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泸沽湖沉积物-水界面扩散作用对上覆水体基本化学组成的影响*

吴丰昌　万国江

（中国科学院贵阳地球化学研究所环境地球化学国家重点实验室，贵阳　550002）

摘要　通过云南泸沽湖——半封闭深水湖泊湖水和沉积物孔隙水中 Ca^{2+}、K^+、Na^+、HCO_3^- 等基本组分及 pH 等剖面分布的研究，结果表明，这些基本组分可以自底部沉积物向上覆水体扩散迁移。定量地估算了扩散通量及其对上覆水体的影响程度，说明湖泊沉积物-水界面作用在控制整个水体水化学基本组成中起着重要的作用。

关键词　扩散作用，沉积物-水界面，泸沽湖。

一般认为湖水的基本化学组成主要受3个因素控制：大气降雨，流域岩石，土壤风化和蒸发、结晶作用[1,2]，同时人们也已经注意到底部沉积物进入上覆水体的流通量可能是影响整个水体的重要因素之一[3]，但近年来，主要对沉积物-水界面中 Fe、Mn 及氮、磷等地球化学循环和它们对上覆水体的影响进行了很多的研究[4—7]，然而对 Ca^{2+}、K^+、Na^+、HCO_3^- 等基本组分是否存在自沉积物向上覆水体扩散的现象及扩散对上覆水体的影响程度如何等人们知道的很少。

本文通过云南泸沽湖，一个半封闭湖泊中 Ca^{2+}、K^+、Na^+、HCO_3^- 等基本组分自底部沉积物向上覆水体扩散迁移通量的计算，定量评估扩散迁移过程对上覆水体的影响程度，说明湖泊沉积物-水界面作用在控制整个水体水化学基本组成中所起的作用。

1　样品的采集和分析

泸沽湖[8]位于云南和四川省交界处（北纬27°41′—45′，东经110°45′—50′）基本上属半封闭深水湖泊。湖泊平均海拔1970 m，湖水水面面积为50.5 km^2，汇水面积为171.4 km^2，湖泊补给系数仅有3.4，这在我国所有湖泊中是比较少的；平均水深为40 m，最大水深达93 m，湖泊寄宿时间长达18.5 a；湖区人口少，生产方式以农业和畜牧业为主，因而人为活动对湖水组成的干扰很小。

本研究分别于1991-11和1994-07在泸沽湖的深水湖心（60和65 m）进行了2次采样，样品用自行设计的沉积物-水界面采样装置[9]采样，沉积物表层和界面水样品均未受扰动。湖水样品按5 m 间隔采样，沉积物柱芯在野外按0.5—2.0 cm间隔精细分截，高速离心后经0.45 nm 的滤孔滤膜过滤获得孔隙水；而湖水和孔隙水中的 pH 值在野外现场用电极测定，HCO_3^- 用容量法测得，而 Ca^{2+}、K^+、Na^+ 等经酸化后用 PE-5100型原子吸收分光光度计火焰法直接测定。

