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(editor)

DEEP OCEAN CIRCULATION

PHYSICAL AND CHEMICAL ASPECTS

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DEEP OCEAN CIRCULATION

PHYSICAL AND CHEMICAL ASPECTS

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Preface

This book comprises the final report of the project research titled the Dynamics of the Deep Ocean Circulation. The project was organized and conducted under the chairmanship of myself for four fiscal years from 1987 to 1990, with financial support of the Ministry of Education, Science and Culture of Japan under the grant in aid of Priority Area Programme.

As will be described in Chap. 1 in more detail, the project needed to involve research groups who had sufficient experiences in long-term current measurements, accurate chemical analyses of dissolved heavy metals and isotope tracers, numerical and hydraulic modellings, sediment trappings, and so on. These experiences had been gained through two preceding research projects, the first of which bore the title, "Fundamental Studies on Preservation of Ocean Environment", and the second, the "Ocean Characteristics and their Changes."

The former was carried out for four years from 1975 to 1978 under the chairmanship of Prof. Y. Horibe and the latter for four years from 1981 to 1984 under the chairmanship of Prof. K. Kajiura. Both were financially supported by the Ministry of Education, Science and Culture, too. I am greatly indebted to these supports and express my sincere gratitude to these chairmen.

Throughout the period of research, I had arranged symposia several times, in which ocean scientists who were not directly committed to the project also joined. Comments and criticisms given there were very helpful for the promotion of the project.

Here, I would like to express my sincere gratitude to Dr. Susumu Tabata, the former senior scientist of the Institute of Ocean Sciences in Sidney, B. C., CANADA, for reviewing whole the papers involved and giving valuable advices and appropriate comments.

Toshihiko TERAMOTO
Kanagawa University, 1992

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Table of Contents

Chapter 6: Development of Acoustic Technology for Ocean Measurement

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Chapter 1

Motivation of the Project Research and a Hypothetical Circulation model presented prior to the Research

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Deep Ocean Circulation, Physical and Chemical Aspects
edited by T. Teramoto

Motivation of the Project Research and a Hypothetical Circulation Model Presented Prior to the Research

Toshihiko TERAMOTO*

1. Motivation of the Project Research

The subtropical area of the western North Pacific is much different in topographic feature from that of the western North Atlantic. The former is characterized by the Izu-Ogasawara-Mariana Ridges running almost longitudinally across the western part of it and the latter, by the Grand Banks occupying the north of the western part of it (Fig. 1).

The difference, however, does not actually exert any serious influence upon the surface subtropical circulation, and the circulations in the both oceans are almost similar in configuration. In another words, the Kuroshio flowing along the continental boundary and the subsequent Kuroshio Extension flowing into the central ocean of the Pacific correspond well in their combination to the Florida Current and the subsequent Gulf Stream of the Atlantic.

In contrast to this, the characteristic bottom topographies described above seem to affect greatly to the deep circulations of the oceans. According to the deep circulation model hypothetically delineated by Stommel and Arons (1960), the deep western boundary current in the North Pacific flows along the eastern side of the above-stated ridges and not along the continental boundary but that in the North Atlantic flows closely along the continental boundary (Fig. 1). Thus, the Philippine Sea, which is bounded by the continental boundary in the west and with the ridges in the east, has long been considered to be isolated in the deep layer from the main part of the North Pacific (Fig. 1). This leads to an understanding that the deep water of the sea is almost stagnant and is old in age.

The age determination with ^{14}C indicated the deep water of the Philippine Sea is younger by about 200 years than that of the main North Pacific (Gamo, personal communication). This fact suggests that the deep western boundary current branches into the sea through the Yap-Palao Trough on the Mariana ridge soon after the current flows into the northern hemisphere upon passing over the equator (Fig. 2). This implies the deep Philippine Sea water is also involved in the deep circulation of the North Pacific.

What is the configuration of the deep circulation of the western North Pacific? This question motivated the author to programme the present project research.

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Fig. 1. The bottom topography of the world ocean (lower panel) and the configurational model of the deep circulation by stommel and Arons (upper panel) (Open university/Pergamon).

The programme is naturally expected to give a solution to the question on what the flow configuration under the Kuroshio is, a question that has long been borne in minds of many Japanese oceanographers.

