

## diatom assemblages in INW2012 drilling cores from Lake Inawashiro , Tohoku, Japan

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Inawashiro-ko Formation is named by a 28.13m sediment core taken from Lake Inawashiro-ko, Fukushima Prefecture, Japan. Stratigraphy and facies analysis combined with tephra and AMS radiocarbon dating were carried out on INW-2012. The Inawashiro-ko Formation are divided into three stratigraphic units: the Lower part (37.17-26.60m) consisted by medium sand-sandy silt (vertically varied in grain size) with granule and wood fragments, the Middle part (26.60-24.89m) consisted by very fine sand-silt with upper level grain refinement, and the Upper part (24.89-0.00m) consisted by dense alternation of brighter and darker clay layers including fallout tephra and Lahars by sediment gravity flow. Each unit are formed by fluvial basin before the form of the lake, early stage of the lake, lake with deep water as present, respectively. <sup>14</sup>C dating indicate that Lake Inawashiro-ko is formed 42 cal k BP, and characteristic dense alternation of brighter and darker clay layers deposit continuously except for the most early stage of the Lake. The sedimentation rate in the upper part is 0.3-1.0(mm/yr). Additionally, We report the temporal variation of diatom assemblage and its relation to water environment in the past 2000 years from upper 2.00m of IN2012.

Keywords: Lake Inawashiro-ko, lacustrine sediment core, stratigraphy, diatom assemblage, late Pleistocene, <sup>14</sup>C dating

## Two different types of regime shift appeared in a 2900-yr record of Japanese sardine abundance

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Regime shift, revealed in climates and marine ecosystem, is one of key dynamics to predict rapid changes in marine ecosystems and fisheries resources for decades. The regime shift is defined as a relatively rapid change (occurring within a year or two) from one decadal-scale period of a persistent state (regime) to another decadal-scale period of a persistent state (Minobe 1997; King 2005). In the Pacific it has been detected in Pacific Decadal Oscillation (PDO) (Mantua et al., 1997) and species replacement between anchovy and sardine (Lluch-Belda et al., 1989). There is so far no sufficient evidence of how regime shift changes in its feature on longer timescales because of paucity of long-term high-resolution marine records in the Pacific. Here we present a 2900-year record of ecosystem regime shift in the western North Pacific using Japanese sardine abundance which can be reconstructed from fossil scales in the coastal marine sediments; timing of decreases and increases in the abundance can be used as an index of regime shift. Sardine abundance showed two different types of regime shift in the time series. One is a regime shift similar to that previously detected in the 20th century, which repeatedly occurs on interdecadal timescales. The other is a regime shift in relation to centennial-scale variability in sardine abundance, which could be followed by a centennial-scale low or high abundance period characterized by respective small or large amplitudes of decadal variations in abundance. Our estimation suggests that the maximum abundance is depleted one-quarter to one-tenth of that in the sardine regime in 1980s. Similar patterns of the latter regime shift are revealed in the time series of sardine abundance off California (Baumgartner et al., 1992) and Chile (Valdes et al. 2008), PDO index reconstructed from North America (Macdonald and Case 2005), and abnormal snow index in East Asia (Chu et al., 2008). This indicates that the latter regime shifts that we found are associated with those of marine ecosystems and climate over the Pacific. The recent high sardine abundance period lasted 200 years in the Pacific, suggesting transition to next centennial low abundance period in the near future. Careful examinations on whether the latest regime shift in 1990s is the case of the latter regime shift are important for the long-term prediction of climate and fisheries resources.

Keywords: regime shift, marine ecosystem, sardine fossil scale record, Pacific, Beppu Bay

## Modern changes of sedimentary environments in the brackish Lake Shinji, the east part of Shimane prefecture, Japan

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Lake Shinji is oligohaline brackish lake in the east part of Shimane prefecture. Area of Lake Shinji is 79.1km<sup>2</sup>, water depth shows less than 6m. The water column of Lake Shinji is divided into oligohaline surface water, mesohaline pycnocline, and mesohaline bottom water.

In recent years, Lake Shinji is observed environmental events such as Cyanobacterial water bloom, anomaly overgrowth of aquatic plants, decrease in the catch of Corbicula and so on. The purpose of this study is to reveal the changes in the sedimentary environment by using the comparison with the spatial investigation of surface sediments in 2006 and 2013 and the result of monitoring since 2010 in Lake Shinji.

The surface sediments in Lake Shinji in 2006 are sandy deposits shallower than 3.5m in water depth, but are muddy deposits deeper than its depth. Mean grain size of surface sediments deeper than 3.5m tend to be fine-grained with water depth, and shows 7.5 phi in deepest site. In shallower than 3.5m, many surface sediments shows fine to medium sand around 2 phi. Total organic carbon (TOC) contents of surface sediments was less than 4%. TOC contents shows high positive correlation coefficient 0.85 with mean grain size. This is suggested that the spatial distribution of TOC contents depend on grain size. Total Sulfur (TS) contents of surface sediments were less than 1%, and tend to be decreased with water depth. However, TS contents were less than 0.2% shallower than 4.5m. In deeper than its depth, TS contents decreases dramatically.

The surface sediments in Lake Shinji in 2013 are sandy deposits shallower than 3.5m in water depth, but are muddy deposits deeper than its depth. Mean grain size in 2013 was similar to the 2006. TOC contents of surface sediments were 6 to 8%. TS contents were less than 2%. TS contents were less than 0.2% shallower than 3.0m. This depth is shallow clearly than in 2006.

TOC contents in monitoring site from 2010 to 2013 fluctuated greatly in the range of 4% to 10%. TOC contents shows low values in summer season, and high values in winter season. It is considered that the fluctuation of TOC contents is caused by the dilution effect of inorganic sediment due to rainfall in the summer. In addition, TOC contents tend to increase from 2010 to 2013. TS contents fluctuated greatly in the range of 0.5% to 2.0%. TOC contents shows high values in summer season, and low values in winter season, and tend to increase from 2010 to 2013 as with the TOC contents. This is suggested that the increase of TS contents is caused by the inflow of mesohaline water and the decrease of dissolved oxygen in bottom water.

From the results of these, surface sediments and bottom water environments in Lake Shinji are a distinct change during term from 2006 to 2013. We are thinking that some of this cause.

Keywords: Lake Shinji, Surface sediments, Total organic carbon contents, Total Sulfur contents, Grain size analysis

## Provenances of detrital materials in the Lake Suigetsu sediment and quantitative evaluation of their mixing ratio

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Lake Suigetsu, central Japan, is characterized by annually laminated sediment, and extremely high resolution and precise age-depth model was established using drilled cores retrieved on 1993 and 2006. For this reason, Lake Suigetsu sediment is ideal subject of high resolution and precise paleo-climate reconstruction. Detrital material accumulated in Lake Suigetsu is thought to have 3 provenances with 3 different transport paths. One is eolian dust transported by wind from Asian continent. Second is detrital material transported by small rivers from surrounding slopes. Third is suspended sediment supplied from Hasu River and transported through Lake Mikata, which is connected to Lake Suigetsu with shallow channel. Mechanism and flux of detrital materials from these 3 sources could be controlled by the behavior of westerly jet, slope failure due to flood and/or earthquake, and rainfall and erosional process within the drainage area. Therefore, if we could reconstruct the flux of detrital materials from each provenance, we could gain detailed information on histories of paleo-climate and disasters.

