2001－2010

^{1}， ^{2}， ^{3}， ^{1}， ^{2}，

^{1}， ^{4}， ^{2}， ^{1}

1.   ， 430074；2.

，   430074；3.   ，   266071；4.   ，

:   21

:   ;   ;   ;   ;   ;

An Overview on Biogeochemistry During the Decade of 2001 to 2010

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Abstract: The significant achievements and future research orientation of biogeochemistry during the decade of 2001 to 2010 are briefly reviewed. Some carbon pools and related flux have been quantified in modern marine/ocean and land ecosystems. New microbial functional groups involved in sulfur and nitrogen cycles of modern ecosystems have been identified. The features and the possible causes of the abnormal carbon cycle occurring during the biotic crisis in Phanerozoic have been deciphered but the biogeochemical cycles of sulfur and nitrogen need more investigation. The relationship of carbon and sulfur cycles of the early Earth with life origins, atmospheric and oceanic chemistry conditions has been understood. Biogeochemical impacts on ecosystems via the chemical substances, climatic and o-ceanic changes are reviewed concerning both the modern and the ancient times. Some biogeochemical techniques including geotraces, metagenomics, micro-scale and in-situ analyses are particularly introduced in current biogeochemical studies. The quantification and spatial variations of the elemental cycles need further investigations in the future. The biogeochemical processes in some extreme environments and the various interfaces as well as the relationship among different elemental cycles demand more attentions. Introduction of new techniques in life science will further improve investigations of biogeochemical processes.

Key words: elemental cycles; global change; paleoceanography; geomicrobes; origin of life; biotic mass extinction

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2011 ，《2011～2020
》
。2012 ，

、、
[1]。，

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（、）（）
，、
。《Global Biogeochemical cycles》 －
，

1.1

JGOFS、
SOLAS IMBER ，
[2~6]。
[6]。

，
、

，CaCO₃
CO₂ ， CO₂
[4~6]。" "
[7]。 /
， /
、、
/ ，
[3,5,6]。
－

，（ ） （
），
（ ）， （ ），
1990～2000 ，，
－
[3,5]。 （ 、、
） CO₂ ，
[5,6,8]， [9~11]
[6,12]、 [6,12~14]
CO₂ 。 －
（ ），
[6]。
[15]，

23%， a
。 POC，
98% ， 68% [5]。

， ，
，
[16]。

，
（DOC）
。McCarthy [17]
DOC $\delta^{13}C$（ $\delta^{13}C_{DOC}$ ） $\delta^{14}C$（
$\delta^{14}C_{DOC}$ ）， DOC
。
， DOC。
[18]。 CH₄
CO₂ ， DOC，
。 ,CH₄
（AOM） CH₄
， CH₄ [20,21]。
AOM 、
[22]，

，
[23]。
3 （ANME-1,ANME-2 ANME-3），
[24,25]。
，
， $(1.1\pm0.8)\times10^{12}$ kg/a [26]，
[27]。

$(0.19\sim0.26)\times10^{12}$ kg/a [28]，

，　　　　　　　　　。　　　　，

。

[29]。

CO_2　　　　　[30]，

CH_4　　　　　[31,32]。

，

[33]。

，　CH_4　　　CO_2，

[34]，

[35]。

CH_4

30%[34,36]，　　　　　CH_4

1.2

3　　　。

（Trichodesmium），

（Crocosphaera watsonii）　Trichodes-mium [37,38]。　CH_4

，　　　　ANME-2

，　　CH_4　，

AOM　　　　－　－　　　　[39]。

。　，　　，

[40]。

、　　、

，　　　　[41,42]

，　3-　　　/4-

[23,43]。

HCO_3^-　　CO_2　　　[44,45]，

[46]。

，

，

[47]。

、

[48~50]。

，　　　　GDGTs　　　。

（SST）

。

TEX_{86}　　　　　　　[51~53]。

GDGTs　　　　　GDGTs

，

[54]。　　，

GDGTs

，　　　　　、

，　　　，

。

[55]，　　　NH_4^+　　NO_2^-　　　　N_2，

[56]

（Planctomycetales），

，　[55]，　　　　　-A

CO_2　[57]，　　　" "（ladder-ane）[58]。

，　　、　　、

[59~61]，　　　[62]、　　[63]