2. The Subsurface Circulation Model Presented to be Verified through the Project Research

2.1. The mid-depth circulation model

Through long-term measurements of vertical profile of velocity in the Kuroshio area south of Japan, the level of no motion is determined to be at the depth around

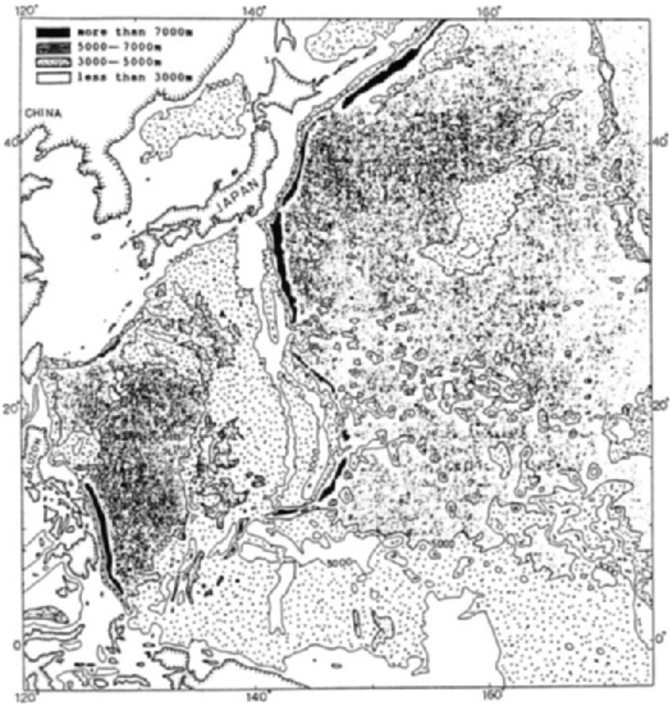

Fig. 2. The detailed bottom topography of the Philippine Sea and western North Pacific (Mogi, 1972).

2,000 m (Fukasawa and Teramoto, 1986). Thus, on taking the reference level at the isobaric surface of 2,000 db, the contour maps of geopotential anomalies on the isobaric surfaces of 1,000 and 3,000 db for the Philippine Sea and western North Pacific (Fig. 3) are drawn on the basis of accurate hydrographic observations (Kaneko and Teramoto, submitted to J. Oceanogr.). The figure gives the configurational model of the mid-depth circulation, which has a two-layer structure separated at the isobaric surface of 2,000 db. The mid-depth used here is defined to involve depths below 1,000 m and above 3,000 m. The most characteristic feature of the configuration is the elliptic eddy occupying the whole area of the Shikoku Basin (Fig. 2). The eddy is commonly of the size of about 1,200 km in longer diameter and 600 km in shorter one both in the upper and lower mid-depth layers but is rotating clockwise in the upper layer and anticlockwise in the lower one. The geostrophic velocity profile associated with the eddy is almost equal to that from the direct measurements stated above.

Through the water-mass analysis, the mid-depth water of the Philippine Sea and western North Pacific is understood to be classified typically into three water types; that is, the South Philippine Sea Water, Shikoku Basin Water and Northwest Pacific Water (Kaneko and Teramoto, submitted to J. Oceanogr.). These water types, each of which is identified here by a combination of S (Salinity), DO

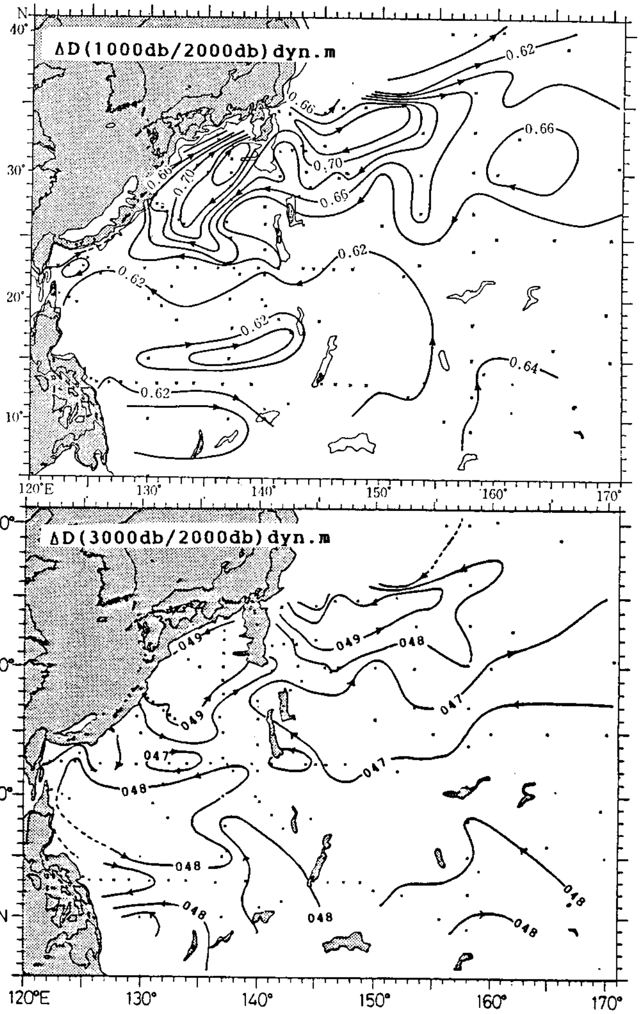

Fig. 3. Contour maps of geopotential anomaly on isobaric surfaces of 1,000 db (upper panel) and 3,000 db (lower panel) for the Philippine Sea and western North Pacific. The reference level is put at 2,000 db surface.