In this study, we did factor analysis of chemical composition of detrital fraction extracted from the sediment by chemical treatment. Each end-member extracted by factor analysis was characterized with respect to mineral composition, color, and grain-size distribution. We compared these characteristics with samples taken from probable sources and from event layers in the sediment, and tried to re-construct the flux change of each detrital component.

Keywords: Lake Suigetsu, Deglaciation, Holocene, Factor analysis, Multi-regression analysis

## Wetter condition during the Heinrich Event 1? deduced from detrital flux and provenance records from Lake Suigetsu

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Stalagmites in Chinese caves, loess/paleosol sequence of the Chinese Loess Plateau, and lacustrine sediments in Asian countries are favorable to monitor the past changes in East Asian summer monsoon (EASM). However, not much is known about EASM spatial changes during the last deglaciation mostly due to the large uncertainty in the chronologies of the lacustrine and loess/paleosol sediments.

Lake Suigetsu in Central Japan is known for the varved sediments which cover at least last 70 kyr. Recently, accurate age model is established for SG06 core based on varve counting and more than 800 radiocarbon dates (e.g., Ramsey et al., 2012; Staff et al., 2013). Here we examine the precipitation changes in Central Japan during the last deglaciation from the flux and provenance changes of the detrital materials found in the SG06 core sediment.

We analysed flux of detrital materials for the last glacial part of the SG06 core (1402-1810 cm interval of the SG06 composite depth) with 1 cm resolution (corresponding to 7-13 yrs) and estimated provenance of the detrital materials using chemical and mineral compositions, grain sizes, and electron spin resonance intensity and crystallinity of the quartz. The reconstructed flux of detrital materials are characterized by the millennial-scale increases exceeding 12 mg/cm<sup>2</sup>/yr at 16,600-14,800 and 13,700-12,800 SG06<sub>2012</sub> yr BP and short-lived (decadal to centennial) episodes of higher flux repeated more than thirty times throughout the deglaciation interval.

The grain size, color, chemical composition, and crystallinity of quartz records suggest that the increase of the detrital materials during 16,600-14,800 SG06<sub>2012</sub> yr BP was mainly due to increase of suspended particles supplied from Hasu river through Lake Mikata, that is located immediately upstream of Lake Suigetsu and trapping most of coarse detrital grains. In contrast, the increase of detrital materials during 13,700-12,800 SG06<sub>2012</sub> yr BP likely reflects local slope erosion around the lake and partly the long-distance aeolian transport from the Asian deserts. Our result suggests the wetter condition in Central Japan during the Heinrich Event 1 in contrast to the dry condition in Yangtze River Basin, China, according to the  $\delta^{18}O$  stalagmite record (Wang et al., 2001).

Keywords: Lake Suigetsu, Heinrich Event, East Asian Summer Monsoon, detrital material, quartz

## Variation of very fine grained elemental carbon deposition to the Rebun Island, Hokkaido, during the last 5 ky

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Elemental carbon (EC) is a combustion product which is composed of rich C and depleted O, H, S, N. Biomass burning is major source of Pre-industrial EC, while fossil fuel burning has been the most important source since the 18th century. Black carbon (BC) transferred in the atmosphere as aerosols, including EC have a great impact on the climate. EC is also the second strongest contributor to global warming, and has effect to darken snow and ice surface. On the other hand, aerosols including EC have also negative effect on radiative forcing, which lead cooling. Although it is difficult to evaluate the net EC effect on climate, it is necessary to discriminate EC produced by fossil fuel burning from those from biomass burning. EC is not a single chemical compound, but it can be classified into two types, char and soot. Char is produced by pyrolysis, while soot is formed via gas-to-particle conversion. The char particles which are countable under microscope are called charcoal. There are many researches to reconstruct paleo-fire by counting charcoal, and in the late Holocene, the fire sometimes synchronized with human activity. Therefore, it is very important to understand the past EC variation to examine the relationship between climate change and history of human.

There are some methods for analysis of EC, and in this study, we use the method called thermal optical reflectance (TOR)-method. This method is principally used to analyze EC/OC in aerosols, where we can evaluate an interference of pyrolyzed OC produced during the temperature rise under He atmosphere by measuring the transmittance of near-infrared laser. In order to apply TOR-method to analysis of sediment, we examined thermograms for sucrose, fulvic acid, humic acid, and fullerene in advance. As a result, we confirmed that carbon fraction decomposed at 700-850 °C under O<sub>2</sub> atmosphere can be regarded as an EC.

The sediment sample we used was collected from the Kusyu Lake in the Rebun Island. We established the stratigraphy of the sediment core of 20 m long as well as the sedimentation rate of the surface sediment. From variation of the ratio of coarse/fine particles down to 12 m depth, the sedimentary environment would be changed from marine to fresh water at 600 cm. We analyzed EC/OC both for coarse and fine particles for 0-600 cm interval. The result shows that the variation of EC in coarse particle reflects local variation, while the EC in the fine fraction reflects local and/or distal variation. The local biomass burning increased at 521 cm. The influence of distal EC variability was larger in the interval of >217 cm, with the maximum at 217 cm and the minimum at 263 cm. The long-distance transportation of EC could be influenced not only by increase and decrease of supply from biomass burning but also by the variation of wind pathway which transports distant EC.

Keywords: elemental carbon, biomass burning, Holocene, Rebun Island

## Chronological study on widespread tephras for the past 50,000 years in and around Japanese Islands

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After discovery of Aira Tn (AT) tephra, many widespread tephras have been recognized. The tephra for the past 50,000 years can be dated by the radiocarbon (<sup>14</sup>C) age determination. All <sup>14</sup>C dates for tephras after Spfa-1 can be calibrated to a calendar year using calibration dataset "IntCal13". On the other hand, the stratigraphy and the age of tephras intercalated with core sample from marine and lake have been made highly precise. In this presentation, we review the chronological research on widespread tephras for the past 50,000 years, and then present its perspective

Keywords: widespread tephra, radiocarbon dating

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MIS30-08

Room:501

Time:April 28 11:00-11:30

## The door that the IntCal13 and Suigetsu dataset opened for us all

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See the Japanese abstract (the presentation will be in Japanese)

Keywords: IntCal13, Radiocarbon dating, Radiocarbon calibration, varved sediment, climate change, age-based correlation



## A new high resolution dating method using tree-ring cellulose oxygen isotope ratio

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### Introduction

Dendrochronology is the most accurate dating method by comparing of inter-annual variations in tree-ring width of wood samples from sedimentary layers, archaeological remains or old architectures against the predated standard ring width variations. Master chronologies of tree-ring width, necessary to be built for each region and species, have been established all over world. Some of them based on many living and buried trees cover the whole Holocene in Northern Europe and New Zealand. Tree rings contain other parameters than ring width, applicable for dendrochronological dating. Oxygen isotope ratio (d18O) of cellulose is one of them. Here, we demonstrate merits, methods and problems of the tree-ring d18O chronology in details.

