Source: *Schweizer et al. (2005)*

Benthic foraminifera *Uvigerina peregrina* (left) and *Planulina wuellerstorfi* (right)

Source: *Lutze (1978)*

A Glacial-Interglacial Record of the North Pacific Biological Pump for the Past 600,000 Years

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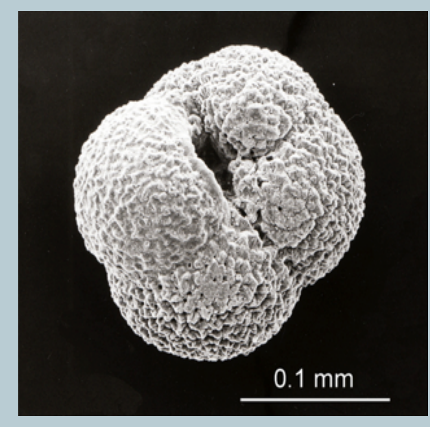
Tianjia Liu[1] (tl2581@columbia.edu), Jerry F. McManus[1,2] (jmcmanus@ldeo.columbia.edu), Kassandra M. Costa[1,2] (kcosta@ldeo.columbia.edu), and Tanzhuo Liu[2] (tanzhuo@ldeo.columbia.edu)

[1]Department of Earth and Environmental Sciences, Columbia University, New York, NY
[2]Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY

Lamont-Doherty Earth Observatory
Columbia University | Earth Institute
Columbia University in the City of New York



Source: T. Struve, IFM-GEOMAR

Planktonic Foraminifera *Neogloboquadrina pachyderma, sinistral*

Introduction

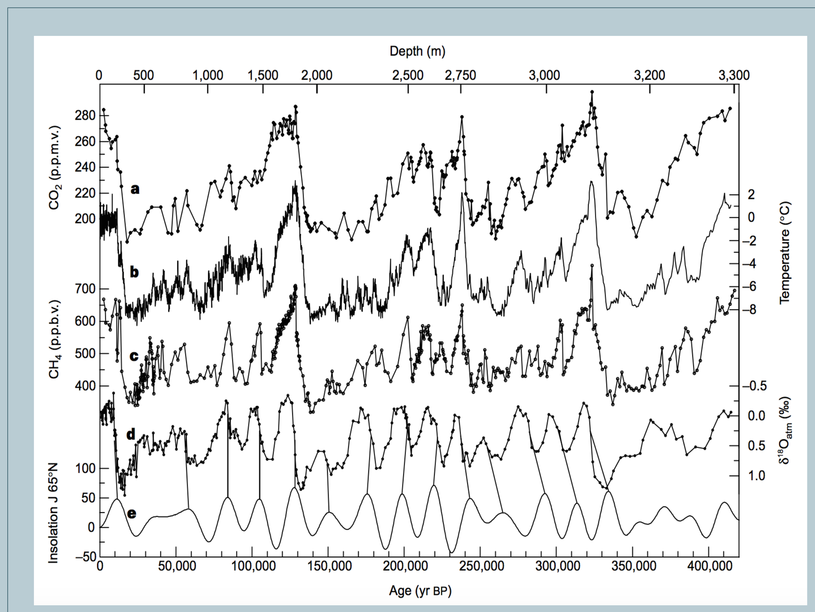


Figure 1. As seen in the Vostok ice core record, changes in solar insolation drove glacial-interglacial cycles, during which atmospheric CO_2 varied, with low CO_2 during glacials and high CO_2 during interglacials (*Petit et al.*, 1999).

- The North Pacific deep ocean is a prime location for carbon sequestration and storage.
  - No deep water source
  - No strong upwelling
- Through photosynthesis and gas exchange, the surface ocean sequesters CO_2 from the atmosphere, and its biological pump subsequently buries the carbon in the deep ocean.
- $\delta^{13}C$ is a proxy for marine productivity based on the preferential utilization of the lighter ^{12}C for photosynthesis and reintroduction of ^{12}C into seawater during respiration.
- Organic carbon, or organic matter that fails to decompose, accumulates on the seafloor, and is subsequently preserved in sediments.

