博士論文

Water Mass Characterization in the Okinawa Trough Based on Physical Properties and Isotopic Compositions

（物理特性と同位体組成に基づく沖縄トラフの水塊のキャラクタリゼーション）

Cruz Salmerón Andros Daniel

令和 4 年

博士論文要約

This work aims to characterize the Nd isotope composition (ε_{Nd} = $^{143}Nd/^{144}Nd$ ratios) of the Kuroshio Current (KC) from the southern Okinawa Trough (SOT) to the central Okinawa Trough (COT) to provide information that serves as a proxy to trace changes in the Kuroshio Current flow in the Okinawa Trough (OT) since the late Cenozoic.

Southern Okinawa Trough

The KC enters the East China Sea (ECS) through the strait between Taiwan and Yonaguni Jima Island. It flows bordering the ECS shelf, along the OT. Nevertheless, the KC meandering increases from time to time according to different temporal conditions i.e., eddies. The ECS is influenced by multiple sources of Nd. The primary sources are the Philippine Sea (PS) (ε_{Nd} –4.4 to –2.0); the South China Sea (SCS) (ε_{Nd} = –4.5 in deep water to –3.6 in subsurface water, with a surface-water ε_{Nd} value of –4.5. Many rivers in China flow into the ECS, with the most significant influence being from the Changjiang (ε_{Nd} = –11.6), Yellow (ε_{Nd} = –13.9 to –9.6), and Yangtze (ε_{Nd} = –14.3 to –8.7) rivers (Meng et al. 2008; Dou et al. 2012). The OT is also influenced by rivers in Taiwan (ε_{Nd} = –11.1; Lan et al. 2002). In this chapter, we analyzed Nd, H and O isotope compositions for the OT side and Pacific side of the South Ryukyu Islands and report our results according to three subareas: Yonaguni, Iriomote and Ishigaki. The ε_{Nd} composition of 42 surface sediment samples was analyzed along with 189 Hydrogen (δD) and Oxygen ($\delta^{18}O$) compositions of seawater samples, with a depth range from 68 to 2620 m.

OT side

Nd isotopes

The ε_{Nd} values show a range from –8.2 to –2.2. Moreover, the general trend shows an eastward increase at < 300 m depth in the Iriomote and Ishigaki subareas, central water and upper intermediate water show a wide range of ε_{Nd} values (–5.9 to –2.8) at 300–600 m depth and almost constant ε_{Nd} values between –5.9 and –4.8 at > 600 m depth. Two low ε_{Nd} values of –7.6 and –8.2 were recorded in the Yonaguni OT at depths of 848 and 1026 m, respectively, suggesting the presence of an external Nd source such as sediment plumes and turbidites. Below intermediate water, the ε_{Nd} compositions remain almost around –5.0 suggesting the presence of only one water mass.

Hydrogen and Oxygen isotopes

The δD values show similar depth trends for the three subareas, nevertheless the Ishigaki OT, showed higher values at 250–500 m depth. δD values of up to 4.9‰ were recorded at 117–388 m depth, decreasing steadily to a minimum value of –1.0‰ at 1093 m depth. The average δD values were almost constant at greater depths, with one outlier of >1.3‰ at 1800 m depth. The $\delta^{18}O$ values of seawater show similar depth trends in the three subareas. The highest values of up to 0.7‰ were recorded at > 298 m depth. Values decreased to–0.2‰ at 760 m depth, remaining around ~0.0‰ at greater depths. One outlier of 0.3‰ was recorded at 1800 m.

The δD–$\delta^{18}O$ cross-plots for from < 433 m depth suggest that the lower intercept of the Yonaguni subarea may result from the influence of freshwater inputs. The relationships of the three subareas are different from surface to bottom waters, suggesting different circulation patterns likely because of the abrupt bathymetry and upwellings within the OT.

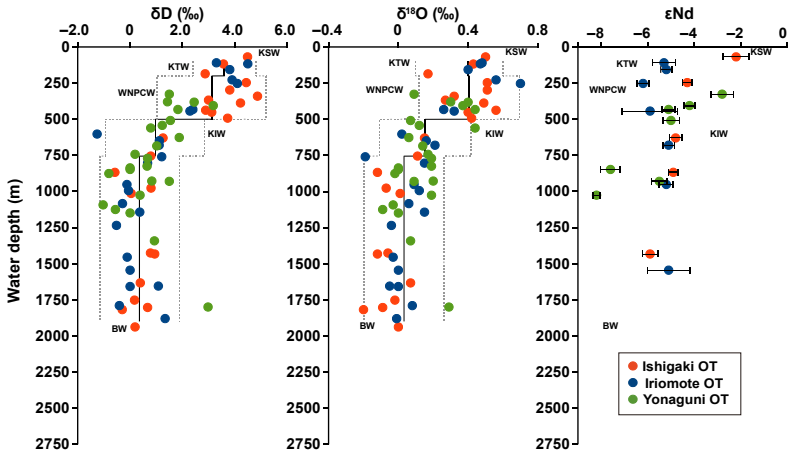

Fig. 1. H (left), O (middle) and Nd (right) isotope compositions of Yonaguni (green), Iriomote (blue) and Ishigaki (orange) subareas of the OT side. Dashed grey lines represent ± 2σ values of H and O isotope compositions. Values outside this range are considered outliers. Solid line represents the average. ε_{Nd} compositions are presented with error bars (2σ, black lines)