### Merits of tree-ring cellulose d18O chronology

Because tree-ring cellulose d18O is controlled solely by two meteorological factors, precipitation d18O and relative humidity, its inter-annual variation is usually independent from ecophysiological conditions of each tree. As the result, highly correlated tree-ring cellulose d18O variations between different trees ensure high success rate of dating. Moreover, the master chronology of tree-ring cellulose d18O built on cedar and cypress trees can be applied to date wood samples from all other tree species living in the same region and period. Therefore, many tree-ring d18O chronologies are now being created very rapidly all over Japan during the late Holocene, and the established tree-ring cellulose d18O chronologies have been applied for dating of various natural and artificial wood samples to promote new inter-disciplinary studies in both natural and human sciences.

### Methods in tree-ring cellulose d18O chronology

There are two important progresses in analytical method behind the emergence of tree-ring d18O chronology. One is the combined instrument of a pyrolysis-type elemental analyzer and an isotope ratio mass spectrometer. The other is "plate method for cellulose extraction" from tree ring samples. Before 2000AD, it was extremely difficult to measure d18O of organic matter because combustion of samples to gases inevitably causes terrible oxygen contamination. The development of an instrument, which converts organic oxygen to CO without any oxidant at 1400 degree C and transfer the CO to mass spectrometer directly, solved the question how to measure d18O in huge numbers of tree ring cellulose. So far, cellulose extraction from many tree ring samples has been too time-consuming and labor-intensive to meet the huge number of samples in dendrochronological purposes. In 2010, we have developed a new method to extract cellulose directly from thin wood plates with hundreds of rings, which enabled us to start the tree-ring cellulose d18O chronology at last.

### Perspectives of tree-ring cellulose d18O chronology

Although it is much more time-consuming to analyze tree-ring cellulose d18O than to measure tree ring width, we have accumulated many tree-ring d18O data from various kinds of samples and obtained many essential knowledge. While some data have successfully dated important archaeological remains, new problems have also emerged. Here, we show those problems and discuss future perspective of the tree-ring d18O chronology. <Tree Species>There are usually high correlations in tree-ring d18O time series between conifer and deciduous hardwood. But, evergreen hardwood may be somewhat different due to the longer photosynthetic season. <Spatial Correlation>Tree-ring d18O chronology in central Japan is coincident with those in western Japan, reflecting inter-annual changes of stationary rain band (Baiu front) activity in early summer. However, tree-ring d18O time series on Japan Sea side sometimes becomes complicated due to effect of heavy snow cover. <Analytical Method>"Plate method" sometimes destroys ring boundary of buried wood, so that it is necessary to further improve cellulose extraction procedure.

Keywords: tree ring, cellulose, oxygen isotope ratio, dendrochronology

## Calcareous nodules for sea floor paleothermometry

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Paleothermometry is one of the most important proxies for paleoceanographers. Benthic foraminifers have been used for reconstructing paleotemperature on the bottom of the sea. They are excellent materials for calcareous ooze, while mudstone sequences shows lots of difficulty to apply this technique for terrigenous sediments distributed around Pacific. Calcareous nodules are commonly observed in mudstone sequences, however, no study discussed potential paleothermometry based on calcareous nodules. It might supplements the role of benthic foraminifers. We described occurrences at outcrops, general configurations including their cut sections, analyzed carbon content, total organic carbon, and carbon and oxygen isotopes of nodules collected from Cretaceous strata of several regions in Hokkaido including the Haboro area.

Structure suggesting consolidation just below the sea floor includes burrows that eject calcareous material from nodule. Nodules consolidated associated with anaerobic oxidation of methane with sulfate reduction appear to be just-below-the-sea-bottom origin. Such nodules show the exactly same oxygen isotope values with that of benthic foraminifers. A bivalve fossil found on one of the methane seep nodules preserved aragonite of the shell and yielded close oxygen isotope temperature with that of host nodule.

Carbonate content and oxygen isotope values had positive relation suggesting carbonate content was controlled by the depth of nodule production. Nodules with lower carbonate content (<50%) exclusively show low oxygen isotope values and inappropriate for the sea bottom paleothermometry.

Study on nodules from the Haboro area showed that selections in front of outcrops and at laboratory enable us to select "high quality nodules" for oxygen isotope paleothermometry. As it is simple procedure, large numbers of analyses are available. The cross-plot of these data can emerge "upper limit line" of oxygen isotope values. The paleotemperature based on that value could provide reliable temperature for the sea bottom. On the other hand, nodules with similar condition from the Oyubari area appeared to be recrystallized and inappropriate for paleothermometry. It might be derived from the difference of burial depth between sediments of the Haboro and Oyubari areas. Even if it was originally consolidated near the bottom of the sea, strong compaction during burial would have caused permeation of pore water into the nodule. Carbon dioxide or bicarbonate ions derived from decomposed organic matter would have caused recrystallization of calcite with oxygen isotopes as low as -10 permil in the nodule.

Keywords: nodules, paleothermometry, oxygen isotope

## Identification of single pollen grains found in a glacier using a whole genome amplification method

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Pollen taxon in sediment samples can be identified by analyzing pollen morphology. Identification of related species based on pollen morphology is difficult and is limited primarily to genus or family. Because many pollen grains in glaciers contain protoplasm, genetic information of pollen grains should enable identification of plant taxa below the genus level. The present study attempted to analyze the DNA of *Pinus* pollen grains collected from subsurface snow layers on the Belukha Glacier in the Altai Mountains of Russia in the summer of 2003 in order to identify them. *Pinus* is a taxon with approximately 111 recognized species in two subgenera, four sections and 11 subsections. Each *Pinus* pollen grain was amplified using a whole genome amplification method, and some regions of chloroplast genome were sequenced. As a result, each pollen grain was identified at subsection level and was narrowed down to around 10 species.

Keywords: glacier, ice core, pollen analysis, *Pinus*, DNA, WGA

## Dissolution process of *G. bulloides* shell observed by X-ray CT based on dissolution experiment

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We performed nine-day dissolution experiments with shells of the planktic foraminifera *Globigerina bulloides* at a pH of  $6.7 \pm 0.1$  in water undersaturated with respect to calcite. *Globigerina bulloides* shells were collected from sediment trap samples in the western subarctic Pacific. The process of dissolution of the shells was quantitatively evaluated with observations made with X-ray micro-computed tomography (CT). On the basis of these observations, we divided the shell structures of *G. bulloides* shells into three categories: early-developed calcite formed during the juvenile stage, inner calcite, and outer calcite. The early-developed and inner calcites had low CT numbers (low density) and were sensitive to dissolution. In contrast, the outer calcite had high CT numbers (high density) and resisted dissolution. Both the mode and frequencies of the CT numbers of *G. bulloides* shells decreased as dissolution progressed. Temporal changes of the histogram of CT numbers as the shells dissolved were quantified in terms of the percentage of calcite volume accounted for by low-density calcite (%low-CT-number calcite volume). There was a linear relationship ( $R^2 = 0.62$ ) between the volume ratio of low-density calcite and shell weight loss. This relationship indicates that shell weight loss can be estimated from the CT number distribution, regardless of the initial condition of the shell, such as size or thickness. We suggest that the X-ray micro-CT method may be used to estimate the extent of foraminiferal shell dissolution with respect to effects on internal structure and shell density.

