Chronostratigraphy and Stratigraphic Classification of the Cretaceous of the Songliao Basin

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Abstract

Isotopic ages of synsedimentary clay minerals were directly determined with the ultrasonic scattering–settlement separation–K–Ar dilution technique. The apparent age of black mudstone is 123 Ma for the Quantou Formation, 111.9–89.0 Ma for the Qingshankou Formation and 77.6–76.8 Ma for the upper part of the Nenjiang Formation. The Rb–Sr isochrone age of the muddy limestone–mudstone sequence of the lower part of the Nenjiang Formation is 81 Ma and that of the muddy evaporite of the middle part of the Quantou Formation is 122.2 Ma. On the basis of the above isotopic ages, the authors propose a modified scheme of stratigraphic classification of the Cretaceous of the Songliao basin.

Key words: Songliao basin, Cretaceous, lake transgressive depositional sequence, isotopic age, stratigraphic classification

1 Chronostratigraphic Study of the Cretaceous Lake Transgressive Sequence in the Songliao Basin

The present dating methods for synsedimentary components are mainly the K–Ar dilution, Rb–Sr isochrone and apatite or zircon fission track methods (Roden et al., 1993; Phelps and Harrison, 1986). Broadly speaking, any synsedimentary mineral which has been kept in a closed system can be used for dating. Specifically, samples for the K–Ar age must be: (1) real synsedimentary (or early diagenetic) mineral(s), (2) without extra argon captured since its formation (this can be generally met because fluid inclusions are commonly not developed in sedimentary authigenic minerals), and (3) in a closed system for both ^{40}Ar and ^{40}K from its formation up to the present (for sedimentary rocks, this means that the samples should be fresh and have not been weathered, leached, dissolved, recrystallized or heated by hydrothermal fluids). All the samples used for Rb–Sr isochrone dating must be: (1) synchronous deposits (collected from the same horizon), (2) with the same initial $^{87}Sr/^{86}Sr$ ratio (deposited in the same basin), and (3) kept in a closed system all the time

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since their deposition (Faure, 1978).

The present composition and fabric of the samples cannot always definitely tell us whether their isotopes have been homogenized when initially formed, so whether the determined isotopic age is a sedimentary, diagenetic or geothermal event age should be explained. It addition, detrital minerals including the clay minerals formed by weathering, which are not completely separated, can exaggerate the sedimentary ages.

1.1 Sample selection

The purpose of this study is to determine the accurate sedimentary ages of the Cretaceous Quantou to Nenjiang Formations in the Songliao basin. The components representative of real sedimentary ages must be chosen, which are either authigenic minerals or detrital minerals (e.g. synchronous pyroclasts). According to the features of the sedimentary sequence and facies① and the results of thin–section and electron microscope– energy spectrum (EMES) analyses (Wang Pujun et al., 1994), we chose lacustrine argillaceous rocks for K–Ar dating of the Quantou, Qingshankou and Nenjiang Formations, muddy evaporites for Rb–Sr isochrone dating of the Quantou Formation and nodular muddy dolomite, biogenic limestone and mudstone for dating of the Nenjiang Formation.

The foundation of this study is that the samples dated must be "synsedimentary". To ensure this we chose the samples by means of thin–section, EMES, XRD and bulk chemical analyses. The procedure and main grounds of sample selection are as follows.

(1) Evaporites They consist mainly of anhydrite, barite and celestine, which are present in subhedral–anhedral crystals several to tens of microns in size, mosaicked with calcite. Their interstices are filled by synsedimentary clay minerals such as illite, chlorite and zeolite (Hay, 1978; Andreason, 1992). Various minerals show clear boundaries and sharp compositional change, no replacement features being observed under EMES. The evaporites (anhydrite mixed with barite and celestine) observed in the studied core section are as long as a few centimeters and mostly occur as irregular concretions or honeycombs, lenses and string breads. They are parallel to the bedding, never cutting it (or showing obscure relation with the bedding). Geopetal structure is commonly observed, characterized by a smooth arc bottom and flat or angular top. In thin–sections the "basal" cementation structure is recognized, and characterized by silk–sized clasts dotted (suspended) in the evaporites. According to the features mentioned above we are sure that the evaporites are synsedimentary minerals and have not undergone leaching and recrystallization which might cause the redistribution of the original components.

