Temperatures, Ventilation

Deep-sea corals and Paleoceanography

Norbert Frank, Laboratoire des Science du Climat et de L'Environnement, Gif-sur-Yvette, France



Ocean circulation and global (regional) climate

.... Through their fluid motions, their high heat capacity, and their ecosystems, the oceans play a central role in shaping the Earth's climate and its variability....

The atmosphere does not have much capability to store heat. The heat capacity of the global atmosphere corresponds to that of only a 3.2 m layer of the ocean.

How does the ocean influence the earth climate system through time and vise versa ?



The role of ocean circulation in climate dynamics

Surface:

wind forcing - latitudinal heat transport - deep convection - well mixed - sea ice cover - productivity (years)

Deep ocean

thermohaline circulation - poorly mixed -

/latitudinal heat transport - carbon storage (centennial variability)

Intermediate Ocean:

Eddy driven ? - vertical heat exchange across thermocline - nutrient recycling (decades ?)

If corals record temperature, ventilation, flow, productivity, etc... its the one of the intermediate to deep ocean !



Temperature and Salinity (annual mean)



Wind-forcing, Buoyancy forcing, Eddy-driven flow, Deep convection, upwelling ...

Vostok Gases and Temperature



Rapid climate change was observed in Greenland Ice cores



from: Liu 2006, Steig and Alley 2002

Ocean circulation does show similar oscillations



Curry and Oppo 2005



Why deep-water corals as oceanographic archive ?

They lives where the currents move fast (Gateways)

They grow quickly and over long times scales

(Time-resolution variable: mm/yrs for single species cm/kyrs for Coral reefs)

Their skeleton monitors environmental parameters (vital processes) and it can be precisely dated (Temperature, Salinity?, Productivity, pH, etc...) (Dating: ²³⁰Th/U, ²¹⁰Pb, Ra/Ba, ¹⁴C, ...)

They incorporated ventilation and advection tracers applied in modern oceanography (Nd-isotopes, ¹⁴C)

Distribution of deep-water and tropical corals



Key areas of intermediate and deep water production and flow !





What about long time series?

U-series dating of framework builders



-> Coral development on mounds depends on climate ?

Age pattern of solitary deep-water corals



Age (years)

Adkins et al. 1998, Mangini et al. 1998, Frank et al. 2004/2005, **Robinson et al. 2005**, Schroeder-Ritzrau et al. 2004, etc....

Solitary corals (30°-50°N) seem almost independent to climate and thus temporal records can be constructed from large sample collections by age determination of each specimen !

1998



 Nielam, C. Antrod Ercheston. Internelationships of the Living Phylic 10–117 (Oxford Univ. Press, Oxford, 1995).
McGinnis, W., Lavine, M. S., Heine, E., Karotwa, A. & Gehring, W. U. Naccor 308, 429–433 (1994).

Coral provides way to age deep water.

We propose a new method for computing the ratio of the isotopes carbon-14 to carbon-12 in deep water from the past, and for testing the results derived from the normal method of age difference between benthic and planktic foraminifera in deepsea sediments⁴.

scientific correspondence

determined as $13,530 \pm 75$ minus $12,447 \pm 100$ years, assuming a reservoir effect of 400 years. This method is similar to the one applied to forams.

However, 14,100 years ago the atmospheric Δ "C ("O"C relative to an oxalic standard) amounted to 221.1 ± 14 ‰ and was decreasing at a rate of approximately 30‰ per 1,000 years". Thus the deep water bathing the deep-sea coral equilibrated with an atmosphere that had a "O"C ratio, G^{ast}, enriched in "C compared with the atmosphere synchronous with the coral growth.

The relationship between a non-reservoir-corrected "C age and the measured "Cf¹³C ratio, "C¹⁰⁴, applying the conventional mean life of "C, is

 ${}^{M}C^{max} = C^{text} e^{-|{}^{H}C \cdot sp(mx)|}$ (1)

Nature 1998



Deep-Sea Coral Evidence for Rapid Change in Ventilation of the Deep North Atlantic 15,400 Years Ago

tion of the deep sea, because these corals are

unaffected by bioturbation14. Moreover,

protactinium-231/uranium disequilibrium

dating by thermal ionization mass spectrometry can be used to corroborate the

coral's 'true age' derived from its

sample that was collected from gravity box

core GeoB 1503-1 (02º 18.7' N, 30º 38.8'

W) taken at 2,306 metres depth during the

cruise of the research vessel Meteor 16/2

(ref. 5). The coral lay at a depth of 17 cm in

the core, in a layer rich in pteropods. This

layer probably corresponds to the deep-sea

carbonate-preservation spike that has been

observed in the Atlantic Ocean, centred at

an age of 13,500 years ("C) and with a max-

We analysed a solitary ahermatypic coral

thorium/uranium ratio (Th/U).

Jess F. Adkins,*† Hai Cheng, Edward A. Boyle, Ellen R. M. Druffel, R. Lawrence Edwards

Coupled radiocarbon and thorium-230 dates from benthic coral species reveal that the ventilation rate of the North Atlantic upper deep water varied greatly during the last deglaciation. Radiocarbon ages in several corals of the same age, 15.41 ± 0.17 thousand years, and nearly the same depth, 1800 meters, in the western North Atlantic Ocean increased by as much as 670 years during the 30- to 160-year life spans of the samples. Cadmium/calcium ratios in one coral imply that the nutrient content of these deep waters also increased. Our data show that the deep ocean changed on decadal-centennial time scales during rapid changes in the surface ocean and the atmosphere.

Science 1998

We have two radioactive clocks in deep-water corals !

Coral aragonite originates from seawater bicarbonate. Its ¹⁴C activity depends on

1) the ¹⁴C activity of seawater at the time of coral growth and 2) on the age of the coral itself (radioactive decay $T_{y_2} = 5730a$)

Knowing the age of the coral (U-series dating) allows thus to reconstruct seawater ¹⁴C.





WOCE - Transatlantic section

Very rapid, very large shifts in ∆¹4C from Upper Deep Waters



Individual corals can record deep water events. Multiple corals at the same depth "catch" same event.

> Squares are 1700m Diamonds are 2000 Triangles are 2500m

Robinson et al. 2005

Nd in the Ocean



Isotopic signature of Nd-sources



$\epsilon_{\rm Nd^-}$ in the eastern North Atlantic intermediate water



Temperature reconstruction from C and O isotopes



Isotope fractionation (vital effect)

Lutringer et al. (2005)

What can corals tell on water mass characteristics ?



Age (Cal. years BP)

Lutringer Ph.D. Thesis (2005)

FOR TRACES: Key issues:

Dates, Dates, Dates....

Study corals along with oceanic gateways and major current pathways! (Transect north 55°, temperate 27°, South -40°)

Calibrate novel tracers ?