi system; Black dots: worked wells

Ca, Mg, Na, K, P), and 16 trace elements (Ba, Be, Cd, Co, Cr, Cu, La, Mo, Ni, Pb, Sr, V, Y, Zn, S, C) with ICAP, ARF and chemical methods. These analytical results and the 7 ratios of Mn/Fe, Ti/V, Ni/Co, Sr/Ba, Mg/Al, Ca/Mg, Mg/Fe were used as the variates for statistics.

PRINCIPLES AND METHODS

The comparison of loggings chemical compositions of debris/core can more directly reflect the rock's features and the palaeoenvironments. They should have been used as efficient information in basin analysis. After sorting above 34 indexes with stepwise method, the authors finally selected 23 from them for further statistics (Al, Fe, Ca, Mg, Mn, P, Ti, Ba, Co, Cr, Cu, Ni, Sr, V, Y, Zn, S, C as well as Mn/Fe, Ti/V, Ni/Co, Sr/Ba and Mg/Al). The variate-sieving procedures are as follows: ①in the core-taking sections, chose the samples containing all of the (8) types of rock feature—facies associations; ②computed with Q-type cluster analysis program; ③rejected some of the 34 variates and checked the results repeatedly, untill the similar samples with the same associations came together in the hierarchical diagram (Fig. 2)

