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我国海洋生物地球化学过程研究的新突破
——评《中国近海生物地球化学》

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由中国科学院海洋研究所宋金明博士完成88万字的我国第一部海洋生物地球化学研究专著——《中国近海生物地球化学》已由山东科技出版社出版发行。作为国家杰出青年科学基金(No.49925614)主体成果和中国科学院知识创新重大项目(KZCXI-SW-01-08)部分成果体现的《中国近海生物地球化学》,第一次系统地研究了中国近海主要生源要素碳、氮、磷、硅等的生物地球化学过程,这是我国第一部有关中国近海的生物地球化学专著,它标志着我国海洋生物地球化学学科的形成与发展,并为其后的研究奠定了基础。

这本专著的研究涉及中国近海主要典型海域的陆架生态系、河口生态系和珊瑚礁生态系,在不同的海域有不同的侧重,渤海主要研究沉积物中氮、磷、硅的迁移、转化特征;黄、东海侧重对海水中碳、氧同位素的分布变化及生态环境演变和碳源汇的研究;而南海北部,特别是珠江口外则侧重研究其生态环境:南沙珊瑚礁生态系主要研究沉降颗粒物中生源要素与非生源要素的循环过程。专著中提出了一些新的理论观点,如海洋表观碳源汇与实际碳源汇、维持珊瑚礁生态系高生产力原因的拟流网理论、珊瑚奢侈消费营养盐、沉积物自然粒度下的形态研究等,所以创新性是这本专著的最大特色。

专著分四篇十二章。第一篇阐述了生物地球化学产生与发展的历程,海洋生物地球化学研究的主要进展,特别阐述了海洋环境中碳、氮、磷、硅等生源要素的生物地球化学过程,这一部分至目前是海洋生物地球化学作为独立学科最系统的论述。

第二篇研究的对象是渤海沉积物中的氮、磷、硅,海洋沉积物是生源要素氮、磷、硅的主要源与汇,在氮、磷、硅的循环中起着非常重要的作用,但究竟具体起多少和多大的作用到目前为止还不清楚。作者基于这个重大科学问题,在一个全新的思路下进行了系统的研究。首先定义了一个新概念,即"沉积物自然粒度下形态研究",其核心的内容是认为,在海洋沉积物中能进行循环的物质处于大颗粒的外层或海洋自生的微小颗粒中,颗粒大小的差异、处在颗粒内外层的不同以及结合形态的强弱,在其生物地球化学循环中所起的作用截然不同,颗粒物外层起的作用较大,而包含在颗粒物内层就起很小的作用或不起作用而成为"隋性态"或"非转化态"。对渤海沉积物中氮、磷、硅的研究表明,通过沉积物-海水界面过程提供给水体的氮、磷、硅分别占其循环总量的26.1%、86.4%和31.7%,在表层沉积物中可转化的氮、磷、硅的浓度分别为551.7μg/g、56.3μg/g、349.7μg/g,仅占沉积物中其总含量的30.8%、19.2%和0.12%。

第三篇集中研究了南黄海的生态环境,沉积物中的氮在其生物地球化学循环中的作用,黄、东海海水中无机碳、氧同位素和东中国海的碳源汇强度。南黄海表层沉积物24.01%的TN能被释放进入再循环,每年可释放19.54×10^9mol N参与海洋生产,占本海区海洋新生产力所需氮的6.54%;而北黄海沉积物每年则可释放65.31×10^7mol N进入水体参与再循环,可达到此海区海洋新生产力所需氮的12.03%,即不同海域沉积物中所释放的氮对该海域海洋新生产力具有一定的补充和调控作用,在氮的生物地球化学循环中具有重要地位。黄、东海海水中的$\delta^{13}C$和$\delta^{18}O$明显随深度发生变化,反映了碳、氧同位素受多种因素的影响,所以碳、氧同位素可用于研究海水的混合状况,并可作为海水来源和物质循环的示踪剂。春季和冬季东中国海皆为大气二氧化碳的汇,分别可吸收的碳为769万吨和1356万吨;夏季皆为二氧化碳的源,可释放到大气中的二氧化碳为459万吨;秋季渤海与北黄海为二氧化碳的汇,可吸收27万吨,南黄海与东海是二氧化碳的源,可释放324万吨的碳,在秋季整个东中国海可释放的碳为297万吨。全年总平均,东中国海作为大气

二氧化碳的汇可吸收1369万吨的碳。丰水期,东海POC净垂直通量的平均值表层水为53.00mgC/(m^2·d),次表层水为117.40mgC/(m^2·d),中层水为8.18mgC/(m^2·d),底层水为5.73mgC/(m^2·d)。由于表层沉积物的再悬浮,导致海水海-气交换得到的CO_2仅有13.0%以颗粒有机碳的形式垂直转移而形成表层沉积物中的有机碳。

