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学位の種類	博士(理学)
学位記番号	理博第2143号
学位授与年月日	平成16年9月22日
学位授与の要件	学位規則第4条第1項該当
研究科, 専攻	東北大学大学院理学研究科(博士課程)地学専攻
学位論文題目	A Coral-based Reconstruction of Paleoceanographic Changes in the Western Pacific for the Last 2 Centuries (サンゴ骨格に基づく過去200年間の西太平洋海洋環境変動復元)
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論文目次

論文内容要旨

Tropical ocean-atmosphere interactions play a significant role in global climate changes on interannual and decadal timescales. Knowledge of past climate and ocean variability is crucial for understanding and modeling current and future climate trends. There are gridded SST products that go back to 1870 or so but the spatial and temporal instrumental climate records from the tropics, especially continuous time series before 1950, are scarce and limited. Thus there is a strong need for high-fidelity paleoclimate proxies that overlap with, and extend beyond the instrumental records such as those derived from corals [e.g., Cole *et al.*, 1993; Quinn *et al.*, 1998], tree rings [e.g., Briffa *et al.*, 1998; Mann *et al.*, 1998], and ice cores [e.g., Tompson, 1986; Langway *et al.*, 1995].

A massive hermatypic coral is a useful paleoclimatic and paleoceanographic recorder because it commonly lives in shallow tropical to subtropical oceans, grows at a rapid rate (up to 2cm/year), and contains a remarkable array of geochemical tracers within its skeleton such as carbon and oxygen isotopic composition and element/Ca ratios. In particular, oxygen isotopic composition of a coral skeleton ($\delta^{18}O_{coral}$) is a powerful tool for reconstructing past thermal and hydrologic variations in sea surface conditions [e.g., Cole and Fairbanks, 1990; Tudhope *et al.*, 1995; Wellington *et al.*, 1996] because $\delta^{18}O_{coral}$ variations are a function of both sea surface temperature (SST) and $\delta^{18}O$ composition of seawater ($\delta^{18}O_{seawater}$), the latter of which is commonly related to salinity [e.g., Weber and Woodhead, 1972; McConnaughey, 1989]. In regions where the $\delta^{18}O_{seawater}$ is fairly constant and/or seasonal variation in SST is large, the $\delta^{18}O_{coral}$ can be used as a paleothermometer (e.g., Dunbar *et al.*, 1994; Wellington *et al.*, 1996; Charles *et al.*, 1997). Conversely, in localities where there is little variation in SST, the $\delta^{18}O_{coral}$ can be used to reconstruct sea surface salinity (SSS) and $\delta^{18}O_{seawater}$ variations, which are related to changes in the $\delta^{18}O$ of rainfall (e.g., Cole and Fairbanks, 1990; Linsley *et al.*, 1994; Tudhope *et al.*, 1995) and in evaporation/precipitation ratios. Element/Ca ratios of coral skeletons have also been used to estimate various environmental signals such as SST (Sr/Ca: Beck *et al.*, 1992; Alibert and McCulloch, 1997; and Mg/Ca: Mitsuguchi *et al.*, 1996) and nutrient levels (Cd/Ca, Ba/Ca and Mn/Ca: Shen *et al.*, 1987, 1991, 1992; Lea *et al.*, 1989). A multi-proxy approach that combines Sr/Ca and Mg/Ca ratios and $\delta^{18}O_{coral}$ allows separation and identification of the specific thermal and hydrologic variations at the site of coral growth.