Keywords: carbonate, planktic foraminifera, X-ray CT, shell weight, shell density, dissolution index

## Relationship between modern speleothem formation and surface weather in an Asian tropical cave

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### Introduction

For precise climate prediction, it is necessary to reconstruct high time and space resolution paleo-climate (especially past 2000 years) from paleo-climate proxies and assimilate the result to climate model. Tropical Asia, including Indonesia, is well affected by El Nino Southern Oscillation (ENSO). The ENSO does not only directly affect on precipitation in tropical Asia, but also indirectly on middle and high latitude climate through teleconnection [1]. In Indonesia, Watanabe et al. [2] suggested inverse-correlation between  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  in speleothems and instrumental precipitation. However, relationship between modern speleothem formation and surface weather is not revealed clearly.

Therefore, the cave monitoring program, which included cave air temperature, relative humidity, airflow current, air  $\text{CO}_2$  concentration monitoring and  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  analysis of dripwater and farmed speleothems, was initiated from 2011 in Petruk Cave (Central Java, Indonesia) in order to study the recording mechanism of precipitation variation into the  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  fluctuation in speleothems.

### Result and Discussion

Air  $\text{CO}_2$  concentration in Petruk Cave is fluctuated daily and seasonally until over 100 m deep site from the entrance.

It is revealed that cave air  $\text{CO}_2$  concentration may be a significant factor that controls stable isotope value in speleothems, because temperature, humidity and drip rate in Petruk cave are nearly stable.

A scenario of precipitation recording is as follows: (1) surface rainfall cools outside air temperature; (2) cave airflow direction is inverted; (3) outside fresh air flows into the cave and air  $\text{CO}_2$  concentration is dropped; (4)  $\text{pCO}_2$  difference between cave air and dripwater becomes higher and calcite precipitation is promoted; (5)  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  in dripwaters and speleothems are decreased.

In addition to above discussion, we will show you  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  values in dripwaters and farmed speleothems and confirm the scenario by these data.

[1] Hastenrath (1991) Climate dynamics of the tropics. [2] Watanabe et al. (2010) Palaeogeography, Palaeoclimatology, Palaeoecology 293, 90-97.

Keywords: cave monitoring, speleothem, isotope, paleo-climate

## Millennial changes recorded in a stalagmite from central Gifu, Japan

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A 13-cm-long stalagmite collected from Gujyo City (central Gifu Prefecture) was formed from Marine isotopic stage 3 (MIS-3) to mid-Holocene. The stalagmite is divided into the lower and upper parts by a long-time hiatus during the Last Glacial time. Textural difference appears between the homogenous and transparent upper part and the dark-colored lower part. Oxygen isotopic values are also different; the values of the lower part are 0.5-1.0 permil higher than the values of the upper part. This difference is comparable to one that has been reported from stalagmites in south China, revealing that the Gifu stalagmite was formed under the influence from East Asian summer monsoon.

The most prominent feature of this stalagmite is cyclic changes of ~1 cm intervals in the lower stalagmite. Assuming that the lower part had grown continuous with a uniform rate, it includes a period from 56-35 ka. Eight cyclic changes could coincide to the dark layers in deep-sea sediments from the Japan Sea, which are likely associated with Dansgaard-Oeschger (D-O) events. In each cycle, the stalagmite increases transparency to the upward, and suddenly becomes darker at the base of the upper cycle. Similarly, oxygen isotopic values gradually increase in each cycle and rapidly decrease at the base of the upper cycle.

Millennial changes in the Gifu stalagmite indicate D-O cycles, and further records regular intervals that cannot be seen in the Greenland ice sheet. Records of the lower stalagmite support the global extension of D-O events, and suggest that D-O cycles were not necessary originated from the phenomena in North Atlantic. Assuming that the oxygen isotopic values reflect precipitation intensity, it became dry during a gradual cooling period and shifted wet with an abrupt warming.

U-Th dating was performed in National Taiwan University under the guidance of Prof. C.C. Shen.

Keywords: stalagmite, oxygen isotope, late Pleistocene

## Changes in precipitation over the last 2000 yrs recorded in a stalagmite and famine and disaster records in Iwate Pref.

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Stalagmites are excellent archives of terrestrial paleoclimate information. Some of them are formed in caves near the noosphere and may have recorded past climatic changes influenced human activity. Stable oxygen isotopic compositions of stalagmites especially have been utilized in many paleoclimate studies. However, many factors controlling stalagmite oxygen isotopic composition are known and the degrees of their influence varied from region to region. It is not easy to specify the main controlling factor in Northeast Japan, because the climate is influenced by the East Asian Monsoon and surrounding continental and oceanic air masses struggling with each other. Therefore stalagmite climatic studies is not advanced in this region.

We collected growing stalagmite UT-A from Uchimagi-do Cave, Iwate Prefecture, Northeast Japan. UT-A is 25 cm in height and obvious annual growth layers are found entirely under UV light. The age model of UT-A was based on these growth bands and it revealed that the mean growth rate is 0.12 mm/year and the stalagmite has continuously grown over the last 2000 years. In order to specify the major factor controlling isotopic composition of UT-A, we analyzed changes in annual layer thickness and oxygen isotopic composition of the uppermost part of UT-A and examined the correlations between these changes and weather around the cave over the last 30 years. As the changes in  $d^{18}O$  correlates well with the growth rates and amount of precipitation, the oxygen isotopic profiles of UT-A could be interpreted as a proxy of precipitation change over the last 2000 years. The past precipitation deduced from oxygen isotopic composition of UT-A has a 100-200-year cycle and synchronized with famine and disaster caused by excess and lack of precipitation in regional historical records (e.g. Nihon'yanagi, 1968MS). Thus oxygen isotopic composition of stalagmites in Northeast Japan could be a good proxy of past precipitation and we can reconstruct past precipitation and possible famine and disaster events in prehistoric times. Moreover, we may be able to forecast the near future precipitation change in this region by the cyclic fluctuation.

### Reference

Nihon'yanagi, S., 1968MS. *Small history of famines in Nanbu-Hachinohe Han in the Thousand Years* (in Japanese). Aomori.

Keywords: stalagmite,  $d^{18}O$ , precipitation, famine and disaster records, Uchimagi-do Cave, Iwate Prefecture

## Skeletal records in a long-lived *Porites* coral from Okinoerabu-jima, Ryukyu Islands

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Tropical and subtropical ocean-atmosphere interactions play a significant role in global climate changes on seasonal, interannual and decadal timescales. Knowledge of past ocean variability is crucial for understanding and modeling current and future climate. However, spatial and temporal instrumental time series from tropical and subtropical oceans before 1950 are quite limited. There is, therefore, a strong need for high-resolution paleoclimate proxies such as corals and sclerosponges from the oceans that extend beyond the instrumental data.