(Dissolved Oxygen) and DSi (Dissolved Silica) of water, are defined as averages of S,DO and DSi of water samples from ten stations in regions of 10°00' to 13°02'N, 125°37' to 137°00'E in the South Philippine Sea, 32°30' to 33°32'N, 135°49'to 138°05'E in the Shikoku Basin and 29°55' to 35°56'N, 146°34' to 160°00'E in the western North Pacific, respectively. Actually, waters of S, DO and DSi in ranges of twice the standard deviations in distributions of S, DO and DSi over the ten stations are regarded as those of water types under consideration. Thus, the water

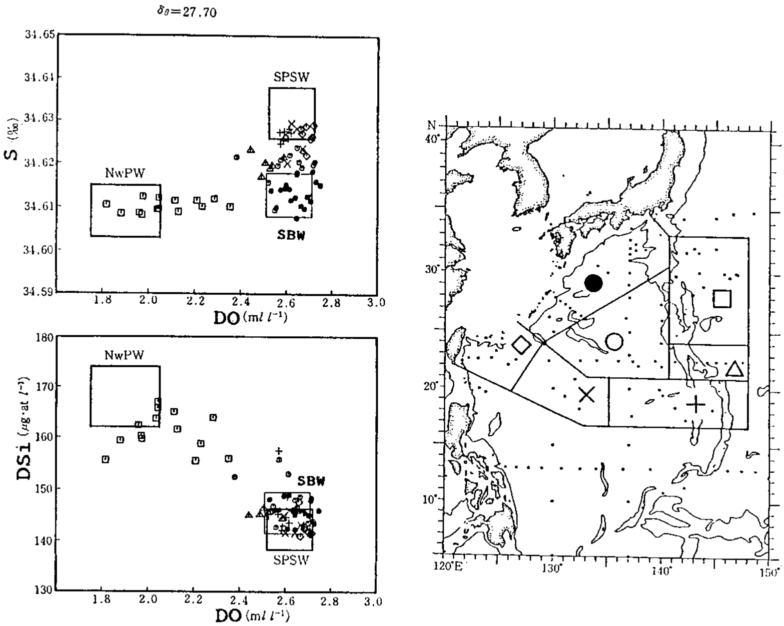

Fig. 4. S–DO diagramme (left upper panel) and DSi–DO diagramme (left lower panel) on the isopycnal surface of $\sigma_\theta = 27.70$ for water samples in the Philippine Sea and western North Pacific. Positions for these water samplings are shown by the use of six kinds of symbol, which are used to identify the six areas illustrated on the right panel of the figure. Squares with symbols of SPSW, SBW and NWPW on the diagrammes indicate the domains for water types of south Philippine Sea Water, Shikoku Basin Water and Northwest Pacific Water, respectively.

types are specified not at points but within square domains on S–DO and DO–DSi diagrammes as illustrated for the isopycnal surface of $\sigma_\theta = 27.70$ in Fig. 4. This isopycnal surface almost corresponds with isobaric surface of 2,000 db. The geographic distribution of these three water types on the isopycnal surface of $\sigma_\theta = 27.70$ is drawn in Fig. 5 (Kaneko and Teramoto, submitted to J. Oceanogr.).

Upon comparison of this figure to Fig. 3 it is clearly indicated that the area of the Shikoku Basin Water in the mid-depth layer around 2,000 db coincides very well with those occupied by the elliptic eddy described above. As suggested from S–DO and DO–DSi relations in Fig. 4, the Shikoku Basin Water cannot be formed through the linear horizontal mixing of waters of the other two water types. And so, the formation seems to be made through vertical mixing associated with the eddy motion of the intense vertical shear of velocity.

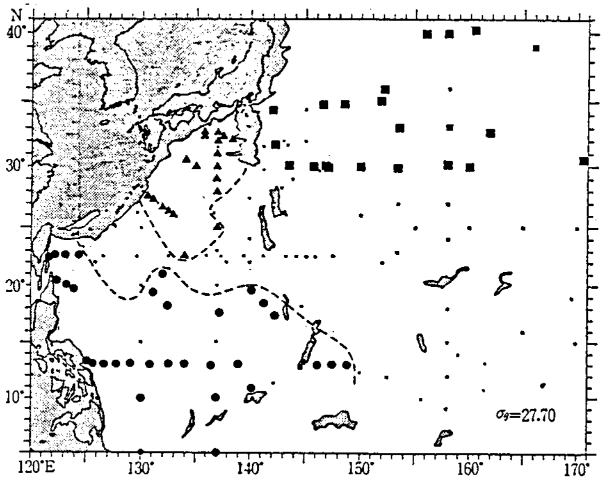

Fig. 5. The geographical distributions of water types of SPSW (●), SBW (▲) and NWPW (■) on the isopycnal surface of $\sigma_\theta = 27.70$.