[64]。

1.3

，

。

，　pH　　　2~3，　　　　-3[64]。

（　Fe^{2+}，Cu^{2+}）。

，

[65]

[66]，

[67,68]

，

[69]，

3~4　　　[70]。

[69,71]。

、　、

，　　　　（　As）

[72,73]、

[74]、

[75,76]、　　　　[77]

，　　　，

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2

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、 、

（ ）[78~90]。

－ ，

、 、 （ 、 ） （ ）

2.1
2.1.1 奥陶纪末期

，

[91]。

90 ，

[92~96]。 ，

，

[97]。 $\delta^{13}C$

（$\delta^{13}C_{carb}$ $\delta^{13}C_{org}$），

[85,86,98~100] ，

Normalograptus extraordinarius

，

N. persculptus [98,99]。 $\delta^{13}C_{carb}$

，

[98]，

[98]。

$\delta^{13}C_{org}$ $\delta^{13}C_{carb}$ [86,96,101]。 $\delta^{13}C_{org}$

（$-30‰$

$\sim -27‰$）[84~86]，

[94,96,99,101,102]。 $\delta^{13}C_{org}$

$\delta^{13}C_{carb}$。 Young [102] p_{CO_2}

，

。

[96,99]，

[98]。

2.1.2 晚泥盆世弗拉阶-法门阶之交

－

$\delta^{13}C_{carb}$ ， （

、 Kellwasser ）[103]。 ，

$\delta^{13}C_{carb}$

[79,104,105] Kellwasser

， 。 Kell-

wasser [79,104]，$\delta^{13}C_{org}$

， 3‰ [104,106]。

，$\delta^{13}C_{carb}$

[79,107,108] ，

，

[108]。

（ ）

。 Izokh [109]

$\delta^{13}C_{carb}$ （$4.6‰$）

（$3‰$）， $\delta^{13}C_{org}$ （$1.5‰$）

， （ ）$\delta^{13}C_{org}$

（$4‰$）。 CO_2 ，

（$\delta^{13}C_{carb}-$

$\delta^{13}C_{org}$ ）

。 Joachimski [110] CO_2

（ 7~9 ），

。 Chen [79]

p_{CO_2}

－

[106]，

[111,112]

$\delta^{13}C_{carb}$ [86]，

－

（ 5℃）[110]。 ， $\delta^{13}C_{carb}$

[113]

2.1.3 二叠纪-三叠纪之交 －

80

[114~118] ， Holser [115] ，

－

[119]。 ， $\delta^{13}C_{carb}$

、 ， －

， ，

$\delta^{13}C_{carb}$

[120,121]，

[88,119,122]，

[78]。 ，

$\delta^{13}C_{carb}$ $-1‰$ [87,119,123]，

$(-6‰)$

，

[87,117,123~125]， $\delta^{13}C_{carb}$ ，

[87,125]。 ，

，$\delta^{13}C_{carb}$

[87,89,123,125]。

。 $\delta^{13}C_{org}$ ，

$\delta^{13}C_{org}$[88,126,127]。

，　　　　–

$\delta^{13}C_{org}$

[87,128~131]， [132]。

，

。

，

$\delta^{13}C_{carb}$ [133,134]。

，

CH_4 [88]。

$\delta^{13}C_{carb}$

[135]。 ，　　–

$\delta^{13}C_{carb}$ [89,123,125]。

2.1.4 三叠纪-侏罗纪之交

–　　　$\delta^{13}C_{org}$

[136,137]，

[138,139]。$\delta^{13}C_{org}$

[136,137,140~146]。

–　[146,147]

$(10\sim20$ ka)[148]。 $\delta^{13}C$

8.5‰， 12,000 Gt CH_4($\delta^{13}C_{CH_4}$

$=-60‰$) ，

[146]。 ， p_{CO_2} ， 1000

$\times10^{-6}$ 2700×10^{-6} [149~151]。 ，

$\delta^{13}C_{carb}$ [141,143,144,152] –

， ，　　–

，

Hettagian ， $\delta^{13}C$

[146,147,153]

，

2.2

。 ， O_2 ，

O_2 ，

[154]

，

N_2。 ，

[155,156]

，

。

LaPorte [101]

$\delta^{15}N$， $\delta^{15}N$ $(-1‰$

$1‰)$ ，

。

–　[157]，

[101]