Massive *Porites* corals, living in shallow waters of the tropical to subtropical oceans, precipitate annually banded aragonite skeletons. These colonies provide robust chronological control and allow sub-sampling at monthly-to-seasonal resolution. Oxygen isotope composition of coral skeleton reflects variations in sea surface temperature and seawater oxygen isotope composition (salinity) with the latter being closely related to the precipitation-evaporation balance at sea surface and changes in water mass transport (e.g., Gagan et al., 1998). Long-lived corals are an excellent archive for documenting high temporal resolved time series of thermal and hydrologic changes at sea surface for the last several centuries (e.g., Quinn et al., 1998). Nevertheless, there are a few published long coral records of more than 100 years in the tropical northwestern Pacific (Guam: Asami et al., 2005; Ogasawara: Felis et al., 2009; Ishigaki: Mishima et al., 2010).

We collected a 4.5-m-long skeleton core from a modern *Porites* coral colony in Okinoerabu-jima, Ryukyu Islands on October 2011. Our continuous observational data at the coral living site for the years 2009-2011 are consistent with gridded sea surface temperature and salinity products, suggesting that the site is exposed directly to open sea surface conditions. X-ray images of the coral skeleton showed well-developed annual density bands for the last several centuries. Here we present monthly-to-bimonthly resolved oxygen and carbon isotope composition time series from the coral skeleton to reconstruct secular trend of oceanographic changes before and after the Industrial Revolution. Along with previously published long coral records, our coral-based climate reconstruction will document spatial changes in thermal and hydrologic conditions in the northwestern Pacific for the last several centuries.

Keywords: coral skeleton, oxygen isotope composition, carbon isotope composition, paleo-temperature, paleo-salinity, Ryukyu Islands



## Particle flux and paleoceanographic studies in the subarctic Pacific and the Arctic Ocean

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Particle flux studies employing time-series sediment traps have been very useful in obtaining novel knowledge concerning the environmental conditions in ever changing upper water columns of the subarctic Pacific since there had essentially been no such information available prior to our attempt. We employed T/S Oshoro-maru of the Hokkaido University in deploying the sediment traps in two remote areas of the subarctic Pacific during 1989-2010, for >20 years: one in the pelagic central subarctic Pacific (49.5 degree N, 174 degree E) and the other at a hemipelagic site of the Aleutian Basin of the Bering Sea (53.5 degree N, 177 degree E). Major biogenic particles in the flues include siliceous shells such as diatoms, radiolarians, and silicoflagellates as well as carbonate shells such as coccolithophores, foraminifers.

These shell-bearing plankton particles are useful in identifying detailed environmental conditions concerning seasonal and inter-annual changes. In particular, the effectiveness of biological pumps has been clarified, showing uptake of atmospheric CO<sub>2</sub> into the upper water columns at a different extent depending of the sites for the first time. Another important aspect of the biogenic particles is initial fossilization process during the settling phase in the water column, which also will be discussed.

Furthermore, application of what had been learnt from the particle flux studies to the sediment records of the past climate changes has been quite a challenge, but rewarding. Integrated Ocean Drilling Program (IODP) Expedition 302 (Arctic Coring Expedition: ACEX) in the vicinity of the North Pole at 88 degree N on the Lomonosov Ridge provided an opportunity of studying the middle Eocene environmental conditions of the paleo-Arctic. The conditions revealed for the first time mainly by siliceous microfossils such as diatoms, silicoflagellates, ebridians and chrysophytes are: fresh water at the top, brackish water next within the euphotic layer, and salty marine water supplied from the outside palegic realm. Another important aspect of the paleoceanographic exploration had been focused on the Bering Sea as IODP Expedition 323, for which the author proposed during the ODP era and materialized during the IODP era after 14 years of drilling preparation effort. The successful drilling down to ca. 5 Ma led to novel knowledge of many aspects such as evolution of sea-ice, the linkages both to the Pacific Ocean and the Arctic Ocean through the Beringian gateway. The Bering Sea drilling data linking to the intensification of the Northern Hemisphere Glaciation (NHG) ca. 2.7 Ma as well as the Mid-Pleistocene Transition (MPT) during 1.2-0.8 Ma are of extremely of interest and will be discussed in details.

Keywords: particle flux, Bering Sea, Arctic Ocean, Northern Hemisphere glaciation, Oceanic gateway

## Calcareous nanoplanktons and nanofossils as useful tools for paleoceanography

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Microfossils are useful tools for paleoceanographic studies in two ways: age identification by detailed biostratigraphy, and reconstruction of sea state such as water temperature, productivity and dynamic properties of water mass. Needless to say, calcareous nanofossils are powerful age-diagnostic tool for oceanic sediments, but because of their minute size, its usefulness for oxygen and carbon isotopic analysis are limited. On the other hand, the unique existence of *Florisphaera profunda*, a deep photic-zone dweller, provide an useful method for paleoproductivity and dynamic analysis of water column. By the way, new discoveries or break through in any disciplines are often resulted from unexpected encounters or conversations between researchers. Personal relationships are also very important factor to progress career and to accomplish scientific achievement for young scientists. Utilizing this opportunity, I will summarize major points for paleoceanographic applications of calcareous nanofossils, and also, I will explain my own experiences of various encounters that resulted fruitful scientific achievements.

Keywords: paleoceanography, calcareous nanofossils, biostratigraphy, water dynamics, lower photic-zone

## Mechanism of ice age cycle and paleoclimate modeling

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The 100-kyr cycle of the waxing and waning of the large Northern Hemisphere ice sheets and fast termination of the glacial cycles are the prominent pattern known from paleoceanographic records which can not be explained by the summer insolation proposed by the Milankovitch theory alone. Conceptual models imposing a threshold for the terminations by a large size of the ice sheet and/or large insolation can reproduce the patterns of glacial cycles, however, a physical explanation was not given. Here we simulated the past seven glacial cycles successfully with an ice sheet model in combination with a general circulation model imposing the time series of insolation and atmospheric CO<sub>2</sub>. The response of climate to ice sheet, greenhouse gases and orbital forcings is examined with high resolution. The stationary wave feedback of ice sheet is also taken into account. Our model reproduces 100-kyr periodicity of the glacial cycles even with the astronomical forcing alone under a certain range of CO<sub>2</sub> level for the case of North America ice sheet. We show that the threshold which leads to the termination of the glacial cycle is governed by how the ice sheet responds to a given insolation. The characteristics of how the ice sheet responds to external forcing strongly depends on the climatic condition, such as the north-south temperature gradient and the topographic condition for each continent.

Keywords: climate, paleoclimate

## Cretaceous-Paleogene stratigraphy in Northwest Pacific and its significance for paleoenvironmental study

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The Cretaceous – Paleogene period is known as the latest Greenhouse climate in the history of earth. In order to understand ocean – climate system during past Greenhouse climate, numerous attempt has long been made for the marine sequences in the Atlantic and Southern oceans and the Tethyas Sea. The Pacific Ocean was the outstandingly largest ocean during Cretaceous – Paleogene, and it may have played important roles in Earth's ocean – climate system. Despite its importance, very little work has been done to establish detailed paleo-oceanographic changes during Cretaceous – Paleogene. This is largely because most of the Cretaceous – Paleogene Pacific oceanic crusts have subducted under continents, and bad recoveries of Cretaceous – Paleogene sediments of the ODP and DSDP cores from the Pacific sites have prevented researchers from studying paleoenvironmental changes of the Pacific Ocean.