(2) Argillaceous rocks We chose those with laterally continuous bedding from deep lacustrine sequences. Samples taken from the Nenjiang Formation are mainly bentonite. The authigenic clay minerals are dominantly illite, smectite, I / S and kaolinite with minor chlorite. The aggregates of clay minerals have scaly structure, and separate crystals are < 2 μm across. The rock contains abundant fine–grained and silt–sized clasts of quartz, cristobalite, alkali–feldspar and plagioclase (Table 1). Volcanic crystal and vitric fragments

① Wang Dongpo, Liu Zhaojun and Wang Pujun. Sedimentary facies and the characteristics of source, reservoir and cap rocks of the Cretaceous of Songliao basin. Report on National Supported Project No. 75–54–01–11 –01. 1989, 6–54.4

can commonly be recognized in argillaceous rocks of the Nenjiang Formation.

Table 1 Composition of Argillaceous Rock Samples Determined by XRD

No.	Original composition of samples (%)						Composition after being separated (%)					
	Q	Cri.	AlF.	Pl.	CC.	CM.	Sm.	I / S	Ill.	Kao.	I / S ratio	D.O
1	56	8	10	14	0	12	0	65	31	4	40	Partly ordered
2	23	5	12	27	0	33	92	0	3	5	93	Disordered
3	11	7	14	13	0	55	70	0	1	29	95	Disordered
4	53	4	11	14	7	11	0	76	23	1	47	Partly ordered
5	53	4	11	14	10	8	0	76	23	1	50	Disordered
6	50	6	13	21	0	10	0	69	21	10	40	Partly ordered
7	40	3	11	13	22	3	0	41	52	7	35	Ordered
8	41	3	20	23	0	13	0	64	33	3	35	Ordered
9	53	5	11	16	6	9	0	54	43	7	40	Partly ordered

Note: Sample selection and pretreatment by Wang Pujun et al., analysis by the XFF Lab Changchun College of Geology. Q = quartz; Cri. = cristobalite; AlF = alkali–feldspar; Pl. = plagioclase; CC. = calcite; CM. = clay minerals; Sm. = smectite; I / S = mixed–layer illite–smectite; Ill. = illite; Kao. = kaolinite; D.O. = degree of order.

(3) Biogenic carbonate rocks, nodular carbonate rocks and argillaceous rocks Samples were taken from lacustrine deposits of the same or corresponding horizons in order to meet the requirements of deposition at the same time and having the same initial $^{87}Sr / ^{86}Sr$ ratio. According to the stratal sequence and the textures and structures of the rocks, the authors believe that they are really synsedimentary (Wang Pujun et al., 1994). Though the low concentration of Rb and high concerntrations of interfering elements such as Ca and Mg in some of the above samples may make experiments difficult, several low values of Rb / Sr are necessary for calibrating the lower end–point of the Rb–Sr isochrone. It is still possible for us to get a precise Rb–Sr isochrone if appropriate samples are selected. According to the results of thin section, EMES and chemical analyses (Table 2), we have selected and analysed a group of suitable samples for Rb–Sr ages (Fig. 1).

1.2 Sample separation and purification

Authigenic components were quantitatively separated from detrital components. Authigenic clay minerals such as illite, smectite and mixed–layer I / S were used for K–Ar dating. Authigenic minerals with a wide range of Rb / Sr ratios were used for Rb–Sr dating in order to improve the fitting of the isochrone.

(1) Muddy evaporites for Rb–Sr isochrone dating: The purpose of the treatment is to obtain a group of samples including pure anhydrite, barite and celestine and synsedimentary clay–bearing evaporites. Based on the results of thin section and EMES identification, we chose the muddy evaporites with the crystal size >0.1 mm. Smash the selected samples with the iron mortar and sieve them to 60–100 mesh (0.25–0.15 mm) to sep-

arate the evaporite from clay completely or partly Rinse the sieved samples with distilled water several times to remove very fine suspended particles and then separate the muddy evaporites from clastic minerals with Dulia heavy fluids (81 ml distilled water: 270 g HgI_2: 130 g KI). Rinse the separated evaporites with distilled water and bake them dry. Pick out >5 g of evaporite grains and "muddy" evaporite grains under the binocular microscope. Grind them to −200 mesh (< 0.075 mm) for analysis. The key for this procedure was to remove detrital minerals completely and, on the other hand, to preserve varying amounts of synsedimentary clay in some evaporite samples.