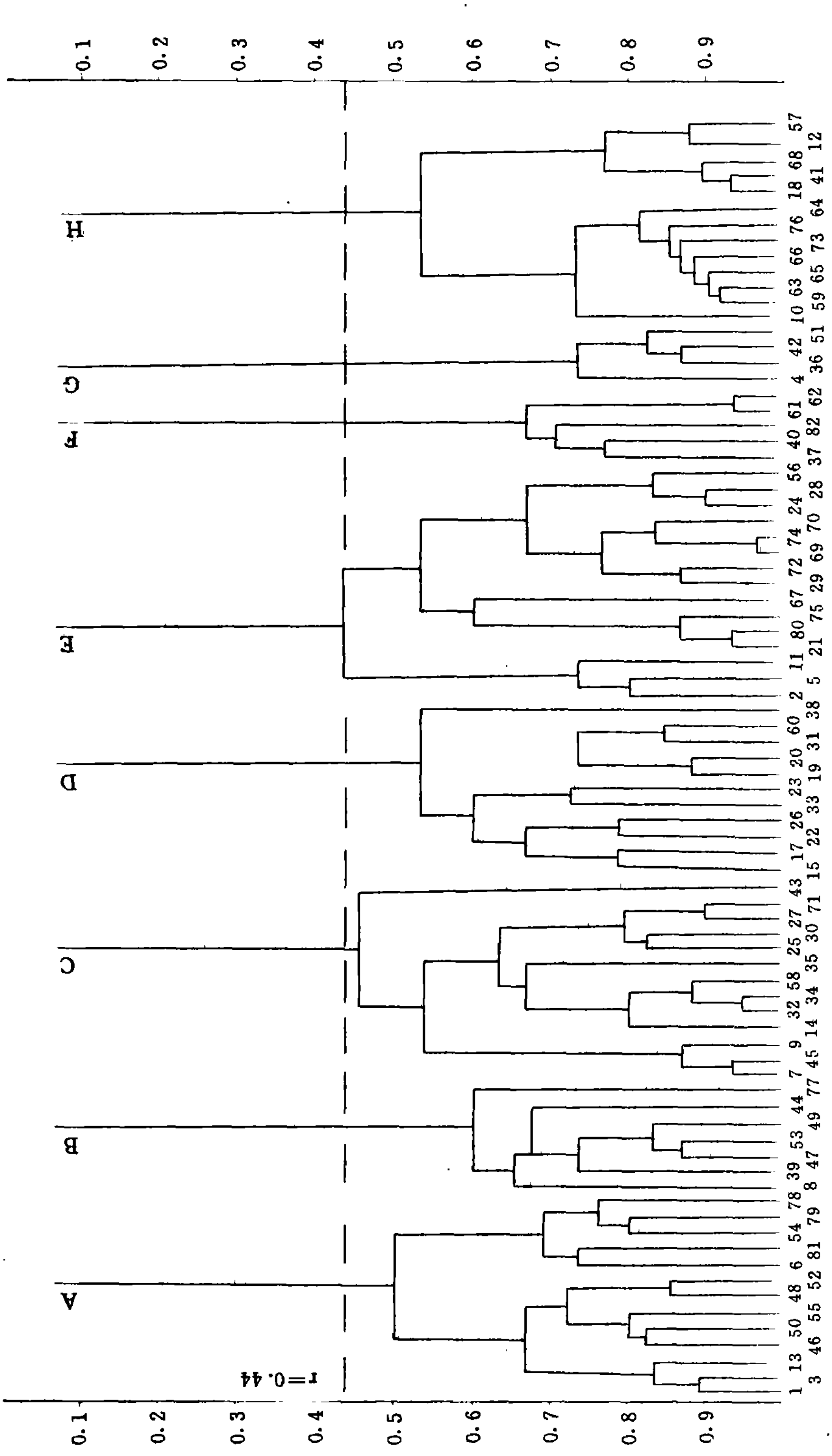

Fig. 2 Cluster analysis hierarchical diagram with the well studied samples in the core-taking section to select the suitable variates and similarity level

STRATIGRAPHIC CLASSIFICATION AND CORRELATION

Here we use well W_3 as illustrations. First equal distance debris core samples(intervals <5m)were systematically collected and the 23 indexes were determined. Then the 23 variates of all samples were computed with cluster analysis program and in this case 8 types of rocks were obtained: A. greyish green shale of semideep lake; B. deep lacustrine black shale; C. parti-coloured silty mudstone of shore-shallow lake; D. purplish red-greyish green mudstone of shallow lake flat; E. greyish purple muddy siltstone of beach lake; F. purplish red siltstone of fluvial plain; G. greyish green silty mudstone of shore-shallow lake; H. parti-coloured mudstone of shore-shallow lake.

A Markov chain transitional matrix(Liu Baojun and Zeng Yunfu, 1985)was obtained from the successional relations of the 8 rock types above. In the matrix, there are some small values(<0. 01)which reflect the small probable events in the geological history, and should be taken as the boundaries of different strata. Here, we got 9 classification boundaries which have good correlations with geological and well logging results(Tables 1 and 2)

Table 1　Markov chain transitional matrix

				To					
		A	B	C	D	E	F	G	H
From	A	.00	.04	.03	.01	.02	.01	.03	.00
	B	.05	.00	.03	.00	.00	.02	.00	.00
	C	.02	.03	.00	.04	.04	.00	.01	.03
	D	.00	.02	.03	.02	.03	.01	.00	.04
	E	.04	.00	.05	.01	.00	.00	.00	.04
	F	.00	.00	.00	.02	.00	.00	.02	.03
	G	.01	.00	.01	.00	.01	.02	.00	.00
	H	.01	.02	.02	.04	.04	.00	.02	.03

Table 2　Comparison of stratigraphic division results of element geochemistry with other methods

Formation	Member	Lithologic classification result	Well logging classification result	Bulk chemical composition—statistics transitional relation	Bulk chemical composition—statistics well depth (m)
Nenjiang	K_2n^2				
		73.5	UN	G→E	60—70
	K_2n^1				
		133	136.5	H→A	132.5—133
Yaojia	K_2y^{2+3}				
		235	UN	E→D	209—212
	K_2y^1				
		334.5	335	C→G	334—335
Qingshankou	K_2qn^3				
		399	400	G→B	393.5—402
	K_2qn^2				
		UN	455	G→A	454.7—462
	K_2qn^1				
		495.5	500	A→D	523.8—526.8
Quantou	K_1q^4				
		586.2	583	D→F	570—580
	K_1q^3				
		UN	UN	A→F	857—869
	K_1q^2				

* Classification boundary between two samples; UN=unclassified

SEDIMENTARY RHYTHM AND SEDIMENTARY CYCLE ANALYSIS

With the results of Q cluster analysis and the stacking sequence of the 8 rock types, we got theoretical probability matrix(Eig)and practical transitional probability matrix(Pig). The latter subduct the former(Pig−Eig)equals to the difference value matrix(Table 3), which represent the transitional probability difference between practice and theory. In the matrix the large number(> 0.1)reflects that the real transitional frequences are much more than the theoretical ones suggesting the occurrences of regular repetition of sedimentary units, which are called as sedimentary rhythms/cycles. Here we got the main types of rhythms of A⇆B, indicating the interbedded dark shales of semideep to deep lake sequences, and the main types of cycles: F→G→A⇆B→C→E, corresponding to the sequence of red to dark again to red silt-mudstone beddings. This sedimentary rhythm and cycle analysis results agree with the lake transgression-regression events during the deposition of the Early Cretaceous Quantou Formation to the Late Cretaceous Nenjiang Formation (Albian—Campanian)(Fig. 3).