Pacific side

Nd isotopes

The Pacific side showed ε_{Nd} values from –7.0 to –1.0. The ε_{Nd} profiles of the three subareas show similar values and trends from surface to deeper waters, with ε_{Nd} values of –2.8 to –1.1 above 157 m depth and one outlier of –4.1 at 125 m at Iriomote Pacific. The ε_{Nd} values decreased to –5.5 at 656 m depth, with an outlier of –7.0 at 497 m at Yonaguni Pacific. Below this depth the ε_{Nd} increased to –4.0 at 1239 m depth. A value of –5.3 to was measured at 2264 m depth at the Iriomote Pacific.

Hydrogen and Oxygen isotopes

The δD of the Pacific side is similar at the three subareas. The highest values of up to 5.3‰ are recorded above 380 m depth. The lowest composition of –0.7‰ was found at 976 m depth and increased to 1.8‰ at 2128 m depth. One value of –0.8‰ was measured at 2620 m depth. The $\delta^{18}O$ profiles show similar behavior to that of the δD for the three subareas. $\delta^{18}O$ values were high above 285 m depth (up to 0.7‰) and low (–0.2‰) at 726–976 m depth. Finally increased to 0.2‰ at >1239 m depth.

The δD–$\delta^{18}O$ cross-plots for from surface to bottom waters of the three subarea shows almost identical slopes and intercepts. This suggests very similar oceanographic conditions between the three subareas.

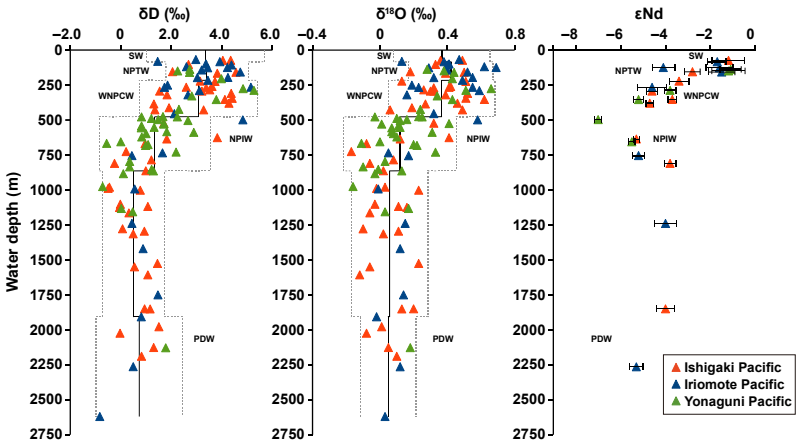

Fig. 2. H (left), O (middle) and Nd (right) isotope compositions of Yonaguni (green), Iriomote (blue) and Ishigaki (orange) subareas of the OT side. Dashed grey lines represent ± 2σ values of H and O isotope compositions. Values outside this range are considered outliers. Solid line represents the average. ε_{Nd} compositions are presented with error bars (2σ, black lines)

Summary

The Nd isotope composition in the OT side is controlled in different ways according to different layers. Surface-subsurface waters are mostly affected by temporal variations, such as rainy season, typhoons, freshwater inputs and eddies. These phenomena strongly affect the KC pathway and therefore the particle distribution within the OT. The intermediate water domain is strongly affected by sediment plumes and turbidites.

Central Okinawa Trough

Studying the Nd isotope composition of sediments around Okinawa Island is very important, since IT divides the Pacific Ocean from the OT and it is located to the north of the Kerama Gap (KG), which connects the Pacific Ocean and the OT in the Central Ryukyu Islands. The PS water flows into the OT is constant almost all the year

at the intermediate layer (below 500 m depth), whereas surface-subsurface waters inflow-outflow are very dynamic and closely related to KC fluctuations. Identifying the Nd compositions from both OT and Pacific sides and within the KG it is crucial to understanding the long-term circulation around this channel. 48 recent sea surface sediment samples were dredged from Ishigaki Island to Amami Island from a depth range between 56 to 2679 m. Moreover, the $\delta^{18}O$ composition measured during previous cruises was analyzed and correlated with the salinity and temperature of seawater in order to identify freshwater inputs and water mass mixing.