–

[89,124,158~161]

。 Luo

[89]

，

$\delta^{15}N_{org}$ ，

。

$\delta^{15}N_{org}$ $-1‰$ $1‰$ ， $\delta^{15}N$ ，

， ， 。

$\delta^{13}C_{org}$

，

N_2。 –

， N_2O

， [89]。

Sephton [153] –

，

–　 ， Hettangian

$\delta^{15}N$ $\delta^{13}C_{org}$ [153,163,164]，

。 Paris [164] ，$\delta^{15}N$

$\delta^{13}C_{org}$ ，

$\delta^{13}C_{org}$ 。

2.3

。

。

H_2S，　　　　　　　　　　，

　　　　　　　　　。　　　，

　　　，

　　　　　　　　　。

　　　，　　　　　　　　　　　[165,166]。

（Carbonate Associated Sulfate，

CAS)　　　　　　　　　　　　　，

　　　　　　　　　　[167～169]。

　　　　　　　　　　　　　　　。

Yan [84]　　　　　　　　　$\delta^{34}S_{py}$

　　　，　$\delta^{13}C_{org}$　　　　　。Zhang

[85]　　　　　　　，　　　　Yan

[84]　　　　。$\delta^{34}S_{py}$　　　　　　　，

[84,85]。

　　　　　　　　　－　　　，

　　　　　　　　　　　[170,171]，

　　$\delta^{34}S_{py}$　　　　　　，

　　　，　　　　　Kellwasser　，

Kellwasser　　　　　[106]。　　，

CAS　　　（$\delta^{34}S_{CAS}$）　　，　　－

　　　　　　　　　，

　　$\delta^{34}S_{py}$　　　　　[172]。

　　　，　　$\delta^{34}S_{CAS}$　　　，

　　$\delta^{34}S$　　　　$\delta^{34}S$

－　　，　　　　　$\delta^{34}S$

　　　　　，

[90,173～178]。　　　　－

　，　　$\delta^{34}S_{CAS}$　　，

　　　　　。　　　$\delta^{34}S_{CAS}$

，　　　　　　[90]。

　　　－　　，Luo [90]

　　　　15%。

　　　　。

－　　　　，

[176]。　$\delta^{34}S_{CAS}$　，

$\delta^{34}S$　　，

[179]，　　[176,180]　CAS

　。Shen [181]

－　　　，

　　　　。

Williford [182]　。

　　　　　　，　　　　Hettangian

$\delta^{34}S_{py}$　　　，

　　　。

　　　，

[183, 184]、

[185,186]、　　　－

[187, 188]　　　　　，

　　　。

3

　　　，

　　　。

3.1

　　　，

　　，

　　　。　　　，

CH_4　　S(　S_0、H_2S)　，

　　　，　　　CH_4、

`、　、　　、　　　　[189]

(*Caldanaerobacter*)

CO [190]。

　　，

[191, 192]

　　　HCO_3^- [192]。

，　　　（　　　），

Lost City　　。

（　　），

，pH　（9～11），

60 m [193]，　　　[194]。

，　　　H_2，

CH_4（　　$\delta^{13}C$　[193,195]）、

[196]、$C_1～C_4$　[192]。

CH_4

。　，　（Lost

City *Methanosarcinales*）　[193]。

　，　[197]。

[198]。Lost City　，　，

$\delta^{13}C$　　3.6‰[199]。

　　。Kashefi　Lovley[200]
Juan de Fuca
，　121℃
Takai [201]　122℃（20 MPa）
Methanopyrus kandleri strain 116。
　CH₄
。 ，　（AOA）
。de la Torre
[202]　*Candidatus* Nitroso-
caldus yellowstonii　74℃
。 *amoA* ，AOA
， 94℃[203]。
[204]
（　　　）
， [205]。
，
[206]。
1.6 km[207]。
、
[208]。
、 [209,210]。
[210,211]， [212]。
，
H_2 ，
[213]。
H_2 ， 、 、
H_2。 H_2
，
[214,215] [210,216]，
（ ， ） H_2[217]。
，
H_2 。Stevens [218]
H_2
。
H_2 [219]。Mpo-
neng　2825 m　H_2
（*Fermicutes*）[220]。 ，
，
O_2 ， O_2
，
， [221,222]，
， CO_2

