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Watermass properties and deep currents in the northern Yap Trench observed by the Submersible Jiaolong system

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A R T I C L E I N F O

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A B S T R A C T

According to the field experiment implemented by the cruise with the observation by Submersible Jiaolong in No. 37 and 38 Cruise of China Ocean Mineral Resources R&D Association, detailed investigations about northern Yap Trench, including the water properties, bottom currents, turbulent mixing were presented. The deep watermass properties indicate that the deep water originates from East Mariana Basin (EMB) and East Caroline Basin (ECB), as part of the west propagating Lower Circumpolar Deep Water (LCPW). The volume transport results further prove it. The variability of salinity, potential temperature presents semidiurnal variations. The isothermal level variations indicate the existence of semidiurnal internal tide. The phase of salinity lags about 12 h than that of potential temperature. The salinity serves as the compensation on the isopycnal. The bottom currents mainly consist of the low frequency motions, near inertial motions, semidiurnal and diurnal motions. The strong semidiurnal motions derived by Lanczos band-pass filter and reconstructed current indicate the existence of internal tide in the western side of Yap Trench. Enhanced turbulent mixing is observed at the central part and slope of the northern Yap Trench, and weakens the stratification. The strong mixing seems to be caused by internal tides dissipation. Though mesoscale eddies are active around the Yap Trench, the bottom currents are not directly associated with mesoscale eddies.

1. Introduction

The Yap Trench is located at the southern margin of the Philippine Sea Plate, as one segment of the continuous system of arcuate trenches which include the IzuBonin, Mariana, Yap and Palau trenches (Sato et al., 1997), with the maximum depth exceeding 8000 m in the central basin and a total length of near 700 km (Fujioka et al., 2002). It made a link between the Palau and Mariana Trenches (Kobayashi, 2004).

Previous researches mainly focused on morphology and tectonics of the Yap Trench (Sato et al., 1997; Fujiwara et al., 2000; Fujioka et al., 2002; Kobayashi, 2004), however, due to the lack of observations, no hydrodynamic researches were implemented in the Yap Trench.

In the 1960s, Stommel and Arons (1959a, 1959b) presented their basic theory of large-scale deep circulation in their simplified model with deep western boundary current driven by source-sink of global ocean and upwelling over flat bottom. However, researches showed that the variable upwelling and bathymetric features were essential in deep circulation (Siedler et al., 2004). The relatively cold and saline deep waters in the western Pacific Ocean were essential components of the global thermohaline circulation. The west boundary region of Pacific Ocean was characterized by a series of deep trenches, which made the deep circulation there abstruse (Fujiwara et al., 2000). Several studies have shown that the deep water in western Pacific Ocean was mainly influenced by the overlying Antarctic Intermediate Water, the North Pacific Deep Water and the Lower Circumpolar Deep Water (LCPW) (Johnson and Toole, 1993; Reid, 1997; Kawabe and Taira, 1998). They suggested the inflow of LCPW into the East Mariana Basin (EMB) and a partial outflow to the West Mariana Basin. Siedler et al. (2004) modified the flow pattern of LCPW in the southern EMB and found the channels at the Yap Marian Junction and Caroline Ridge were essential for the exchange of deep watermass, such as the flow from EMB to ECB (East Caroline Basin). However, the deep circulation in the Yap Trench, which is an important part of the global thermohaline circulation, remains unrevealed.

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As the first deep-sea manned submersible in China, the Submersible Jiaolong was built in 2007 (Liu et al., 2010) and has made hundreds of deep dives in the northwestern Pacific, southwestern Indian Ocean and Atlantic for multidisciplinary explorations such as marine geology, biology, chemistry and physical oceanography (Li, 2017). Furthermore, the Submersible Jiaolong is capable of presenting a series of high precision observations for scientific researches. As part of the researches implemented in deep trenches by No. 37 Cruise of China Ocean Mineral Resources R&D Association, this study attempts to quantitatively describe the bottom current and water properties in the northern Yap Trench with observations of the Submersible Jiaolong system obtained by conductivity-temperature-depth (CTD) sensor system, RINKO dissolved oxygen sensors, recording current meter (RCM).

The configuration of submersible Jiaolong can be referred from Liu et al. (2010). The CTD system equipped in the 'Sampling basket' in submersible Jiaolong is SBE 49 FastCAT CTD Sensor. The SBE 49 FastCAT is an integrated CTD sensor intended for towed vehicle, ROV, AUV, or other autonomous profiling applications in marine or freshwater environments at depths up to 7000 m. The FastCAT is pump-controlled, TC-ducted flow minimizes salinity spiking, and its 16 Hz sampling provides high spatial resolution of oceanographic structures and gradients.

In the study presented here, we use the observations available to study the water properties, bottom current, turbulent mixing in the northern Yap Trench. This paper is organized as follows: In Part 2 we provide a brief introduction of observations and methods used in this paper. Part 3 describes the analysis of water properties, bottom current, turbulent mixing and mesoscale eddy. Summary and discussions of this study are presented in Part 4.