2　结果和讨论

图1为泸沽湖沉积柱芯孔隙水和上覆水体中 Ca^{2+}、K^+、Na^+、HCO_3^- 浓度和 pH 值的剖面分布。

2.1　Ca^{2+}、K^+、Na^+ 和 HCO_3^- 等有可能自沉积物向上覆水体扩散迁移

湖水中 Ca^{2+}、HCO_3^- 等浓度分别在28和

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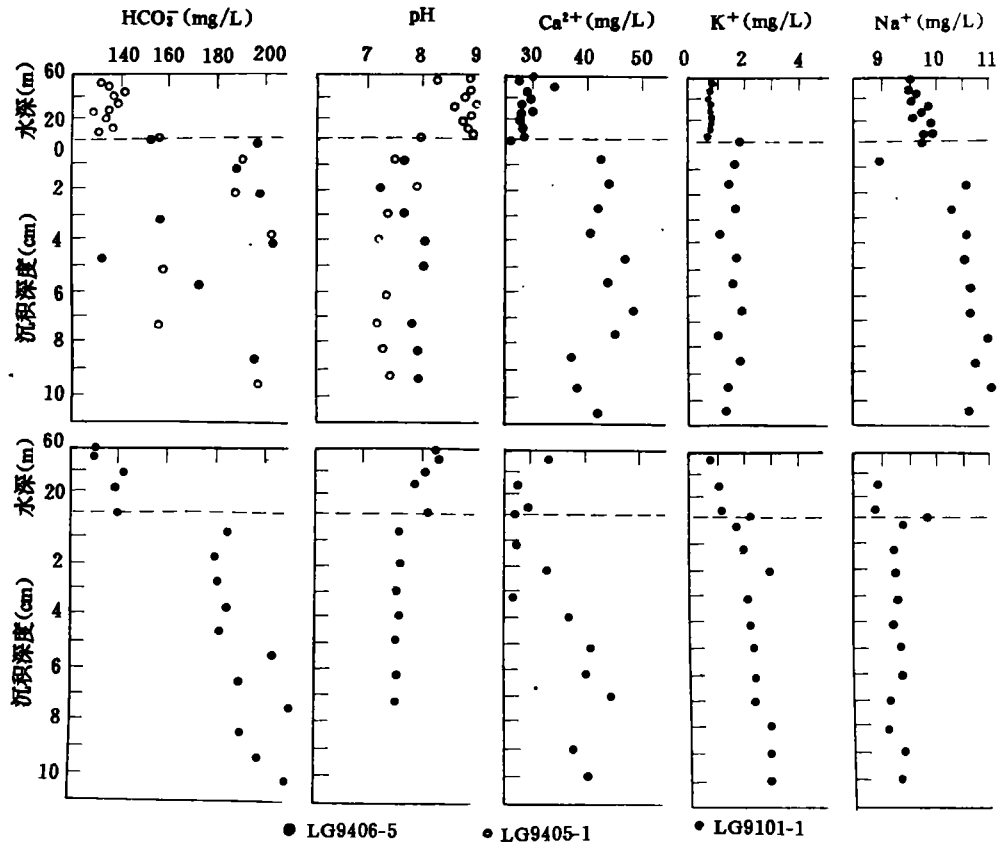

、图1　泸沽湖沉积柱芯孔隙水和上覆水体中 Ca^{2+}、K^+、Na^+、HCO_3^- 浓度和 pH 值的剖面分布

140 mg/L 左右，孔隙水中 Ca^{2+}、HCO_3^- 浓度明显高于上覆水体中的浓度，在 LG9101柱芯孔隙水中 Ca^{2+} 浓度有随深度逐渐递增的趋势。唐德贵等运用沉积物饱和度和早期成岩稳态模型研究[10]表明，泸沽湖沉积物-水界面 Ca^{2+} 和 HCO_3^- 浓度梯度主要变化是沉积物中碳酸钙不饱和溶解作用和早期成岩作用过程中有机质分解的结果。

从图1还可以看出，孔隙水中的 K^+、Na^+ 浓度也明显高于上覆水体中的浓度，随深度增加，孔隙水中 K^+、Na^+ 浓度略有增大的趋势。由于早期成岩作用有机质分解产生大量的 CO_2，促使沉积物中的碳酸钙不饱和溶解[10]：

$$CaCO_3 + CO_2 + H_2O = Ca^{2+} + 2HCO_3^-$$

上述反应可能基本上控制了孔隙水溶液的酸碱平衡；沉积深度的增加，早期成岩作用的加强，不断促使上述反应向形成 HCO_3^- 的方向进行，并使孔隙水中的 pH 值逐渐降低，泸沽湖沉积物孔隙水中 pH 值和 HCO_3^- 浓度的剖面分布可以证实这一点。这也促使了堆积的沉积物进一步淋溶风化，底部沉积物的 pH 值减小，酸度增大，风化速率增大，沉积物有较多的 K^+、Na^+ 等离子风化淋溶出来，进入孔隙水中，孔隙水中 Na^+ 浓度远大于 K^+ 浓度，可能与沉积物富含大量的钠闪石矿物和贫含钾矿物有关。由于沉积物中溶解性物质主要是通过扩散作用经表层扩散层进入上覆水体[11]，在沉积物-水界面附近，HCO_3^-，K^+、Na^+ 和 Ca^{2+} 等均存在一定的浓度梯度变化，那么，它们就有可能通过孔隙水自沉积物向上覆水体扩散迁移，并影响对上覆水体的化学组成。

2.2　界面基本组分扩散通量的计算

在沉积环境中，根据 Fick 第一定律可以用下式估算溶质扩散通量(J)[12]：

$$J = -fD\,dc/dx \qquad (1)$$

式中，f 为沉积物的孔隙度，取0.98；dc/dx 为

孔隙水和上覆水体之间的最大浓度梯度；其中 $D=F^2D_0$，D 和 D_0 分别为实际和理想状态下元素的分子扩散系数，与温度有关，本文近似取18℃左右条件下的 D_0 值，K^+、Na^+ 和 Ca^{2+} 的 D_0 值分别为16.7、11.3和6.73($\times10^{-6}$ $cm^2\cdot s^{-1}$)，HCO_3^- 近似取25℃时的 D_0 值，为11.8($\times10^{-6}$ $cm^2\cdot s^{-1}$)[13]，根据(1)式可以计算出泸沽湖不同水深不同季节 K^+、Na^+、Ca^{2+} 和 HCO_3^- 等在界面处的最大浓度梯度，以及它们自底部沉积物向上覆水体扩散的通量(见表1)。