Long-lived corals have provided continuous time series of environmental variations in sea surface conditions over the past several centuries in many tropical regions, relating to changes in the state of El Niño/Southern Oscillation (ENSO), interdecadal linkages between Indian and Pacific Ocean, movement of the Inter-Tropical Convergence Zone (ITCZ), the South Pacific Convergence Zone (SPCZ) and the Western Pacific Warm Pool (WPWP), and the climatic effects of volcanic eruptions (see reviews of Gagan *et al.* [2000] and Quinn and Tudhope [2002]). However, most of the investigations using more than centennial or bicentennial coral records have been conducted in the regions of the eastern to central Pacific and equatorial to south western Pacific; there are no published long coral records in the northwestern equatorial Pacific. The WPWP, characterized by having a mean annual SST of > 28℃, is a major source of water vapor to the atmosphere and has a significant influence on the global climatic system dynamically linked with ENSO variability. Reliable proxy climate records from corals in the western Pacific may provide insights into the past oceanographic changes associated with ENSO. Therefore, lying at the northern edge of the WPWP, Guam (13° N, 145° E) should be a significant location for paleoceanographic and paleoclimatic studies using coral records.

This paper is composed of two main investigations, "Carbon and oxygen isotopic composition of a Guam coral and their relationships to environmental variables in the western Pacific (chapter 2)" and "Interannual and decadal variability of the western Pacific sea surface condition for the years 1787-2000: Reconstruction based on stable isotope record from a Guam coral (chapter 3)". Chapter 2 documents a detailed analysis of stable isotopic records of a Guam coral skeleton for the last 20 years (1980-2000) and the resultant significant relationships between isotopic data and instrumental records of environmental variables. In chapter 3, monthly carbon and oxygen isotope time series of a Guam coral are analyzed over the full length of the coral core (the years 1787-2000) and significant thermal and hydrologic changes are reconstructed in the northwestern equatorial Pacific over the last two centuries based on the quantitative relationships between coral records and environmental variables for the years 1980-2000.

Carbon and oxygen isotopic composition of a Guam coral and their relationships to environmental

variables in the western Pacific

This study documents the high-resolution (~32 samples/yr: weekly to monthly resolution) $\delta^{13}C_{coral}$ and $\delta^{18}O_{coral}$ in a coral core (*Porites lobata*) from Double Reef, Guam over the years 1980-2000. The $\delta^{13}C_{coral}$ shows clear seasonal variations with mean seasonal amplitude of 1.89‰, which roughly corresponds with seasonal variations in solar radiation. The seasonal amplitude of $\delta^{18}O_{coral}$ variations is small (0.23-0.57‰), but they are significantly correlated with SST and SSS. The $\delta^{18}O_{coral}$ and SST are more strongly correlated during ENSO warm (El Niño) phases (r = -0.81, $p < 0.01$) than during non-ENSO phases (r = -0.65, $p < 0.01$) and ENSO cool (La Niña) phases (r = -0.48, $p < 0.01$). These different relationships are due to differences in winter SST and in $\delta^{18}O_{seawater}$ during ENSO warm phases (<27℃ and higher values of $\delta^{18}O_{seawater}$) compared with cool phases (>28℃ and lower values of $\delta^{18}O_{seawater}$) at Guam. These differences in oceanic parameters result from movements of the WPWP during the different phases of ENSO. Anomalies in $\delta^{18}O_{seawater}$, inferred from the $\delta^{18}O_{coral}$ and instrumental SST, are consistent with SSS anomalies for the years 1980-2000. These $\delta^{18}O_{seawater}$ anomalies may reflect changes in SSS and evaporation-precipitation due to movements of the WPWP. This detail analysis of a coral from Guam suggests that it may contain an excellent archive of past ENSO events.