Table 2 Chemical Composition of Samples Used for Rb–Sr Isochrone Datings

No.	SiO_2 %	CaO %	Fe_2O_3 %	Al_2O_3 %	MgO %	Mn μg / g	Ba μg / g	Sr μg / g	Rb μg / g	Rb / Sr	Lithology
y_1	12.9	34.2	5.2	2.9	17.7	1428	488	2027	37	0.018	Ankerite
y_2	5.5	48.6	2.1	0.22	3.8	2227	482	244	13	0.0053	Ostrocoda limestone
y_3	14.7	31.6	7.8	3.4	15.6	1320	809	1736	39	0.022	Ankerite
y_4	19.4	27.1	8.0	4.4	13.3	1054	1083	1706	46	0.026	Ankerite
y_5	5.4	49.5	2.3	0.18	7.9	1994	725	2267	11	0.0049	Ostrocoda argillaceous–dolomitic limestone
y_6	13.5	32.9	5.2	3.6	16.9	454	480	2083	38	0.018	Ankerite
y_7	5.1	49.1	3.1	0.1	8.0	2497	276	1867	81	0.0043	Ostrocoda limestone
y_8	8.3	44.0	2.7	1.2	4.8	2655	387	2104	15	0.0071	Ostrocoda limestone
y_9	64.7	2.5	4.2	16.6	2.2	409	455	207	121	0.584	Calcareous mudstone
y_{10}	62.2	0.9	2.5	26.8	2.1	111	806	1250	149	0.119	Argillaceous rock
y_{11}	62.5	2.1	4.7	18.1	2.1	374	848	417	151	0.362	Argillaceous rock

Note: Sample selection and pretreatment by Wang Pujun et al., analysis by the XFF Lab Changchun College of Geology.

(2) Argillaceous rocks for K–Ar dating Fine–grained and silt–sized fragments (0.02–0.005 mm) of quartz and feldspar were observed in large amounts in argillaceous rocks with the microscope and XRD (Table 1). Some samples were calcareous mudstone (Table 1). So we first smashed the samples to −100 mesh (< 0.015 mm) and then sieved them to remove the coarse fraction (> 0.075 m). Weigh 10–20 g of −200 mesh (< 0.075 mm) fine fraction and add 100 ml of 5% HCl (V / V). Stir the mixture thoroughly to remove the calcareous fraction, rinse the remaining HCl solution with distilled water. Add 100 ml distilled water and then vibrate the sample solution for 30 minutes. with the ultrasonic apparatus. Put the separated sample solution into a 500 ml beaker and stir it into

suspended solution. Separate the pure clay minerals by settling. Bake the separated sample to dry and check its purity with XRD (Table 1). The key of this step was to refrain from introduction of the detrital components and prevent the Ar loss in the sample preparation (baking temperature < 100℃, not grind the sample too long a time).

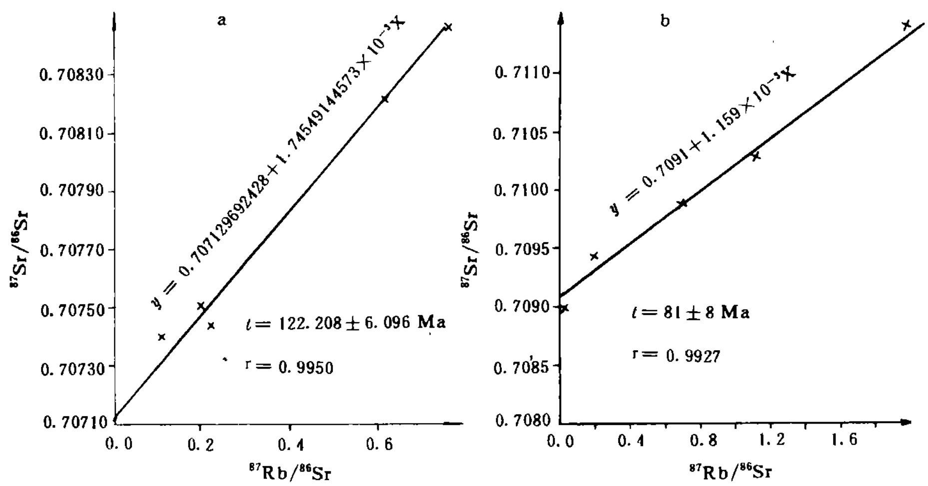

Fig. 1 Rb–Sr isocnrone ages of the Cretaceous transgressional sequence of the Songliao Basin
(a: Quantou Fm.; b: Nenjiang Fm.)