2.2. The deep circulation model

As seen on S–DO–DSi diagramme in Fig. 6, the square domains for the water type of the Shikoku Basin Water overlap with those of the South Philippine Sea Water for the deep layer around the isopycnal surface of $\sigma_\theta = 27.77$. This surface corresponds to the isobaric surface of 3,000 db. The deep layer mentioned here implies the layer between 3,000 and 4,000 m in depth. Thus, the deep layer of the whole Philippine Sea including the Shikoku Basin is known to be filled with the South Philippine Sea Water.

Then, the question arises on where the origin of this water is. For the purpose of tracing the characteristics of the water in contrast to the North Pacific Water, Kaneko and the author draw S–DO (upper panel) and DSi–DO (lower panel) diagrammes in Fig. 7 for water samples from three groups of station in the following cruises; that is, the Ryofu-Maru Cruise along 137°E in the Philippine Sea, the Hakuho-Maru Cruise along 158°E in the western North Pacific and GEOSECS EXPEDITION almost along 180° in the equatorial area over the northern and southern hemispheres (Fig. 7). These diagrammes for the isopycnal surface of σ_θ = 27.77 indicate that the deep Philippine Sea Water can be traced to branches off from the deep equatorial water at around sta. 4 of the GEOSECS EXPEDITION near 10°S and that the deep Northwest Pacific Water, on the contrary, from the deep equatorial water at around sta. 1 of the GEOSECS EXPEDITION near 5°N. These facts suggest that a part of the deep western boundary current, which flows northwards after passing through the Samoan Passage (Fig. 7), branches eastwards into the Philippine Sea and that the rest of the current flows further northwards

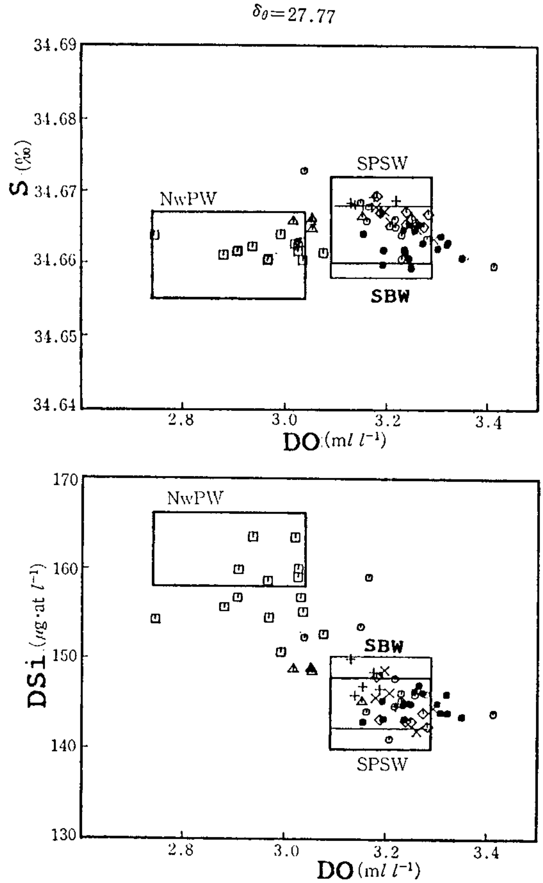

Fig. 6. S–DO diagramme (upper panel) and DSi–DO diagramme (lower panel) on the isopycnal surface of σ_θ = 27.77 for water samples in the Philippine Sea and western North Pacific. Symbols used are the same as in Fig. 5.

into the western North Pacific along the Izu-Ogasawara-Mariana Ridge.

As delineated in Fig. 8 (Kaneko and the author), the isolines for DSi and DO on the isopycnal surface of σ_θ = 27.77 are almost of the longitudinal, configuration, which is clearly different from the latitudinal one on the isopycnal surface of σ_θ = 27.55 in the same figure. The latter surface agrees almost with the isobaric surface of 1,500 db, where the circulation is delineated as in Fig. 9(b). The current associated with the circulation on this surface is zonal and the isolines is parallel to the current except for the western boundary region. On taking into consideration the fact that in the deep layer the isolines for DSi and DO are longitudinal and also the fact that the deep current directly measured flows westwards in the northern boundary region, the author modelled hypothetically the deep circulation of the Philippine Sea as illustrated in Fig. 9(d) on referring to the world deep circulation