First, we establish the detailed integrated stratigraphy (planktic foraminiferal and dinoflagellate cyst biostratigraphy, carbon isotope stratigraphy and U-Pb dating of tuff beds) of the Cretaceous – Paleogene marine sequences exposed in Hokkaido Japan because the resolution of international stratigraphic correlation of these strata is not enough to identify important climatic and/or extinction events such as the OAEs, K/Pg, PETM and others. The strata used in this study is as follows; the Yezo Group (early Aptian – early Campanian: 125 – 75 Ma), the Nemuro Group (Campanian?– early Eocene: 75?– 53 Ma), the Poronai Formation (late Eocene: 42 – 35 Ma) and the Onbetsu Formation (late Eocene – early Oligocene: 34 – 32 Ma). Our integrated stratigraphy enables to identify the exact horizons of following climatic and extinction events. The Cretaceous Oceanic Anoxic Events (OAEs) of the OAE1a (125.5 – 124 Ma), Leenhardt Level of OAE1b (110 Ma), OAE1c (107 Ma), OAE1d (101 Ma), OAE 2(94 – 93.5 Ma) are identified in the Yezo Group exposed in Oyubari and Tomamae areas. Although no so-called black shales were found in these horizons, evidences of oxygen depletion were identified from the most of these horizon based on the analyses of benthic foraminifera, degree of pyritization and sedimentary structure such as degree of bioturbation. The horizons of the K/Pg (66 Ma) and PETM (Paleocene Eocene Thermal Maximum; 56 Ma) in the Nemuro Group and Late Eocene Warming (37 Ma) in the Poronai Formation exhibit no obvious differences in lithology. Especially, the strata across the K/Pg boundary in the Shiranuka Hill consists of massive mudstone and a few intercalations of thin felsic tuff and turbidite sandstone. The middle – late Eocene cooling (40 – 39 Ma) is characterized by abundant occurrences of glendonites and buliminids (benthic foraminifera) in the middle part of the Poronai Formation, which indicates that cooling and eutrophication of surface water occurred in the northwest Pacific. The prominent positive excursion of oxygen isotope around Eocene/Oligocene boundary (34 – 33.6 Ma) is placed at the top of the Urahoro Group. The overlying Onbetsu Formation includes Oi-1a and Oi-1b of early Oligocene. Flood occurrence of buliminids in the lower part of the Onbetsu Formation suggest that surface water eutrophication occurred in response to global cooling after the Oi-1 glaciation.

The horizons of climatic and extinction in Hokkaido have continuous outcrop without significant hiatus and faults. High resolution analyses of these horizons will improve our understanding of climatic and environmental changes in northwest Pacific during the latest greenhouse period.

Keywords: Cretaceous, Paleogene

## Milankovitch forcing and carbon cycle during the Toarcian Oceanic Anoxic event

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One of the most profound environmental changes in the Mesozoic took place during Toarcian (Early Jurassic), including oceanic anoxia (Toarcian Oceanic Anoxic Event; T-OAE). The T-OAE is characterized by negative carbon isotope excursion (CIE) of up to ~8 ‰. The T-OAE is considered to have resulted from the release of CO<sub>2</sub> by Karoo-Ferrar volcanism and possible methane hydrate dissociation. However, the origin of these perturbations remains strongly debated, primarily due to lack of radiometric age constraints across the T-OAE (e.g. Palfy and Smith, 2000; Kemp et al., 2005, 2011; Suan et al., 2008).

Here we present the orbitally-tuned bio-, and  $\delta^{13}\text{C}_{org}$  stratigraphy of the Lower Jurassic deep-sea bedded chert sequence at the Katsuyama-Sakahogi section, in the Inuyama area, central Japan, which covers the T-OAE (Ikeda and Tada, 2013; Ikeda and Hori, in review). The sedimentary rhythms of the bedded chert display a full range of climatic precession related cycles; ~20 kyr cycle as a chert-shale couplet and ~100 kyr, 405 kyr, ~2000 to 4000 kyr cycles as chert bed thickness variations (Ikeda et al., 2010; Ikeda and Tada, 2013). Chert-shale cycles and variations in chert bed thickness are interpreted as resulted from changes in the burial rate of biogenic silica (Hori et al., 1993).

By using 405-kyr eccentricity cycle of constant and stable periodicity (Laskar et al., 2004) observed in the Inuyama bedded chert, we established the astronomical time scale (ATS) by counting 405 kyr cycle (~20 bed cycle; Ikeda and Tada, 2013). Then, this ATS is anchored at the end-Triassic radiolarian extinction level of which age is estimated as  $201.4 \pm 0.2$  Ma based on projection of the U-Pb date measured at the Pucara section, Peru, using the conodont and radiolarian biostratigraphy (e.g. Carter and Hori, 2005; Schoene et al., 2010; Ikeda and Tada, 2013).

This astronomical time scale suggests the absolute ages of the T-OAEs. The timing of two black bedded chert intervals (T-OAEs 1 and 2) and the negative CIE of ~5 ‰ are within the time interval of radiometric ages from the Karoo-Ferrar Lips (Svencen et al., 2007; Jourdan et al., 2008). This result supports the volcanic degassing origin of these carbon cycle perturbations (Palfy and Smith, 2000; Suan et al., 2008).

The termination of black shale deposition occurred at the minimum of 40 kyr obliquity and 100 kyr and 405 kyr eccentricity cycles. These temporal relations imply the possible impacts of these orbital forcing on the stabilization of carbon cycle perturbation through Earth system dynamics, such as weathering and nutrient cycles.

Keywords: Milankovitch cycle, carbon cycle, volcanism, silica cycle, hydrological cycle

## Paleoceanographic evolution of Miocene to Pliocene mud sea in the Ryukyus based on calcareous nannofossil assemblages

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The Cenozoic sedimentary succession in Okinawa-jima, including the upper Miocene to Pleistocene siliciclastic deposits (Shimajiri Group) and the Pleistocene reef to shelf deposits (Ryukyu Group), suggests a drastic paleoceanographic change from a mud sea to a coral sea. To delineate the paleoceanographic evolution of the mud sea, we quantified the stratigraphic distribution of the calcareous nannofossil assemblages from the Shimajiri Group in a 2119.49 m-deep well (Nanjo R1 Exploratory Well) drilled in southern Okinawa-jima (Ryukyu Islands, southwestern Japan). Four late Miocene and Pliocene datum planes were found in the studied interval. The calcareous nannofossil assemblages suggest the existence of oligotrophic conditions between 5.3 and >8.3 Ma followed by eutrophic conditions and a return to oligotrophic conditions at 3.5 Ma. Micropaleontological evidence suggests that these oceanographic changes were likely caused by local tectonic movement (shallowing of the sedimentary basin in which the Shimajiri Group was deposited). We will report calcareous nannofossil records from two exploratory wells drilled in southern Okinawa-jima in 2013 – 2014 as well.