第四篇系统研究了南海与南沙珊瑚礁生态系的生物地球化学过程。在南海北部,沉积物中的氮、磷、硅研究表明,沉积物中高的无机氮是河流输入的污染物在沉积物中积聚的结果,磷与硅则没有这一现象。对南沙珊瑚礁生态系则在研究对象上第一次对海水、沉降颗粒物、浮游生物、海藻、珊瑚及沉积物进行系统集成并结合活体珊瑚培养的方法进行研究,在珊瑚礁生态系研究上取得了一系列突破。首次清晰给出了元素在珊瑚礁生态系中垂直转移过程的轮廓,包括非生源要素在内的所有元素在珊瑚礁生态系中的垂直转移80%以上是由生物来完成的,非生物过程仅占不到20%;生源要素垂直转移到达泻湖底部后,大部分可再生释放进入泻湖水中进行再循环,其中再生释放量占其垂直转移到沉积物中的比例,总碳、总氮、总磷分别为22.9%、91.5%、74.6%;有机碳、有机氮、有机磷分别为90.5%、86.8%、88.8%。发现了珊瑚中的虫黄藻可以"奢侈消费"营养盐的新规律,即当珊瑚礁生态系中营养物质含量快速增高时(如由于生态环境的突变,底部有机质快速分解,释放大量营养物质或短时间海水运动带来较大量的营养盐),虫黄藻可在短时间内大量吸收之,从而间歇得到所需的营养盐,这种机制可对著者以前提出的拟流网理论作以补充。

当然,作为一部为创立学科奠定基础和全新内容的专著,书中肯定会有不足乃至错误之处,但这丝毫不影响它将对促进我国海洋学研究产生重要推动作用的巨大价值,这一点是不容置疑的,这也是我们向海洋学界同行推荐这本专著的初衷,希望海洋学同行在此基础上更加深入地开展研究,以推动海洋生物地球化学过程的研究。

A BREAKTHROUGH IN THE STUDY OF MARINE BIOGEOCHEMICAL PROCESSES IN CHINA

——A Review on Biogeochemistry of China seas

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Biogeochemistry of China seas, is the first monograph concerning marine biogeochemistry published in China, 880 000 words long written by Dr. Jinming Song of the Chinese Academy of Sciences, Institute of Oceanology. Combining primary research findings from two major studies: Sediment-seawater interface and process biogenic element cycling in China seas" (National Science Foundation for Outstanding Young Scientists, 1999, No. 49925614) and biogeochemical processes of the carbon cycle in China seas (Science Innovation Program, 2001, Chinese Academy of Sciences, (No. KZCXI-SW-01-08), in this monograph, the biogeochemical processes of the main biogenic elements present in China seas, such as carbon, nitrogen, phosphorus and silicon, were studied systematically for the first time. The intention is to firmly establish the field of marine biogeochemistry in China and record results from innovative research projects.

Coverage of the book includes, studies of three main marine ecosystems, i.e. estuarine, continental shelf and coral reef ecosystems. A different research focus has been placed on specific sea areas. In the Bohai Sea, attention has been paid to the transformation character of nitrogen, phosphorus and silicon in sediments. In the Yellow Sea and East China Sea, emphasis has been placed on two key issues of research. Firstly, the distributions of carbon & oxygen isotopes and, secondly, evolution of the ecological environment and carbon source/sink. In the northern areas of the South China Sea, especially around the Zhujiang (Pearl River) estuary, the ecological environment was studied. Finally, in the Nansha coral reef ecosystem, cycles of biogenic and non-biogenic elements were investigated.

A number of new theories and viewpoints are put forward including: Apparent and actual carbon source/sink, simulated drift-net reasons for the maintenance of high productivity in coral reef ecosystems, corals luxurious consumption of nutrient materials and a new concept dubbed form research in natural grain size sediment. The innovation of this monograph is apparent.

The monograph contains four sections with twelve chapters. Section one, opens with reviews on the historical development of biogeochemistry, updates on research developments and the biogeochemical process of biogenic elements (C, N, P, Si, etc) in seawater. Section two considers nitrogen, phosphorus and silicon in the Bohai Sea sediments. Marine sediments are the main source and sink of biogenic elements (nitrogen, phosphorus and silicon), and therefore play an important role in their cycles. Currently we have limited understanding of these processes, especially regarding their quantitative functions. Addressing this important scientific problem, a new method is employed, dubbed form research in natural grain size sediment. Materials in the cycle come from two sources, the outer-strata of coarse grains and authigenic fine grains originating in seas. Sediment functions were found to be related to grain size (coarse or fine), layer (outer or inner) and connecting forms (strong or weak). Namely, the outer layer plays an active role in the process, while the inner layer, called an "inert form" or "unconvertible form", plays a less important role in the material cycle of sediments. This conclusion is the key point of the new concept. According to the study on nitrogen, phosphorus and silicon in the Bohai Sea, 26.1%, 86.4% and 31.7%, respectively, of the total nitrogen, phosphorus and silicon in the cycle were provided by sediment-seawater interface process. In surface sediments, the concentrations of transferable nitrogen, phosphorus and silicon were 551.7μg/g, 56.3μg/g and 349.7μg/g, respectively, only 30.8%, 19.2% and 0.12% of their total contents in sediments.