Nd isotopes

The ε_{Nd} composition of bulk benthic foraminifers revealed similar compositions at both OT and Pacific sides, with values between ε_{Nd} = –7.3 to –2.2. The lowest compositions are predominantly present at 0-220 m depth (ε_{Nd} = –7.3 to –5.1). A second group showed values between ε_{Nd} = –6.8 to –3.6 at 220-577 m depth. A third group of samples that are distributed below at intermediate depths (692-1294 m depth) shows ε_{Nd} = –4.8 to –2.3, except for one value of –5.5.

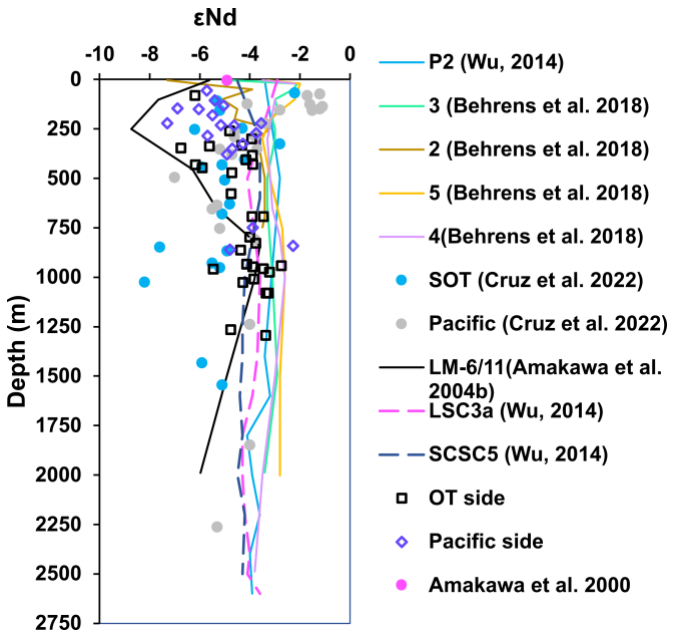

Fig. 3. ε_{Nd} profiles in the central OT. Purple empty rhombuses and black empty squares correspond to the Pacific and OT sides of this study. Previous ε_{Nd} reported from the Philippine Sea and South China Sea are also shown (Amakawa et al. 2004b; Wu, 2014; Behrens et al. 2018).

Oxygen isotopes and physical properties of seawater correlation

The $\delta^{18}O$ values recorded from different cruise excursions GH08, GH09, and GH10, show considerable differences through the water column and are lower on the OT side than on the Pacific side. Surface water, 0 m depth, shows $\delta^{18}O$ = –0.1 to –0.2. From 50-90 m depth, the OT-GH09 shows values from –0.1 to 0.0 ‰ whereas the OT-GH10 composition is ~ 0.1 ‰. In the Pacific side, the P-GH08 shows values of 0.2-0.3 ‰, whereas the P-GH10 shows values of ~0.1 ‰. The highest $\delta^{18}O$ values can be found between 100-213 m depth. The OT-GH09 shows values of 0.0 ‰ whereas the OT-GH10 of ~0.2 ‰. In the Pacific side, the P-GH10 shows values of ~0.2 ‰ whereas the P-GH08 shows values of 0.3-0.4 ‰. The values decrease at 564-760 m depth. In the OT side, the OT-GH09 shows –0.2 ‰, OT-GH10 shows values between –0.2 to –0.0 ‰. In the Pacific side the P-GH10 shows compositions between –0.1 to 0.0 ‰. Below 900 m depth, data reported by the OT-GH09 has $\delta^{18}O$ values of –0.4 to –0.3.

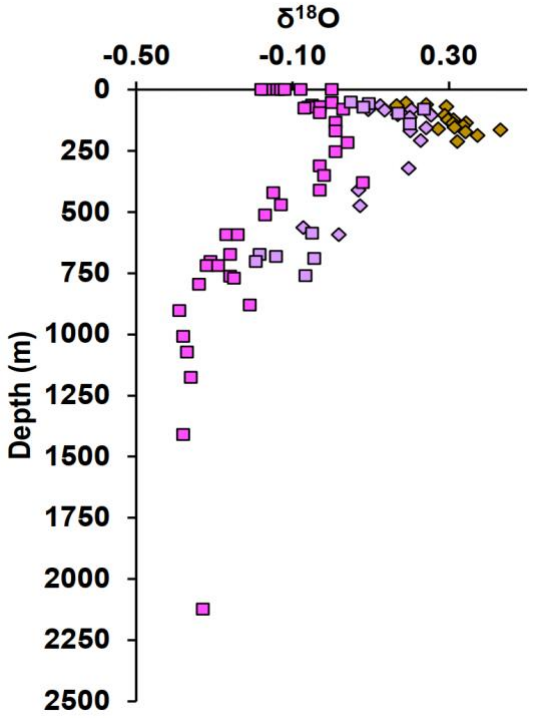

Fig. 4. $\delta^{18}O$ measured during the cruises GH08 (Pacific side, brown rhombuses), GH09 (magenta squares, OT side) and GH10 (pink squares, OT side; pink rhombuses, Pacific side)