(3) Carbonates–mudstones for Rb–Sr isochrone dating The purpose of the treatment was to obtain a group of pure calcite, dolomite, muddy carbonate and clay minerals. Choose fresh samples that were not subjected to weathering, alteration and recrystallization. Pick up the pure ostracod limestone, concretional dolomite and synsedimentary clay minerals. The step to get rid of pure clay minerals in mudstone is similar to step (2). Grind >5 g of the purified sample for each sample to −200 mesh (< 0.075 mm) for analysis. The key of this step was to prevent contamination. Because the sample used for the determination was small (< 100 mg) and the concerntrations of Rb and ^{87}Sr were very low (10^{6}–10^{-10}g / 100 mg), the analysis belongs to super–trace analysis and any contamination may cause the fail of the determination.

1.3 Analytical procedures

(1) Rb–Sr isochrone method Weigh 50–100 mg for each sample (−200 mesh) which has been baked at 90℃ for 8 hours in the thermostat. Put them into 10 ml F_{48} PTFE beakers separately. Put dilution agents of ^{87}Rb and ^{87}Sr following the optimium ratio and then strir them even. Add 2–3 ml HNO_3 and 7 ml HF and heat them on a thermo–controlled oven overnight in order to dissolve the samples thoroughly. Add 3–4 ml HNO_3 and 5 ml $HClO_4$ and then heat them till they are dry and white smoke goes up. Add distilled water and remove CaO and MgO by centrifuging. Put the upper part of the clear solution into the ion exchange column (200–400 mesh Dowe × 50 × 8 model cation exchange resin, $\varphi = 8$ mm, height = 100 mm). Leach Rb with 8 ml 1.5 mol L^{-1} HCl and then Sr with 8 ml 2.5 mol L^{-1} HCl. Bake it dry and then add several drops of 1% HCl to have the sample dis-

solved for analysis.

(2) K–Ar dilution method (method described by Wang 1983) Following the above procedures of sampling, mineral separating and dating, we obtain the K–Ar ages of black mudstone of the Cretaceous Quantou Formation to Nenjiang Formation in the Songliao basin (Tables 3 and 4) and also the Rb–Sr isochrone ages of muddy evaporites, muddy carbonates rocks and mudstone of the same sequence (Fig. 1 and Table 4).

Table 3 K–Ar Ages of the Cretaceous Quantou Formation–Nenjiang Formation Black Mudstone of the Songliao Basin

Samp. No.	Sample	Weight (g)	K (%)	$^{40}Ar*$ 10^{-10}mol/g	^{40}Ara (%)	$^{40}Ar*-^{40}K$	Apparent age t(±1σ) (Ma)	Formation	Biostratigraphic magnetostratigraphic age
R_1	Clay	0.12170	1.35	0.1856	56.4	0.00461	77.6±0.6	Nenjiang	73~84 Ma
R_4	Clay	0.13485	3.45	0.4693	26.0	0.004558	76.8±1.33	Nenjiang	73~84 Ma
R_3	Clay	0.14740	4.07	0.6435	31.4	0.00530	89.0±1.81	Qingshan–kou	88.5~100 Ma
R_5	Clay	0.10365	3.19	0.5270	50.3	0.005535	92.8±1.48	Qingshan–kou	88.5~100 Ma
R_2	Clay	0.1185	2.64	0.5284	36.5	0.00671	111.9±1.47	Qingshan–kou	88.5~100 Ma
AR_4	Clay	0.1055	4.48	9.9174	34.6	0.00742	123.3±8.3	Quantou	100~113 Ma

Notes: (1) Gao Ruiqi and Xiao Deming. Recent progress in oil and gas exploration around the Daqing area. *Acta of Daqing Petroleum Administrative Bureau* (unpublished). 1991, 17, Tables 1–5. (2) $^{40}Ar*$ is radioactive ^{40}Ar; 1σ is standard deviation. (3) The above samples were selected and pretreated by Wang Pujun et al. and isotopic ages determined by the Eighth Lab of the Institute of Geology, Chinese Academy of Sciences.