表1 云南泸沽湖沉积物-水界面 Ca^{2+}、K^+、Na^+ 和 HCO_3^- 的最大浓度梯度和扩散通量及 T_w 和 T_e 的比值

元 素	Ca^{2+}	K^+	Ka^+	HCO_3^-
浓度(mg/L)	28.0	0.82	9.85	140
浓度梯度(dc/dx)[1] ($\times10^{-6}$ mol·cm^{-4})	0.483	0.0369	0.00887	0.447
扩散通量(J) ($\times10^{-6}$N cm$^{-2}\cdot$a^{-1})	0.971	0.183	0.0297	1.564
T_w/T_e(%)[2]	39.44	247.7	1.97	19.39
浓度梯度(dc/dx)[3] ($\times10^{-6}$ mol·cm^{-4})	0.135	0.00154	0.00131	0.963
扩散通量(J) ($\times10^{-4}$N cm$^{-2}\cdot$a^{-1})	0.0269	0.0076	0.0043	3.369
T_w/T_e(%)	1.20	55.1	0.32	45.26

1) LG9406-5(1994-07，水深65 m) 2) T_w 为湖水季宿时间，T_e 为扩散元素的季宿时间 3) LG9101(1991-11，水深60 m)

2.3 界面扩散迁移对上覆水体基本组分的贡献

从孔隙水中迁移出来的溶质在上覆水体中的浓度(c_{in})与湖水中该溶质的浓度(c)的比值可以相对表示界面溶质扩散迁移作用对上覆水体的影响程度，并可知：

$$c_{in}=J_e\cdot T_w/h \qquad (2)$$

其中，J_e 为溶质自底部沉积物向上覆水体扩散的通量，h 为扩散影响上覆水体的有效深度，T_w 为湖水寄宿时间，其中 $J_e\cdot h/c$ 即为扩散溶质的寄宿时间(T_e)，这样

$$c_{in}/c=J_e\cdot T_w/h\ c=T_w/T_e \qquad (3)$$

假设湖水混合均匀，孔隙水中的溶质扩散对整个湖泊水体的影响程度可由湖水寄宿时间(T_w)和扩散溶质的寄宿时间(T_e)的比值表示，其比值主要与扩散通量、湖水寄宿时间、湖水深度有关。代入 J_e、T_w、h 和 c(表1)，据(3)式，可以计算出泸沽湖沉积物-水界面扩散作用对上覆水体的影响程度(见表1)；由表1可以看出，泸沽湖沉积物-水界面 HCO_3^-、Ca^{2+} 和 K^+ 的扩散对上覆水体影响比较大，而 Na^+ 扩散对上覆水体影响比较小，只有0.262%—1.95%，基本上可以忽略。

所以，对于泸沽湖这样一个水体寄宿较长、深水和半封闭湖泊，沉积物-水界面中存在的 HCO_3^-、Ca^{2+} 和 K^+ 等基本化学组分的扩散作用可能是整个湖泊水体化学组成的重要来源之一。说明，研究湖泊水体基本化学组成控制作用必需考虑底部沉积物对上覆水体的影响，并有必要进一步研究湖泊沉积物-水界面组分扩散通量季节性变化规律和作用机理。

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HUANJING KEXUE

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A Study on the Biodegradation of Organic Substances by ATP Test. Sun Lixin et al. (Dept. of Environ. Eng., Tsinghua Univ., Beijing 100084): *Chin. J. Environ. Sci.*, **17**(1), 1996, pp. 1—4

In this paper, the aerobic biodegradation of organic substances is characterized by the determination of the energy change, ATP content in microbial cells during the biodegradation. A satisfactory result was obtained under the following conditions: the initial concentration of the tested substance is 100 mg/L (as DOC), the amount of the inoculum in the biological medium is 500 mg/L (as MLSS), and the duration of test time is 14 days. The evaluating system (peak time, peak height index and IA index) is proposed to assess the biodegradability of 40 organic substances and 7 wastewater.

Key words: biodegradation, ATP, ATP test, IA index.