Table 3 Difference value matrix(Pig−Eig)

				To					
		A	B	C	D	E	F	G	H
	A	0.0	0.232	−0.105	−0.159	0.033	−0.072	0.025	−0.12
	B	0.256	0.0	0.113	−0.004	−0.2	−0.07	−0.053	−0.044
	C	−0.034	0.053	0.00	−0.005	0.11	−0.072	0.019	−0.126
From	D	−0.093	−0.099	0.09	0.0	−0.121	0.02	−0.056	0.076
	E	−0.661	−0.104	0.006	−0.031	0.0	−0.075	−0.007	0.058
	F	0.031	0.109	−0.169	0.057	−0.195	0.0	0.148	−0.182
	G	0.333	−0.09	0.083	−0.141	−0.192	0.064	0.0	0.071
	H	−0.191	−0.103	−0.048	0.0523	0.066	0.07	−0.059	0.0

CONCLUSIONS

1. The chemical compositional statistics method is very useful and effective in basin analysis, especially for the sequence of predominant mudstone, in which the resolutions of most loggings are generally poor. The adventage of this method is that the debris samples from drillings can be widely used in sedimentological studies.

2. If contradiction happened in basin analysis according to geological/geophysical results, the geochemical statistics can be used as an independent method which is testified to be more accurate. As in Table 2, the boundary between the Upper and Lower Cretaceous (K_1-K_2)used to be an argument problem(Wang Pujun *et al.*, 1991), while based on the results of the paper, the boundary should be 25m lower than the previous one(Table 2).

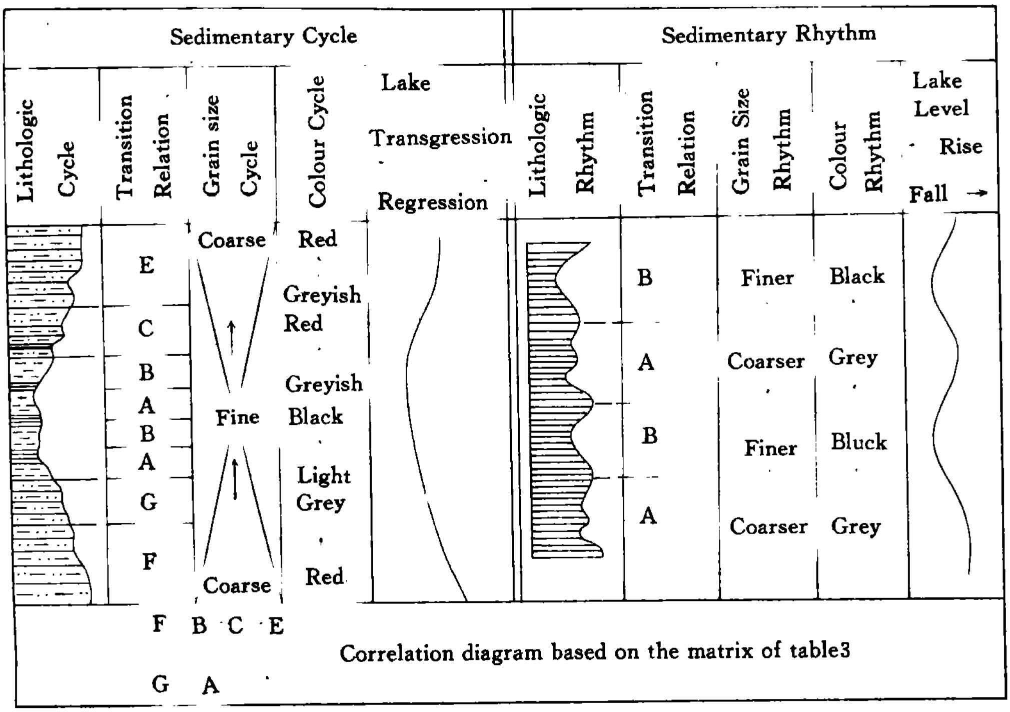

Fig. 3 Correlation between sedimentary cycles and sedimentary rhythms

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