Keywords: calcareous nannofossil, Miocene, Pliocene, Ryukyu Islands

## East Antarctic deglaciation and the link to global cooling since the Pliocene

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Reconstructing past variability of the Antarctic ice sheets is essential to understand their stability and to anticipate their contribution to sea level change as a result of future climate change in a high-CO<sub>2</sub> world. Recent studies have reported a significant decrease in thickness of the East Antarctic Ice Sheet (EAIS) during the last several million years. However, the geographical extent of this decrease and subsequent isostatic rebound remain uncertain and a topic of debate. In this study, we reconstruct magnitude and timing of ice sheet retreat at the Sor Rondane Mountains in Dronning Maud Land, East Antarctica, based on detailed geomorphological survey, cosmogenic exposure dating, and glacial isostatic adjustment modeling. Three distinct deglaciation phases since Pliocene for this sector of the EAIS are identified, based on rock weathering and <sup>10</sup>Be surface exposure data. We estimate that during the Plio-Pleistocene the ice sheet thinned by at least 500 m. This thinning is attributed to the reorganization of Southern Ocean circulation associated with the global cooling into the Pleistocene, which reduced the transport of moisture from the Southern Ocean to the interior of EAIS. The data also show since the Last Glacial Maximum the ice surface has lowered less than ca.50 m and probably started after ca. 14 ka. This suggests that the EAIS in Dronning Maud Land is unlikely to have been a major contributor to postglacial sea-level rise and Meltwater pulse 1A.

## Past 2 Myr Radiolarian Assemblages and Paleoceanographic Changes off the Southwestern Japan (IODP Site C0001)

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The effects of Quaternary paleoceanographic events on the Kuroshio Current off the southwestern Japan, including the mid-Pleistocene Transition (MPT) (1,200?700 ka) and the mid-Brunhes event (MBE) (400?300 ka), are poorly documented at this time because of a lack of long core recovering the MBE and the MPT. In this context, this study aims to establish paleoceanography of this region since the Early Pleistocene, using radiolarian assemblages as paleoceanographical proxy. The Holes C0001E and F, drilled by the R/V Chikyu during IODP Expedition 315 at a depth of 2198 m in the Shikoku Basin off the Kii Peninsula on the slope of the Nankai accretionary prism (southern Japan) are used in this study. The upper 190 m LSF sediments cover the Quaternary based on the shipboard results, the dominant lithology consisted of greenish-gray to grayish-green mud. The age model of Site C0001 is based on calcareous nannofossils datums, planktic foraminifers datums, radiolarians datums and *Globorotalia inflata* oxygen isotope stratigraphy. In this study, 240 samples of 20 cc, covering the Early to Middle Pleistocene, were used for radiolarian faunal analysis. The examination of the polycystine radiolarians was performed using an optical microscope at a magnification of 100?400x. In each sample, 400 to 1000 polycystine radiolarians were identified. The radiolarian-based sea surface temperature (rSST) was estimated using a Modern Analogue Technique (MAT). Several warming event is recorded during the Early Pleistocene. However, the strongest warming event is recorded during the MPT, where the subtropical fauna abundances increased consequently.

Keywords: Pleistocene, Paleoceanography, Mid Pleistocene Transition, Radiolarian



## Sea-ice conditions in the Okhotsk Sea during the last 550 kyr deduced from environmental magnetism

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Reconstructing past sea-ice conditions in the Okhotsk Sea is important because sea-ice conditions vary in response to global climate changes, which in turn may affect global ocean circulation through intermediate water mass formation. We conducted an environmental magnetic study of six cores from three stations in the central Okhotsk Sea to better understand temporal and spatial sea-ice variations. Inter-core correlations and age estimations are based mainly on geomagnetic paleointensity; an oxygen-isotope stratigraphy is available for one station. Magnetic susceptibility (MS) minima are accompanied by maxima in color  $b^*$ , the ratio of the anhysteretic remanent magnetization susceptibility to saturation isothermal remanent magnetization ( $k_{ARM}/SIRM$ ), and the S-ratio, which indicates a higher proportion of biogenic to terrigenous magnetic components. This reflects enhanced ocean productivity. First-order reversal curve diagrams and IRM component analyses support the dominance of biogenic magnetite at MS minima. In contrast, color  $b^*$ ,  $k_{ARM}/SIRM$ , and S-ratio values are low when MS is high, which indicates an increased proportion of the terrigenous component that was probably transported as ice-rafted debris (IRD). For the southern two stations, IRD accumulation increased in glacial and deglacial periods, which implies mobile sea-ice conditions even in full glacials. This was succeeded by extremely enhanced ocean productivity in early interglacials, which suggests nearly ice-free conditions. For the northernmost station, on the other hand, IRD accumulation was low in glacials and increased in early interglacials, which indicates perennial sea-ice coverage with little mobility in glacials. Succeeding ocean-productivity enhancement was delayed compared to the southern stations.

Keywords: Okhotsk Sea, paleoceanography, environmental magnetism, sea ice, IRD

## Pliocene and Pleistocene paleoceanography in the northwestern Pacific and the Bering Sea based on diatom analyses

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Late Pliocene-Pleistocene fossil diatom assemblages from Ocean Drilling Program (ODP) Leg 145 Hole 884B in the western Subarctic North Pacific were investigated and the paleoceanographic records were compared with those at Integrated Ocean Drilling Program (IODP) Expedition 323 Holes U1341B and U1343E in the Bering Sea for an interval of 2.5-0 Ma.

As the results, in Hole 884B, five diatom zones, from the *Neodenticula koizumii*-*N. kamtschatica* Zone to the *N. seminae* Zone, were identified. The cold-water indicators from Hole 884B, which represented high abundances throughout the interval, suggest the cold environmental conditions analogous to the modern sea-surface conditions in the western subarctic Pacific. The drastic decrease of the temperate-water species at ca. 2.2 Ma is related to a rapid cooling event at ~2 Ma. Sporadic appearances of sea-ice related species from ca. 2.3 Ma and a slight increase of neritic species observed at ca. 2.0 Ma may be reflection of a series of the Northern Hemisphere Glaciation (NHG) events. Slightly higher abundances of the sea-ice related species at 1.0-0.8 and 0.4 Ma and those of the neritic species at 2.0, 1.8, 1.2, and 0.9 Ma are likely to correspond to the southward advance of the subarctic front and drop in sea-surface temperature mentioned by Sancetta and Silvestri (1986).

The age differences of the distinct decreases of temperate-water species recognized at ca. 1.9 Ma for Hole U1343E, ca. 2.1 Ma for Hole U1341B and ca. 2.2 Ma for Hole 884B indicate that the East Kamchatka Current in the Western Subarctic Gyre was strengthened and the westward advection of the Alaskan Stream was weakened at ca. 2.2 Ma. In the Bering Sea, the limited input of temperate waters via the Near Strait resulted as a decrease of warm water supply to the region around Site U1341 at ca. 2.1 Ma, while the eastern Bering slope region had been still affected by the warm water masses advected from the Amchitka and Amukta Passes. Further global cooling might have restricted the continuous warm water supply to the Bering slope region around Site U1343 at ca. 1.9 Ma.