Key Questions

(1) Does the North Pacific foraminiferal record at Juan de Fuca Ridge show that the surface ocean is more ^{13}C-enriched (photosynthesis-dominated) and deep ocean, ^{13}C-depleted (respiration-dominated)? And how does the difference in $\delta^{13}C$ between benthic and planktonic foraminifera change with respect to glacial-interglacial cycles?

(2) How does the C_{org} flux record at the same location change with respect to glacial-interglacial cycles?

(3) How successful are the aforementioned proxies at reflecting changes in the biological pump with respect to glacial-interglacial cycles?

Methods

(1) The AT-26-19-05 piston core from Juan de Fuca Ridge was sampled at 4 cm intervals. The samples were washed in sieves to separate the coarse (>63 µm) and fine (<63 µm) fractions.

(2) Three species of foraminifera (*Uvigerina spp., Planulina wuellerstorfi*, and *N. pachyderma, sinistral*) were picked and analyzed for $\delta^{18}O$ and $\delta^{13}C$ by mass spectrometry.

(3) The remaining total sediment fractions were decalcified with concentrated HCl, which then, after left overnight, was diluted with de-ionized water and removed from the samples. The samples were freeze-dried and prepared for C_{org} analysis by mass spectrometry.

Results

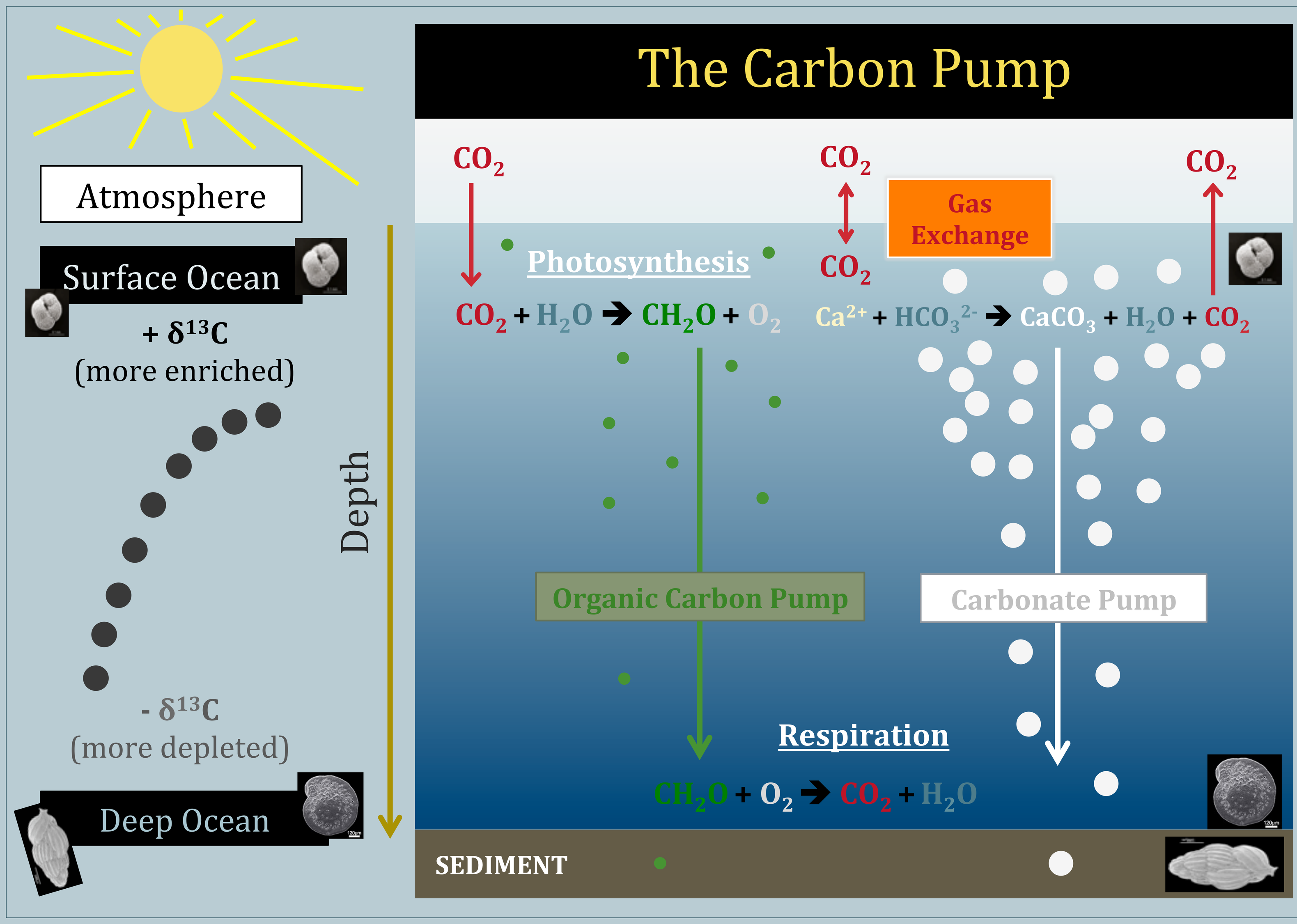


Figure 3.
- Photosynthesis removes CO_2 from the atmosphere and enriches surface waters in ^{13}C.
- Respiration and $CaCO_3$ formation depletes the ocean by releasing ^{12}C into surrounding waters.
- The $\delta^{13}C$ profile in the ocean with respect to depth is shown on the left.
- $CaCO_3$ shells from the open water eventually settle on the seafloor and are preserved in the sediment.