Effect of Salinity and Water Pressure on Adsorption of Toxic Organic Chemicals on Separated Submarine Sediment. Quan Xie et al. (Dalian Univ. of Technology, Dalian 116012): *Chin. J. Environ. Sci.*, **17**(1), 1996, pp. 5—9

The organic and inorganic components of the submarine sediment from Dalian Bay were separated with a sequential chemical separation procedure. The adsorption of several toxic organic chemicals (TOCs) on the separated sediment samples and the effect of salinity and water pressure on the adsorptions were investigated. The conclusions were made as follows: (1) The adsorption capacity of organic components on the sediment increased as the salinity of water increased, but reduced for inorganic components. The relationships could be described with linear equations. (2) The adsorption capacity of both organic and inorganic components increased as the water pressure increased. The relationships could be described with exponential equations.

Key words: salinity, water pressure, submarine sediment, toxic organic chemicals.

The Influence of Diffusive Processes on Overlying Waters at the Sediment-water Interface of Lake Lugu. Wu Fengchang and Wan Guojiang (State Key Lab. of Environ. Geochem., Chinese Academy of Sciences, Guiyang 550002): *Chin. J. Environ. Sci.*, **17**(1), 1996, pp. 10—12

Through the study on Ca^{2+}、K^+、Na^+、HCO_3^- and pH profiles of water column and porewater of Lake Lugu, Yunnan, a half-close and deep lake, it was found that Ca^{2+}、K^+、Na^+ and HCO_3^- in the sediments could diffuse to overlying water and their diffusive flux and their influence extent on overlying water could be quantitatively estimated. At also indicates that the interreactions between sediment and water play a significant role in controlling basic chemical composition of some lakes.

Key words: diffusive processes, sediment-water interface, Lake Lugu.

The Experimental Study on Decolorization of Dye Wastewater with Pulse Corona Discharge. Li Shengli et al. (Environment Center of Science and Technology, HUST 430074): *Chin. J. Environ. Sci.*, **17**(1), 1996, pp. 13—15

A new method to decolor dye wastewater with pulse corona discharge has been developed. Nonequilibrium plasma produced by high voltage pulse discharge contacts with dye wastewater and decolorization of dye wastewater can be achieved quickly. The results showed that the decolorization rate can be reached more than 95% by treating wastewater for 40 s at pulse peak voltage of 38 kV and there is influence, of pH value on decolorization rate. When pulse peak voltage is lower, the influences of pH value on decolorization rate are appeared. The decolorization rate of neutral dye wastewater is only reached about 40%—50% after treating for 40 s. However, the decolorization rate can be reached more than 80% at pH<4 or >7. The experimental results of adding NaCl or Na_2SO_4 into dye wastewater have showed that Cl^- is able to decrease decolorization and SO_4^{2-} just opposite.

Key words: dye wastewater, decolorization, pulse corona discharge, pulse peak voltage.

Study on the Leaching Experiments of Minor and Trace Elements in Coal and Its Burnt Products. Wang Yunquan et al. (Beijing Graduate School, China Univer. of Mining and Technology, Beijing 100083): *Chin. J. Environ. Sci.*, **17**(1), 1996, pp. 16—18

The comparative leaching experiments of coal (C), ashing ash (AA), fly ash (FA) and bottom ash (BA) have been carried out under different pH conditions. The leaching behaviour of As, Zn, Pb, Ni and Sr have been investigated in detail. The results have shown that the pH values of solution, leaching time, and particularly, the properties and species of the elements existed have heavily influenced on the leaching behaviour of elements. Among the 5 elements analysed, the leaching ability of Sr is strong, Pb and As strong to middle, Ni middle and Zn weak.

Key words: coal and its burnt products, minor and trace elements, leaching experiments.

A Study on Adsorption, Desorption and Biodegradation of Pentachlorophenol by Anaerobic Granular Sludge. Shen Dongsheng et al. (Dept. of Environ. Science, Zhejiang Agricultural Univ., Hangzhou, 310029): *Chin. J. Environ. Sci.*, **17**(1), 1996, pp. 20—23

PCP degrading anaerobic sludge granules may be developed in upflow anaerobic digestion reactors (UAD) seeded with sludges acclimated to chlorophenols, the reactors are able to remove more than 99.5% of PCP in a synthetic wastewater at the concentration of 170 to 180 mg/L, volumetric loading rate up to 200 to 220 mg/(L·d), and hydraulic retention time of 20 to 22 hours. Biosorption and desorption isotherms of pentachlorophenol were determined, and the data were fitted to Freundlich equation. However, it was found that the biosorption of PCP was partly irreversible, and the Freundlich models with empirical constants determined from this study can quite well describe the partition behavior of pentachlorophenol in anaerobic upflow digestion reactor. It was demonstrated