Keywords: diatom, paleoceanography, subarctic Pacific, Bering Sea, IODP Expedition 323, ODP Leg 145

## Millennial-scale rock-magnetic variation indicating instability of North Atlantic environments during MIS 100

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Ocean thermohaline circulation (THC) plays an important role in global climate change linked with continental ice sheets. To clarify the variation of ocean THC in the early stage of glaciations in the northern hemisphere, we studied a deep-sea sediment core with high sedimentation rate recovered at IODP Site U1314 in the North Atlantic. Rock magnetic study of the sediments during marine oxygen isotope stage (MIS) 100 indicated links between the millennial-scale variability in deep water circulation and iceberg discharge. The observed abrupt decreases of magnetic coercivity associated with ice-rafted debris (IRD) are interpreted to be reduced transport of high-coercivity material from Icelandic source indicating reduced formation of North Atlantic Deep Water (NADW). In these periods, a current from the south, Lower Deep Water, transports sediments with low magnetic coercivity contributed by coarse grained magnetite of continental sources. Repetition of vigorous and weakened NADW production linked to IRD was observed during MIS 100 in a similar manner to that in the last glacial suggests that the regime of climate change in the millennial-scale was already established in the early stage of glaciations in the northern hemisphere.

Keywords: rock magnetism, thermohaline circulation, North Atlantic Deep Water, Ice rafted debris

## Paleoceanographic reconstruction of the Holocene Arctic Chukchi Sea using fossil diatoms

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The Chukchi Sea, in the Arctic Ocean, receives the warm outflowing waters of the Bering Sea. These waters are one of the causes of Arctic sea ice decline, and change their flow according to the sea ice distribution in the Chukchi Sea. Sea ice in the global climate system has a significant impact on the global environment (e.g., atmospheric circulation, biological production and ocean circulation), due to the albedo effect, maintenance of low temperatures, and high salinity bottom waters. Therefore, the reconstruction of the past sea ice history of the Chukchi Sea is important in understanding the climate system of the Arctic Ocean as well as the global climate system. However, piston cores previously obtained from the Chukchi Sea were too short and/or contained few or no microfossils, making detailed paleoenvironmental analyses and age determinations difficult.

I started working on the diatom analysis of sediment cores taken during the HLY0501 cruise of the United States Coast Guard icebreaker cutter "Healy" in 2005. They took 8 sediment cores, although diatoms were not obtained at six of the sites. So here I show the diatom analysis results from the remaining two cores (cores 5 and 8).

Keywords: Chukchi Sea, Diatom, Holocene

## Thermal threshold of the Atlantic meridional overturning circulation as a trigger for glacial abrupt climate changes

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Abrupt climate changes known as Dansgaard-Oeschger events (DO events) took place frequently during glacial climate. Geological evidences support the idea that changes of the Atlantic meridional overturning circulation (AMOC) are related to these events, but question on what triggers the AMOC changes remains unsolved. Although most studies have regarded freshwater flux from melting ice sheet as a cause of the AMOC changes, we recently identified the existence of the thermal threshold of the AMOC during glacial climate. Here, from the results of numerical simulations about the glacial AMOC, we report that the thermal threshold of the AMOC serves as a triggering mechanism of DO events. We investigated the structure of the thermal threshold in glacial climate by conducting ocean general circulation model simulations under various thermal conditions in which degrees of sea surface cooling are systematically changed separately or simultaneously in northern and southern hemispheres. The results suggest that the threshold is located near the condition under which the climate is slightly warmer than the coldest glacial conditions. We also found that the amplitude of AMOC changes in crossing the threshold depends on thermal conditions in northern and southern hemispheres. The most prominent threshold is identified where the southern hemisphere is somewhat warmer than the coldest glacial conditions. It is also demonstrated that gradual warming in the southern hemisphere from the colder glacial climate leads to crossing this threshold and can cause significant strengthening of AMOC. Our results indicate that the thermal threshold could be a triggering mechanism of DO events, especially for those accompanying the gradual warming of southern hemisphere before their abrupt warming in northern hemisphere.

## Role of Southern Ocean stratification in glacial atmospheric CO<sub>2</sub> reduction

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The global temperatures and atmospheric carbon dioxide (pCO<sub>2</sub>) concentrations varied during the last 800 thousand years. During the glacial times, such as Last Glacial Maximum (LGM), the atmospheric partial pressure of carbon dioxide (pCO<sub>2</sub>) was about 80-100ppmv lower than interglacial times, such as Holocene. Compared to interglacial conditions, terrestrial carbon stocks were reduced during glacial conditions. Marine carbon cycles must have been the main driver for lowering atmospheric pCO<sub>2</sub> during ice ages. A number of candidate mechanisms to explain the reduction in glacial atmospheric pCO<sub>2</sub> have been proposed. However, they failed to explain full amplitude of 80-100ppmv reduction. Based on paleo-proxy reconstructions,  $\delta^{13}\text{C}$  gradient between surface and deep ocean was larger than today, suggesting that the glacial ocean circulation state was different from today. In the deep glacial Southern Ocean, very saline water was identified from paleo proxy data. Moreover, radiocarbon record showed the existence of radiocarbon-depleted old waters in glacial ages. One hypothesis that has been proposed to explain the glacial atmospheric pCO<sub>2</sub> is the isolated reservoir hypothesis: a carbon-rich, radiocarbon-depleted water mass was isolated from the atmosphere during the glacial periods. The stratification of the Southern Ocean water column may have contributed to a reduction of atmospheric pCO<sub>2</sub>.

In this study preindustrial and LGM marine carbon cycle sensitivity experiments are conducted to estimate a role of stratification in glacial Southern Ocean quantitatively, by using an ocean general circulation model (OGCM). In the control case, atmospheric pCO<sub>2</sub> between Modern case and LGM case is about 44ppmv, which was comparable to previous AOGCM study. However, LGM case cannot explain the saline glacial Southern Ocean.

Previous study using intermediate complexity models suggested that glacial atmospheric pCO<sub>2</sub> and  $\delta^{13}\text{C}$  distribution can be reproduced by considering brine induced stratification.

Therefore, we also consider the effect of brine induced stratification. We partly succeeded in reproducing the saline glacial South Atlantic Ocean by imposing body forcing near the bottom in the Weddell Sea, Ross Sea and Eastern Antarctica, whereas saline glacial Southern Ocean resulted in increased northward flow of AABW and increased atmospheric pCO<sub>2</sub>. Additionally, we used stratification-dependent vertical eddy diffusivity parameterization suggested by Gargett (1984) to discuss changes in vertical eddy diffusivity in Southern Ocean. Contrary to our expectation, vertical eddy diffusivity in high latitude becomes very higher under glacial conditions, and sequestered carbon in deep ocean was released into the atmosphere and resulted in higher atmospheric pCO<sub>2</sub>.

Finally, very stratified Southern Ocean achieved by extremely small vertical eddy diffusivity also cannot reduce glacial atmospheric pCO<sub>2</sub>. Other processes, which are not taken into account in our study may be important to reproduce the glacial condition.

Keywords: ocean carbon cycle, Last Glacial Maximum, Southern Ocean, Ocean general circulation model