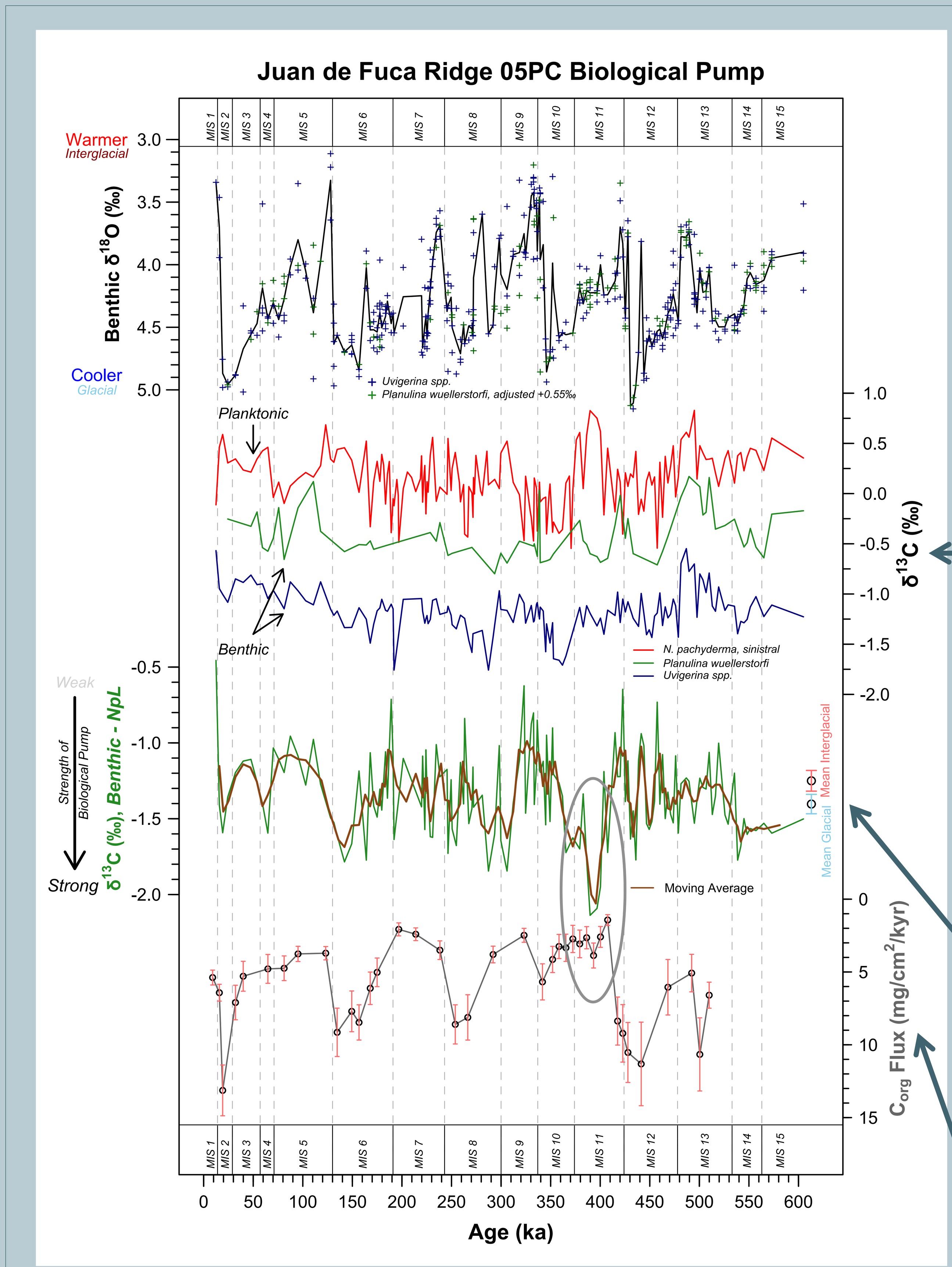


Figure 4. *The strength of the biological pump is characterized by two proxies: 1) the difference in $\delta^{13}C$ fractionation between benthic foraminifera and planktonic species N. pachyderma, sinistral; and 2) C_{org} flux.*

The $\delta^{13}C$ records of *NpL, Planulina wuellerstorfi*, and *Uvigerina, spp.* shows the depletion of $\delta^{13}C$ with depth in the water column as respiration reintroduces ^{12}C into the seawater. The difference in $\delta^{13}C$ between *P. wuellerstorfi* and *NpL* represents respiration in the water column, and that between *Uvigerina spp.* and *P. wuellerstorfi* represents respiration in the mud.

(1) The difference in $\delta^{13}C$ between benthic foraminifera (*P. wuellerstorfi* adjusted -0.735‰) and NpL is relatively large during glacials and small during interglacials.

(2) C_{org} flux is high during glacials, and low during interglacials. It peaks late in deglaciation periods.

Glacials have a strong biological pump. Interglacials have a weak biological pump.

Complications for Interpreting $\delta^{13}C$ and C_{org} flux as Proxies for Biological Productivity:

(1) Depending on the strength of ocean circulation, the age of the North Pacific deep water is variable, and therefore, the time that allows respiration to reintroduce ^{12}C in the deep ocean.

(2) During glacials, the entire ocean negatively shifts ~0.3‰ in $\delta^{13}C$ from terrestrial carbon input, but taking the difference in $\delta^{13}C$ of benthics and *NpL* eliminates these potential errors of absolute productivity for either surface or deep ocean.

(3) Unlike that of deep water, which is derived from other sources and not in contact with the atmosphere, the isotopic composition of surface water may be more susceptible to air-sea interaction and regional climate changes.