Interannual and decadal variability of the western Pacific sea surface condition for the years 1787-2000: Reconstruction based on stable isotope record from a Guam coral

This study presents a monthly resolved, 213-year stable isotope time series (Fig. 1) from a coral from Guam, which is located on the northern edge of the WPWP. The $\delta^{18}O_{coral}$ show seasonal, interannual, and decadal variability, which documents significant oceanographic changes related to thermal and hydrologic variations around Guam. The $\delta^{18}O_{coral}$ anomaly reflects SST anomaly and SSS anomaly with significant r values of -0.69 (for the years 1951-2000) and 0.49 (for the years 1969-1995), respectively, which are strongly linked to oceanographic changes that occur during ENSO warm and cool phases. I identified 46 ENSO warm and 53 cool phases in the coral record, which are consistent with those phases reconstructed by Niño 3.4 SST anomaly. Spectral analyses of the $\delta^{18}O_{coral}$ anomaly record for the years 1790-1999 identified significant peaks around~3 to~7 years. These results indicate that the Guam coral has recorded global ENSO periodicity. The $\delta^{18}O_{coral}$ anomaly shows decadal variability of~15- to~45-year periodicity with significant shift (<0.2‰) from warmer to cooler condition and vice versa, which may correspond to Pacific Decadal Oscillation (PDO) and/or the climatic regime shifts. An accumulative decrease in $\delta^{18}O_{coral}$ time series may imply~0.75℃ warming of SST and/or~0.23‰ freshening of seawater $\delta^{18}O$, corresponding to a decrease of salinity by~0.85, in the northwestern equatorial Pacific over the last 2 centuries.

