

Carbon cycle and global ocean chemistry during the Quaternary: a study using a vertical one-dimensional marine carbon cycle model

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Recent study on the ice core drilling at the Vostok station provides variation of atmospheric CO₂ concentration during the Quaternary. The obtained CO₂ variations are well correlated to those of the marine δ¹⁸O and the local temperature curves, suggesting that climate and carbon cycle change were closely related to each other in association to the glacial-interglacial cycles. The δ¹³C records of foraminiferal shells may be key informations for understanding the carbon cycle during the Quaternary, because they provide δ¹³C value of seawater of various water depths in the past time using according to their habitat depths. Early studies of δ¹³C data concerning to the glacial-interglacial cycles focused on those of benthic foraminifera, which generally show less δ¹³C in the glacial intervals. It has been accepted that the δ¹³C of deep water may stand for that of the global ocean, and hence variations of benthic δ¹³C reflect the carbon transfer from the external reservoir (such as terrestrial biomass). However, recent studies revealed that the δ¹³C records of the sub-surface to intermediate waters are quite different from the deep water: δ¹³C enriched in the glacial intervals, suggesting the vertical redistribution of δ¹³C and dissolved carbon owing to change in the deep water circulation. In this study, we develop a vertical one-dimensional carbon cycle model in order to examine the relations of the marine δ¹³C in various water depths with controlling processes (such as water circulation or carbon transfer from external reservoir) and other chemical constituents.

We first try to separate the influence on the marine δ¹³C by deep water circulation from that of carbon transfer from external reservoir, using forward modeling. We conclude that the δ¹³C at the surface water should reflect the carbon transfer from the external reservoir. The δ¹³C at the intermediate and deep waters should vary in the same phase as that at the surface with no phase lag. On the other hand, change in the global upwelling rate should change the δ¹³C at the intermediate and deep waters in opposite phase to each other. The global upwelling itself should not change the δ¹³C at the surface. Although continental silicate weathering and concentration of preformed nutrient within the mixed layer may have changed during the glacial-interglacial cycles, they change the surface water δ¹³C in the wrong direction to the observation. Hence, carbon transfer from the terrestrial biosphere is the most likely to control δ¹³C at the surface water.

We then try to reconstruct the carbon cycle (upwelling rate, productivities of carbonate and organic carbon, and carbon storage in the terrestrial biosphere) and marine chemistry (dissolved nutrient, total dissolved inorganic carbon, total dissolved δ¹³C, and total alkalinity) during the Quaternary from an inversion modeling using the δ¹³C record of planktonic and benthic foraminifera. The obtained results show that upwelling rate and productivities of carbonate and organic carbon become small during the glacial intervals, resulting in the dissolved nutrient redistribution from intermediate to deep ocean. Correspondingly, the δ¹³C deviation from the surface water shows anti-phase relationship between intermediate and deep ocean. The obtained variation of carbon storage in the terrestrial biosphere is similar to that of δ¹³C at the surface water, and is consistent with the previous estimation at the LGM. The obtained variation of δ¹³C at subsurface to intermediate waters are also consistent with the observed variations. The total alkalinity varies in the same phase throughout the water column. This is because total alkalinity is controlled by the integration of burial flux of carbonate rather than redistribution between intermediate and deep waters, which is different from the case of dissolved nutrient. This may be a reason that atmospheric CO₂ has more strong 100ky periodicity than δ¹³C.