Formation of summer hypoxia in the Yangtze River Estuary of China: 'Cold pool' and 'thermal barrier' effects

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Hypoxia in the Yangtze River Estuary has received increasing attention. It occurs in summer and may last until early autumn, and it has recently become more serious. Based on survey data from October 1958 to September 1959, August 2009, and July 2005, we found that the hypoxia area is located in the trough off the Yangtze River Estuary and affected by many external forcing factors, including water temperature and salinity, runoff from the Yangtze River, the Taiwan Warm Current, upwelling, and the Yellow Sea Coastal Current. These factors promote the formation of hypoxia by influencing the dissolved oxygen saturation level, the strength of stratification, the distribution of temperature and salinity, and water movement. In addition to these factors, there was a cyclonic vortex in the hypoxia area, and the bottom water in the area was much more stable. The vortex was mainly made up of water from the Taiwan Warm Current, which is characterized by low temperature in summer. All these factors promote the formation of a cold pool (isolated, closed, and stable waters with lower temperature under a 15-meter layer of warmer water) in the hypoxia area, and a thermal barrier (water at the periphery of the cold pool with higher temperature that protects the stability of the cold pool and blocks the exchange of dissolved oxygen with surrounding waters) is formed. The existence of the cold pool and thermal barrier greatly increases the residence time of water in the hypoxia zones, restricts the supply of dissolved oxygen, and provides necessary preconditions for the formation of summer hypoxia.

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Balance of Cenozoic carbon cycle maintained by basalt weathering

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The BLAG model proposed that the Cenozoic decline of atmospheric $p\mathrm{CO_2}$ is primarily dirven by the decrease of CO_2 degassing through the $p\mathrm{CO_2}$-weathering feedbacks [1]. However, the sea floor spreading rate, which is believed as the major control of CO_2 degassing, remained relatively constant [2]. Alternative explanation suggests that the drawdown of $p\mathrm{CO_2}$ is forced by the enhanced silicate weathering in response to the widespread Cenozoic tectonic uplift [3], but the increasing CO_2 consumption would deplete the atmosphere of all its CO_2 within a million years [4].

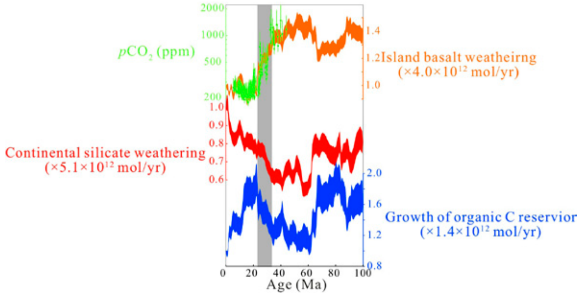

Figure 1: Atmospheric CO_2 sinks and $p\mathrm{CO_2}$ [5] since 100 Ma

Here an reverse calculation coupling the marine isotopic records of C, Sr and Os suggest that the weathering of island basalt is largely controled by $p\mathrm{CO_2}$ (Fig. 1), possibly through the CO_2 fertilization effect on plant weathering. The rate control of $p\mathrm{CO_2}$ on basalt weathering imply that both the BLAG model and the 'uplift driven' hypothesis could stand for the Cenozoic $p\mathrm{CO_2}$ evolution. Tectonic uplift enhanced the atmospheric CO_2 consumption by continental silicate weathering and accumulation of organic carbon during the Oligocene, left the unbalanced carbon cycle compensated by the decreasing island basalt weathering through the $p\mathrm{CO_2}$ controlled basalt weathering rate. Since the Miocene, the increasing CO_2 sink of continental silicate weathering was roughly balanced by the decreasing accumulation rate of organic carbon reservoir, and thus the rate of basalt weathering and $p\mathrm{CO_2}$ kept nearly constant.

[1] Berner *et al*. (1983) *Am. J. Sci*. **283**, 641. [2] Rowley (2002) *GSA Bulletin* **114**, 927. [3] Raymo *et al*. (1988) *Geology* **16**, 649. [4] Berner & Caldeira (1997) *Geology* **25**, 955.[5] Pagani *et al*. (2005) *Science* **309**, 600.