Correlation between the above isotopic ages and those of the previous biostratigraphic–palaeomagnetic ages shows that they are basically coincident. However, the isotopic age of the bottom boundary of the Qingshankou Formation is about 10 Ma older than that of the previous one. There are two possible causes for this. One is that detrital clay minerals mixed in the analysed sample exaggerate the age, and the other is that the boundary age should be 10 Ma earlier. Future study may tell us the exact answer.

The Rb–Sr isochrone age of the 1st member of the Nenjiang Formation is 81±8 Ma (Fig. 1), which coincides with the age interval of 77.4–84.0 Ma defined by biostrati– graphic–palaeomagnetic datings (footnote ① of Table 3). The Rb–Sr age of the 3rd and 4th members of the Quantou Formation is 122±6.096 Ma which is about 10 Ma older than the lower limit (113.0 Ma) of the biostratigraphic–palaeomagnetic age. The fitting of this isochrone is good (r=0.9950), suggesting that the selected samples were formed at the same time, with the same initial Rb/Sr value and in a closed system. Otherwise the samples will not display such a good linear relation. So we believe that, of the two possible causes, an earlier (3–5 Ma) bottom age of the Quantou Formation is very possible, while the detrital exggerated age is almost impossible in this case.

2 Stratigraphic Classification and Correlation of the Cretaceous of the Songliao Basin

Many studies have been up to now concerntrated on the biostratigraphy and magnetstratigraphy of the Cretaceous of the Songliao basin (Gao et al., 1985; Ye, 1991).

Table 4 Isotopic Datings of the Quantou to Nengjiang Formations of the Songliao Basin

Samp. No.	Member	Sampling locality	Lithology	Method	Age (Ma)
R_4	K_2n^4	Well FS2 810m	Black mudstone	K−Ar	76.8 ± 1.33
R_1	K_2n^4	Well FS2 860m	Black mudstone	K−Ar	77.6 ± 0.6
R_3	K_2qn^{2+3}	Well J617 1114m	Black mudstone	K−Ar	89.0 ± 1.81
R_5	K_2qn^{2+3}	Well J617 1162m	Black mudstone	K−Ar	92.8 ± 1.48
R_6	K_2qn^1	Well ZS5 1768m	Black mudstone	K−Ar	111.9 ± 1.47
AR_4	K_1q^3	SHU113−2049m	Black mudstone	K−Ar	123.3 ± 8.3
Y_1	K_2n^{1+2}	Yaojiazhan	Dolomite concretion	Rb−Sr	81 ± 8
Y_2	K_2n^{1+2}	Yaojiazhan	Ostracod limestone	Rb−Sr	81 ± 8
Y_3	K_2n^{1+2}	Yaojiazhan	Dolomite concretion	Rb−Sr	81 ± 8
Y_4	K_2n^{1+2}	Yaojiazhan	Dolomite concretion	Rb−Sr	81 ± 8
Y_5	K_2n^{1+2}	Yaojiazhan	Limestone	Rb−Sr	81 ± 8
Y_6	K_2n^{1+2}	Yaojiazhan	Dolomite concretion	Rb−Sr	81 ± 8
Y_7	K_2n^{1+2}	Yaojiazhan	Ostracod limestone	Rb−Sr	81 ± 8
Y_8	K_2n^{1+2}	Yaojiazhan	Ostracod limestone	Rb−Sr	81 ± 8
Y_9	K_2n^{1+2}	Yaojiazhan	Mudstone	Rb−Sr	81 ± 8
Y_{10}	K_2n^{1+2}	Yaojiazhan	Mudstone	Rb−Sr	81 ± 8
Y_{11}	K_2n^{1+2}	Yaojiazhan	Mudstone	Rb−Sr	81 ± 8
Nos. 1 to 11	K_1q^{3+4}	Well SHU113 2302～2000m	Evaporite	Rb−Sr	122.208 ± 6.096

Notes: (1) All the samples involved in the paper (Tables 1 through 5) were and pretreated by Wang Pujun et al., and analyzed in the XRD Lab, XRF Lab and No. 2 Isotope Lab of Changchun University of Earth Sciences; and K−Ar ages were determined in the Eighth Lab of the Institute of Geology, Chinese Acedemy of Sciences. (2) Codes of formations and members same as in Table 5.