CH_4[223,224]。

3.2

，

[225]，

[226]，

， ，

，

37～39 [227,228]。

，

[229,230]。

，Brocks [231]
（Pilbara Craton）
27

[232]。

，

，

34.7 [233]，
7.5 [234]。
（Hamersley Province），
， 27

[235]。

，
－ －
24.8

[236] ，
，
[237]。

4

，

[5,238～242] ，
，
、 、

4.1
，

、　　　　　　　　。　　，　　　　　　　、　　　　　　　CO_2　　　CH_4　　　　，
、　　　　　POPs　　　　　　　　　　　　，
[5,243,244]，　　　　　　　　　　　　　－　　　，　　　。
　　　[245]　。　　　　　　　　　p_{CO_2}　　　　，　　1000×10^{-6}
[244,246]，　　　　　2700×10^{-6}　　[149~151]，
[152,250]　　　　　　　　　　　　　　　　，
。　　　　　　　　　　　　　　CO_2　　　　　　　　　　CH_4
，　　　　　，　　　　　　－　　　$\delta^{13}C_{carb}$
，　　　，　　[133,134]，　　　CO_2
[5,243]　。　　　　　　　　　[251]　。
，　　　　　　　　　　　　－　　　　　，$\delta^{13}C_{carb}$
。　　　　　　[86,104]，　　　$\delta^{13}C_{carb}$
，　　　　　　　　　　　　　　　[113]，
，　　　　　　　　　。
，　　　　、　　　、　　　　　　－
，　　　　　　，
，　　[5,239~243]　　　　　　　　　，
，　　　　　　　[89]　　　，
、　　　　，　　　　　　　　－　　　，
、　　　、　　，
。　　　　　[176,181]　。

、　、　　　　　、
　　　　　29. 7%、14. 6%　　　4. 3
12. 9%，　　　　6. 4%、14. 6%　　　　　　　　　，
　12. 9%[5]。　　　　　，　、

DNA　　　　DNA　　，　　　　　　　，
　、　　　、　　　　　　，　　　、　　
　　、　　　[154, 252~267]
[5,247~249]　。　　　　　　　－
，　　　　。　　，
　　　　　———"　　"[5,6]　　　(1)。　　，　　　18
"　　"，　　　　[268]，
，　　　(24. 5
[5,6]　　　~23. 2　)，
、　、　　，　　　0. 001% [257,269]。
，　　　[270]。　(8~
[5,238,240,249]　5. 42　)，
4. 2　　　[271,272]。
C、S
，　　[271,273]
。

1 、 ([287])。

Fig. 1 Co-evolution of life，atmosphere with deep oceans in the early time of the earth

(Conflicting Proterozoic shale records were from ref.[287])

，   )

。   ，   。

，   (Canfield

Fe^{2+})   18   。   ，Li [264]

[274]。   ，Canfield [275]   、

"Canfield   " ，   "   "

(～540 Ma)，   。   ，   ，

18   ，   、   ，

(H$_2$S)。Canfield   [276]   (

7   H$_2$S   )。

，   。   22

、   [277,278]   [279]   [285～288]   ，"   "

[259]   。   Canfield

，Anbar   Knoll [280]   ，

(Bioinorganic bridge)，   ，

。

Fe、Mo、Co   ，   、

。   Fe-S-C   [281～283]   Mo、   [264]，   Canfield

Cr[268,279,284]   ，

(Fe、Mo、Co

[289]。

，

，

，

Fe、Mo、Co

[297,298]。

α－　（Ther-

Canfield　moplasmatales），

[299～302]。

。

（　）　（Pro-

chlorococus）

[303]。

5　、　、

，

，

[304～306]。

，

，　、　、

。

5.1

GEOTRACES　，

[307]。

，

，

[156]。

"　，

"　，

、

，　"　，

"，　，

，　，

，

[308]。

、　、　，

[239,290～292]。

5.3

POPs

，

、　、

"　"

[242,244,246～248,290～292]。

，

，

（Nano-SIMS）

，

，

[5]、　，

，

[5,6]。

5.2

Cs^+

。

，

[309]。

，

，

，

[293～296]。　CH_4

α－　[21]。　SIMS

，

，

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            [M].   :   , 2008: 1—533.
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