2. Data and methods

2.1. Data and preprocessing

The field investigation was implemented by No. 37 and 38 Cruise of China Ocean Mineral Resources R&D Association on R/V Xiangyanghong 9 and the deep-sea manned Submersible Jiaolong from April 12 to July 4, 2016 and from February 6 to June 9, 2017, respectively. As shown in Fig. 1(a) and (b), ten stations were selected around the slope of Yap Trench, including three casts of vertical profiles of temperature, salinity and dissolved oxygen (see stations CTD01–03) observed by ship-based CTD and dissolved oxygen sensor, five casts of vertical profiles of temperature and salinity (see stations D109–113) observed by submersible Jiaolong, and three moorings of the time series of bottom currents (see Lander01–03). Details about the stations are listed in Table 1. The salinity measurements are accurate to 0.003 psu and temperature measurements to 0.002 °C. The salinity and potential temperature data derived from World Ocean Database 2013 (WOD13; https://www.nodc.noaa.gov/OC5/WOD13/) were denoted as black points as shown in Fig. 1(a). The two orange arrows denote the deep current carrying LCPW (Kawabe et al., 2003; Siedler et al., 2004).

In Figs. 2 and 3, the WOD13 data in Section III and section IV are presented. The observations in section III were collected by the cruises in October 1996, while the ones in section IV were collected in February 1989. The dissolved oxygen data was absent in section III. Both the two sections indicate the downwelling of the west propagating deep current along the slope. In previous researches, the schematic of the deep current in the Yap Trench remains unrevealed.

The observations with CTDs were preprocessed with SBE Data Processing Software V7.2 to obtain the temperature, salinity and dissolved oxygen data. At each station, these data were vertically interpolated at 1 dbar intervals by the rational shape preserving spline interpolation (Belkin, 1983). The observed bottom current was processed with power spectrum density (PSD) (Xu et al., 2013) to reveal the energy-frequency relation of bottom current.

The topography data used in this paper was obtained from the General Bathymetric Chart of the Oceans (GEBCO, 2014; http://www.gebco.net/data_and_products/gridded_bathymetry_data/.) with a horizontal resolution of 1′ × 1′.

For analysis of the surface geostrophic velocities and detect the mesoscale eddies in the Yap Trench, the gridded daily near-real time sea level anomaly (SLA) and surface geostrophic velocity data from Archiving, Validation and Interpretation of Satellite Oceanographic data (AVISO; http://www.aviso.altimetry.fr/en/home.html) is employed in this paper. The outputs of an eddy-resolving OGCM for the Earth Simulator (OFES; Sasaki et al., 2004, 2008) is introduced to investigate the watermass in the present study.

The barotropic tidal constitutes from an inverse model named as

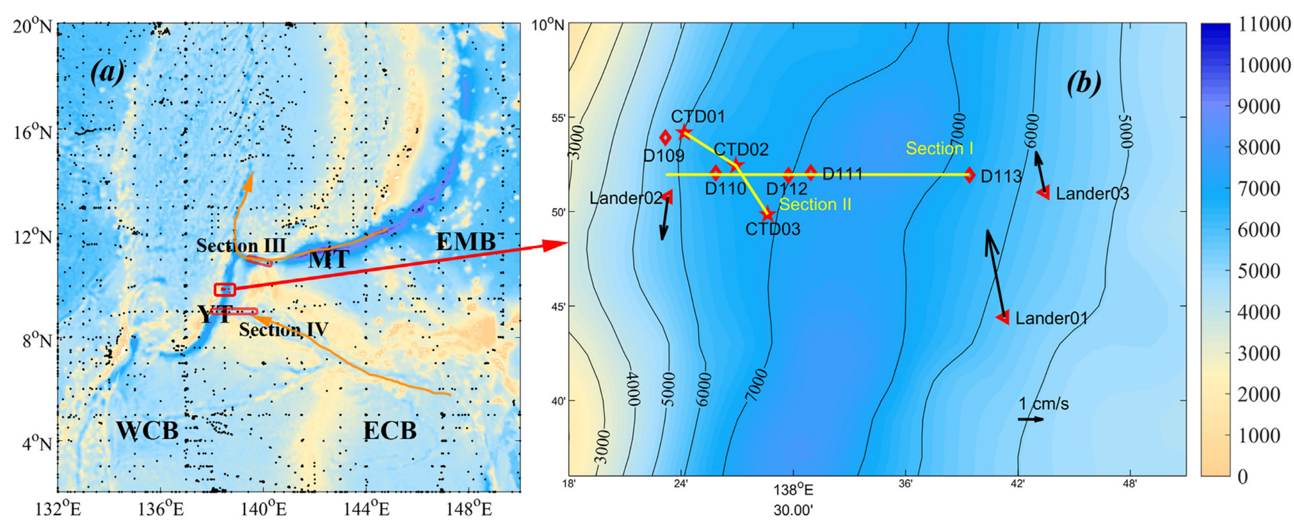

Fig. 1. (a) Bathymetry (GEBCO 2014) and basin structure of the Yap/Mariana region: YT = Yap Trench, MT = Mariana Trench, WCB = West Caroline Basin, ECB = East Caroline Basin, EMB = East Mariana Basin. The red rectangle with red arrow indicates the location of stations. The black points represent the locations of WOD13 data. The red arrow denoted with section III and IV are two sections of WOD13. (b) Bathymetry and location of the stations shown in the red rectangle in panel (a). Stations CTD01–03 represent the stations with ship-based CTDs and RINKO I dissolved oxygen sensors. Stations D109–113 represent the observations with CTDs mounted on the Submersible Jiaolong. Stations Lander01–03 represent the RCMs and CTDs moored at seafloor. The black arrows represent the direction of mean velocities observed in stations Lander01–03. The two yellow lines named as Section I and Section II are selected to analyze the vertical structures of water properties. The two orange arrows denote the deep current carrying LCPW (Kawabe et al., 2003; Siedler et al., 2004).