Differences in $\delta^{18}O$ between the several cruises suggest that the seawater composition changes accordingly to the different seasons. Although the location may play an important role, the cruise GH10 measured $\delta^{18}O$ from both OT and Pacific sides. The results displayed similar composition; therefore, location does not account for the $\delta^{18}O$ variations. Moreover, the salinity-$\delta^{18}O$ correlation showed different trends according to the presence of

different water masses distributed along the water column. These suggest that this correlation must be used carefully when using $\delta^{18}O$ as a proxy for reconstructing temperatures and salinities.

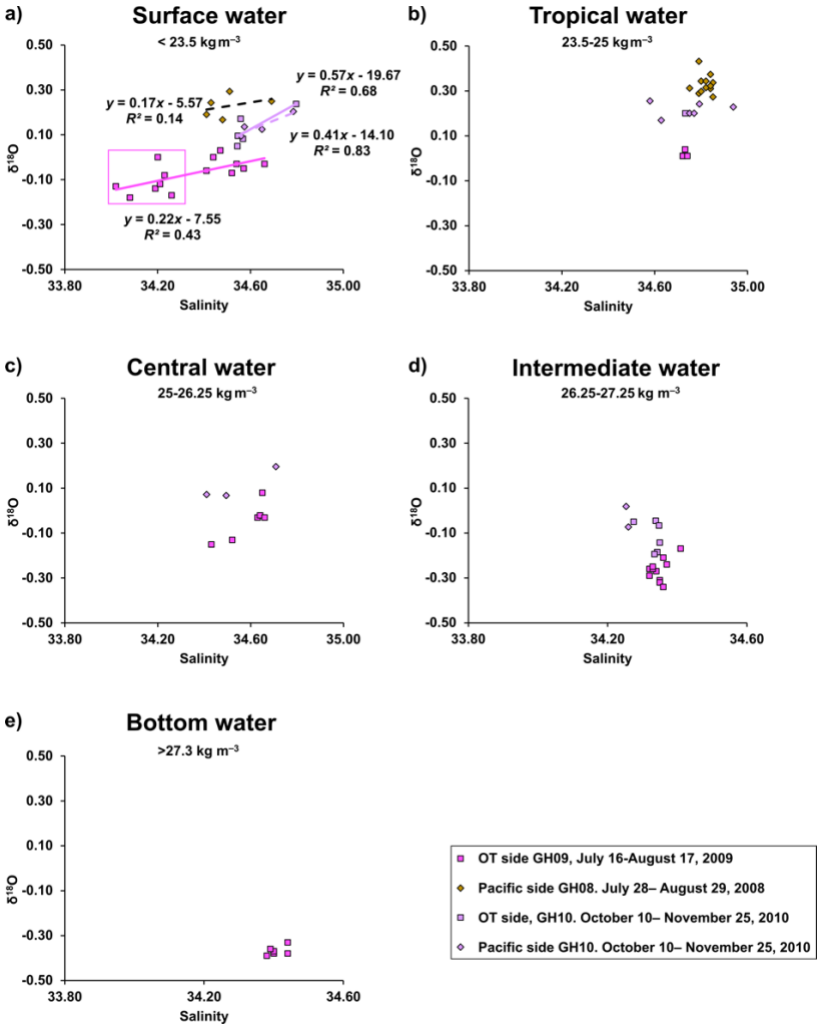

Fig. 5. Salinity-δ O relationship from around Okinawa Island. Cruises GH08, GH09, GH10. Results are separated and shown according to the different potential densities representative of different water masses

Summary

The Nd isotope composition of both OT and Pacific sides showed similar compositions along the water column. This suggests that in the long-term, waters mix horizontally and homogenize the ε_{Nd} values. This is likely because in the KG, the water inflow-outflow may be different in different areas. Surface water is strongly affected by cyclonic and anticyclonic eddies, which are likely to carry water and sediments from the ECS shelf to the limit of Okinawa Island. The ε_{Nd} compositions of the KC decrease from the southern OT to the central OT, revealing constant and strong continental inputs charged with low the ε_{Nd}. Moreover, the ε_{Nd} values of intermediate water around the central OT, fall in between those of the South China Sea intermediate Water and North Pacific Intermediate Water, suggesting that the Kuroshio Intermediate Water results from the mix of these two water masses.