Table 5 Modified Stratigraphic Chart for the Mesozoic and Cenozoic of the Songliao Basin

System	Series	Formation	Mem. and code	(Ma, B.P.)		European stages Harland et al. (1989)	Previous chart	Ma B.P.	Series
Quaternary		Q				Calabrian			Q
				2.0	1.64			2.0Ma	
Neogene	Pliocene	Taikang	Na*t*			Piacenzian–Zanclian	N_2t		Pliocene
				6.0	5.2			6.0	
Neogene	Miocene	Da'an	N_2d			Messinian–Aquitanian	N_2d		Miocene
				25.0	23.3			25.0	
Paleogene	Oligocene	Yi'an	$E_{2-3}y$			Chattian–Danian	$E_{2-3}y$		Oligocene
				65.0	65			65	
Cretaceous	Upper	Mingshui	K_2m^{1-2}			Maastrichtian	K_2m		Upper Cretaceous
				67.7				67.7	
Cretaceous	Upper	Sifangtai	K_2s			Maastrichtian	K_2s		Upper Cretaceous
				73.0					
					74			73	
Cretaceous	Upper	Nenjiang	K_2n^{3-5}			Campanian	K_2n^{3-5}		Upper Cretaceous
				80.0				77.4	
Cretaceous	Upper	Nenjiang	K_2n^{1+2}			Campanian	K_2n^{1+2}		Upper Cretaceous
					83			84	
				84.0					
Cretaceous	Upper	Yaojia	K_2y^{2+3}			Santonian	K_2y^{2+3}		Upper Cretaceous
				86.4	86.6			87.5	
Cretaceous	Upper	Yaojia	K_2y^1			Coniacian	K_2y^1		Upper Cretaceous
				88.5	88.5			88.5	
Cretaceous	Upper	Qingshankou	K_2qn^{2+3}			Turonian	K_2qn^{2+3}		Upper Cretaceous
					90.4			91	
Cretaceous	Upper	Qingshankou	K_2qn^{2+3}			Cenomanian	K_2qn^1		Upper Cretaceous
				97.0	97			100	
Cretaceous	Upper	Qingshankou	K_2qn^1			Albian	K_1q^{3+4}		Lower Cretaceous
				100.0					
Cretaceous	Lower	Quantou	K_1q^{3+4}			Albian	K_1q^{3+4}		Lower Cretaceous
					112			113	
Cretaceous	Lower	Quantou	K_1q^{3+4}			Aptian	K_1q^{1+2}		Lower Cretaceous
				116					
Cretaceous	Lower	Quantou	K_1q^{1+2}			Aptian	K_1q^{1+2}		Lower Cretaceous
								116	
				119					
Cretaceous	Lower	Denglouku	K_1d^{3+4}			Aptian	K_1d^{3+4}		Lower Cretaceous
				122?					
Cretaceous	Lower	Denglouku	K_1d^{1+2}			Aptian	K_1d^{3+4}		Lower Cretaceous
					124.5			119	
				125					
Cretaceous	Lower	Yingcheng	K_1y^{1-2}			Barremian	K_1d^{1+2}		Lower Cretaceous
				131	131.8			125	
Cretaceous	Lower	Shahezi	K_1s^{1-4}			Hauterivian	K_1y^{1-2}		Lower Cretaceous
					135			131.0	
Cretaceous	Lower	Shahezi	K_1s^{1-4}			Valanginian	K_1s		Lower Cretaceous
					140.7				
Cretaceous	Lower	Shahezi	K_1s^{1-4}			Berrinasian	K_1s		Lower Cretaceous
				144	145.6			144	
Jurassic	Upper	Huoshiling	J_3h			Tithonian	J_2h		Upper Jurassic
					152.1				
Jurassic	Upper	Huoshiling	J_3h			Kimmeridgian	J_2h		Upper Jurassic
				156	154.7			156	

Note: The previous chart from Gao and Xiao (1991), the same as footnote ① of Table 3.