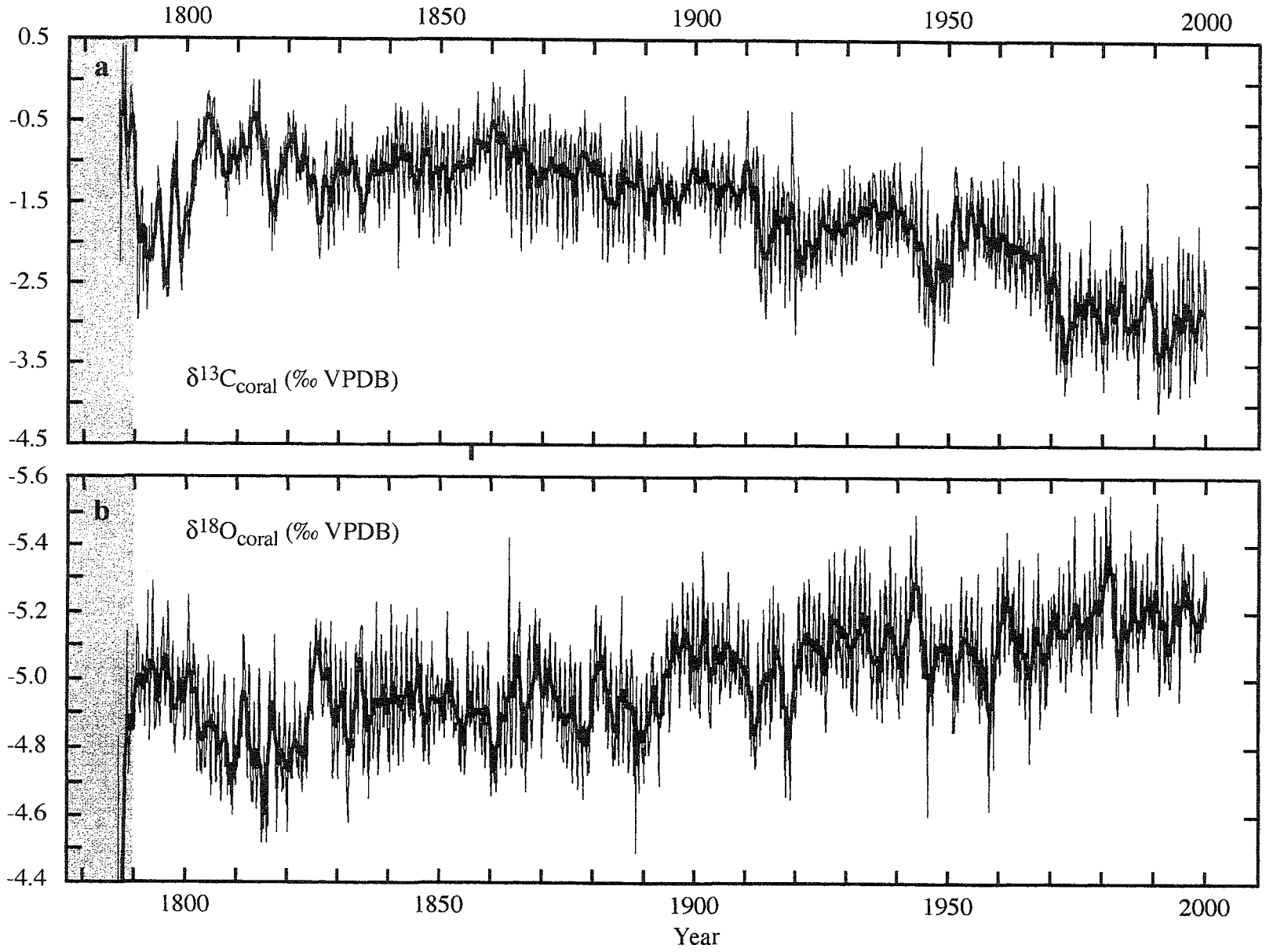

Fig. 1. Monthly time series profiles of carbon (a) and oxygen (b) isotopes for the years 1787-2000. The bold line represents the smoothed variations in stable isotopes with a 13-month moving average window.

論文審査の結果の要旨

浅海竜司君は，本学理学研究科地学専攻博士課程後期において，グアム島の造礁サンゴ骨格のコア試料を用いて西太平洋域の海洋環境変動の復元に関する研究に取り組み，その成果を博士論文として提出した。

まず彼は，1980年以降の骨格の$\delta^{13}C$，$\delta^{18}O$（$\delta^{18}Oc$）を高分解能で測定し，環境データとの関係を解析して次の成果を得た。$\delta^{18}Oc$は海水の酸素同位体比（$\delta^{18}Ow$，塩分と相関）と水温の両方の変化を反映し，エルニーニョ（EN）期とラニーニャ（LN）期における$\delta^{18}Oc$と水温の相関関係には，西太平洋暖水塊（WPWP）の移動に伴う水温年較差の違いに起因した差異が認められる。また，$\delta^{18}Ow$は両時期とも重くなる傾向を示す。これは，EN期には相対的に冷たい水塊の影響を受け，一方，LN期の夏季には蒸発量/降水量比が増加することに起因する。

次いで彼は，1980年以前の骨格の同位体比を月分解能で測定し，$\delta^{18}Oc$から過去213年間の水温と塩分の両変化を示す時系列データを復元した。このデータについて統計解析を行い，ENSOに伴うWPWPの移動によってグアム周辺海域に水温・塩分の偏差が生じ，$\delta^{18}Oc$はEN期に水温との相関が強く，LN期には塩分との相関が強くなることを示した。また，Niño3.4の水温との比較検討から，このサンゴには1787～2000年にENが46回，LNが53回記録されていることを見出した。$\delta^{18}Oc$の周期解析からは，ENSOに対応する3～7年周期と太平洋十数年～数十年変動や気候レジームシフトに呼応した15～45年周期が検出された。$\delta^{18}Oc$の長期変動の傾向は，1787年以降，水温は約0.75℃上昇し，$\delta^{18}Ow$は約0.23‰低下している可能性を示唆する。従来，古海洋データの空白域であるこの海域から過去数百年間の海洋環境変動を復元した例はない。彼は，200年以上の水温・塩分の変化を高分解能で抽出して海洋環境変動を復元し，地球科学の諸分野に新たな知見をもたらした。

上記の成果は，大量のデータと信頼性の高い測定・解析の上に成立していると評価でき，一部は国際誌に受理されている。これらは，浅海竜司君が自立して研究活動を行うのに必要な高度の研究能力と学識を有することを示す。よって，浅海竜司君提出の論文は，博士（理学）の学位論文として合格と認める。