Juan de Fuca Ridge Site Map

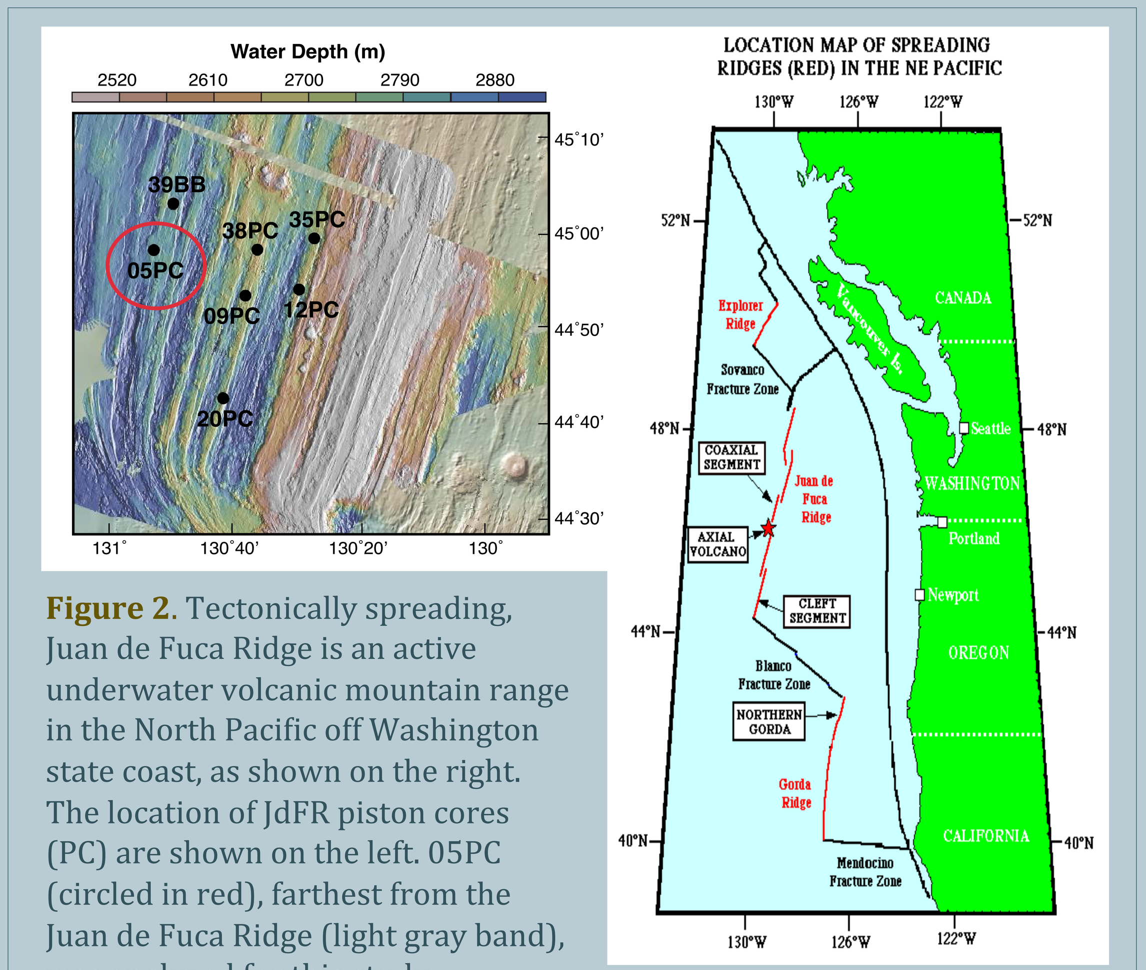


Figure 2. Tectonically spreading, Juan de Fuca Ridge is an active underwater volcanic mountain range in the North Pacific off Washington state coast, as shown on the right. The location of JdFR piston cores (PC) are shown on the left. 05PC (circled in red), farthest from the Juan de Fuca Ridge (light gray band), was analyzed for this study.

Source: NOAA

Conclusions

(1) Because **photosynthesis enriches** the surface water in ^{13}C and ***respiration depletes*** the deep water in ^{13}C, the difference in **$\delta^{13}C$ fractionation** between benthic and planktonic characterizes the **biological pump**.

(2) The North Pacific **biological pump** is relatively **strong** during glacials and ***weak*** during interglacials.

(3) Variations in the **organic carbon flux** support the ***weak*** **biological pump**-interglacial, **strong biological pump**-glacial conclusion.

(4) However, factors, such as regional climate changes, aging of the North Pacific deep water, and air-sea interaction, can complicate proxy interpretation.

Future Work

(1) The MIS 11 enigma: What caused the $\delta^{13}C$ fractionation to suggest an abnormally strong biological pump, yet C_{org} flux a weak biological pump at ~400ka (circled on Fig. 4)? Why did the $\delta^{13}C$ of NpL become very enriched, when the $\delta^{13}C$ of benthic species was relatively stable?

(2) More Data: Proxies, such as opal, and records from other cores are needed to refine and corroborate conclusions on the biological pump reconstruction.

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