Gao and Xiao (1991) (footnote ① of Table 3) summarized almost all the related researches including the isotopic datings of volcanic and pyroclastic rocks of the lower Lower Cretaceous Yincheng Formation and its underlying strata, and then proposed a "tendency stratigraphic chart" of the Cretaceous of the Songliao basin.

The results of the isotopic datings from this study are in general agreement with the "tendency chart". So we have drafted a modified stratigraphic chart of the Songliao basin (Table 5) on the basis of the tendency chart. Here we give some explanations about Table 5.

2.1 Boundary ages of formations

The isotopically studied horizon of the paper is the Cretaceous Quantou and Nenjiang Formations. The K–Ar age of the bottom of the first member of the Qingshankou Formation is 111.9 ± 1.47 Ma, which is about 10 Ma earlier than the previous "tendency age" (100 Ma). Considering the coincidence between the age of the upper part of the Qingshankou Formation to the Nenjiang Formation and the age of the previous chart, the authors infer that the higher isotopic age of the bottom of the Qingshankou Formation may probably result from interference of the destrital clay minerals mixed in the analysed sample. The Rb–Sr isochrone age of the Quantou Formation is 122.208 ± 6.098 Ma and the corresponding K–Ar age is 123.3 ± 8.3 Ma, which are about 10 Ma older than the tendency age (113 Ma). These isotopic ages are reliable since the linear relation of the isochrone is good (see discussion of 1.3 in this paper). Considering the analytical errors of these ages are 6.098 and 8.3 Ma respectively, we believe that the actual boundary age should be at least 2–3 Ma earlier than the previous one (113 Ma) below the Quantou Formation (123–8–113 = 2; 122–6–113 = 3 Ma) (Table 5).

The formation boundaries above the Nenjiang Formation and below the Quantou Formation as well as the boundary between the Late Jurassic and Early Cretaceous are the same as those of the previous chart.

2.2 Boundary ages of members

Compared with the previous chart, the member boundary ages have been modified a lot. However, the authors believe that these modifications are reasonable. For example, the boundary age between the 1st and 2nd members and the 3rd to 5th members of the original Nenjiang Formation K_2N^{1+2}–K_2N^{3-5} is 77.4 Ma, but the K–Ar ages of the mudstone of the 4th member of the Nenjiang Formation obtained from this study are 76.8–77.8 Ma and the Rb–Sr isochrone age of the carbonate and mudstone sequence in the upper–middle part of the 1st and 2nd members of the Nenjiang Formation is 81 ± 8 Ma, so we use 80 Ma as the boundary age. Another example, the previous boundary age between the 1st and 2nd members of the Qingshankou Formation is 91.0 Ma, but the K–Ar ages of argillaceous rocks in the mid–upper part of the 2nd–3rd members of the Qingshankou Formation determined by the authors are 89–92.8 Ma, so we choose 97 Ma as the boundary age between the 1st member and the 2nd–3rd members of the Qingshankou Formation ($K_2Q_n^1$ and $K_2Q_n^{2+3}$) with reference to the relative sedimentary rate and thickness (Du and Wang, 1992).

2.3 Correlation with the European stages

We use the time scale of Harland et al. (1989) in Table 5 mainly because this scale has been used for the Mid–Cretaceous Events (IGCP project No. 58) (Royment and Bengtson, 1986) and moreover,many publications on the Cretaceous have already used the scale. The use of the time scale here favours the correlation of the Cretaceous in the Songliao basin with the Cretaceous in other parts of the world.

We use the isotopic ages for the correlation in Table 5 mainly for the convenience in global correlation. This is different from the previous ones which generally emphasize the time unaminity between the boundaries of the European stages and those of members and formations in Songliao. But the European time scales themselves can be quite different among different authors. Considering the local control on sedimentary sequences and the fact that even the global sea–level changes are not always globally isochronous (Royment and Bengtson, 1986), we regard, for some extent, the emphasis on the unaminity in correlation as an obstacle to our further understanding of the Cretaceous in Songliao. On the other hand, the correlation based on isotopic ages, though the stratigraphic boundaries in the Songliao basin are not completely coincident with those of the related European stages, may help us to study the Songliao Cretaceous in the global context, which can also facilitate a more complete and correct understanding of the generation, development and evolution of the Cretaceous sequences (non–marine) in China and their relationship to the global Cretaceous.

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