Section three looks at the role played by nitrogen in sediments in the biogeochemical cycle, inorganic carbon and oxygen isotopes in the Yellow Sea and East China Sea and the intensity of the carbon source and sink in the East China Sea. If all the released nitrogen partook in recycling, 19.54×10^9mol nitrogen would be released for marine productivity in the southern Yellow Sea surface sediments. This would contribute to 6.54% nitrogen of that the new productivity needed in this area. The northern Yellow Sea sediments could provide 12.03% nitrogen (about 65.31×10^7mol) for the new productivity. This showed that the released nitrogen from sediments could contribute significantly to the primary productivity in this area, and had important functions in the biogeochemical cycling of nitrogen.

$\delta^{13}C$ and $\delta^{18}O$ obviously varied with depth, demonstrating that carbon and oxygen isotopes were affected by several parameters and could be used as a tracer in the study of seawater source, material cycles and the state of seawater mixing. Seasonal distributions in sea-air flux and strength of source/ sink of CO_2 in the East China Sea were obtained for the first time using the data from surface seawater temperatures and partial pressure of atmosphere. In Winter and Spring, the seawater could takes in CO_2 from the atmosphere in the Bohai Sea, Yellow Sea and East China Sea. Flux values are higher in winter than in Spring. In summer, however, the situation is reversed and CO_2 is released into the atmosphere. In autumn, the seawater takes in CO_2 in the Bohai Sea and north Yellow Sea, but releases CO_2 into the atmosphere in the East China Sea and south Yellow Sea. The minimum and maximum sea-air flux CO_2 uptake appears in autumn in the north Yellow Sea [5.3gC/($m^2 \cdot a$)] and winter in the Bohai Sea [106.0gC/($m^2 \cdot a$)]. For the release of CO_2, maximums occur in summer in both the north Yellow Sea [−1.9gC/($m^2 \cdot a$)] and the East China Sea [−18.8gC/($m^2 \cdot a$)]. The annual mean fluxes from seawater to air are 36.8, 35.2, 21.0 and 3.5gC/($m^2 \cdot a$) in the Bohai Sea, north Yellow Sea, south Yellow Sea and East China Sea, respectively (the Yellow Sea flux is 23.7gC/($m^2 \cdot a$). The east China seas are net sinks of atmospheric CO_2 in Spring and Winter when they take in 7.69 and 13.56 million tons carbon, respectively. In summer they release CO_2 to air with 4.59 million tons carbon. The Bohai Sea and northern Yellow Sea are the major sinks of atmospheric CO_2 taking in 0.27 million tons carbon, the southern Yellow Sea and the East China Sea are the major sources, releasing 3.24 million tons of carbon in autumn. As a result, the net carbon sink strength of the is 3.24 million tons in autumn. The annual mean atmospheric CO_2 taken up here is 13.69 million tons of carbon per year, i.e. the East China Sea areas take in 13.69 million tons of carbon per year from air. During the wet season, the mean values of net vertical flux of POC in the surface, subsurface, middle, and bottom layer waters are 53.00mgC/($m^2 \cdot d$), 117.40mgC/($m^2 \cdot d$), 8.18mgC/($m^2 \cdot d$), and 5.37mgC/($m^2 \cdot d$), respectively. Only 13.0% of the CO_2 derived from sea-air exchange, forms organic carbon in the surface sediment in the form of POC vertical transport. Section 4 concerns the biogeochemical processes of the South China Sea and the Nansha coral reef ecosystem. Most results concerning the biogeochemical process in this area are new findings. They represent the most systematic multidisciplinary research developments to date. The ecosystem was studied from a holistic approach; seawater, settling particulates, planktons, alga, corals and sediments were studied in reference to the cultivated living coral. Scientific understanding was advanced in a number of areas. A clear profile was put forward, for the first time, for processes underlying the vertical distributions of elements in the coral ecosystem. More than 80% of vertical diversions were biologically accomplished for all elements, including non-biogenic elements. Most regenerated biogenic elements were diffused in the water of the lagoon, which comprised 22.9%, 91.5%, and 74.6%, respectively, of the total organic carbon, nitrogen and phosphorus, as well as 90.5%, 86.8%, 88.8% of the organic carbon, organic nitrogen and organic phosphorus, respectively. It was found that Zooxanthellae can "luxuriously consume" nutrient materials. If the contents of nutrient increased fleetingly (for example, due to sudden environmental change, rapid decomposition of the sea-bottom organic matter or a large influx of nutrient materials by seawater), a large proportion could be absorbed by Zooxanthellae within a short period of time. This mechanism supplements the "simulated drift-net" theory previously raised by the author.

As a final note on this monograph, it is important to stress that as a platform for establishing a new field in China, relying entirely on new research findings, shortcomings will inevitably occur in some results. It is hoped that the value of the monograph as a whole will not be undermined by these part and parcel deficiencies of scientific endeavor. Moreover, we hope that the monograph will be used as a tool to enrich and promote understanding in this vital area of marine science.