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Spacial and temporal variations of water characteristics in the Japan Sea bottom layer

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ABSTRACT

The Japan Sea is an almost landlocked marginal sea. We measured profiles of CTD potential temperature at 9 stations in the southeastern Japan Sea to clarify the characteristics of the abyssal circulation in the Sea. It was shown that the results were closely correlated with the topography of the Japan Sea which is characterized by a rise in the center of the Sea (Yamato Rise) and three basins (Japan, Yamato and Tsushima Basins) around the Yamato Rise.

At each station in the Basins (6 stations), we observed "the bottom layer," a layer of constant potential temperature (within ±0.0005°C) below 2,000–2,500 m depth to the bottom. Dissolved oxygen is also constant (within ±1 μmol kg^{-1}) in the bottom layer. The bottom layer of the Japan Basin (northern basin) is shown to have lower potential temperature by 0.012°C and higher dissolved oxygen content by 5 μmol kg^{-1} than that of the Yamato Basin (southern basin). There is no bottom layer at the remaining 3 stations located in the passage between the Japan Basin and the Yamato Basin, possibly due to the topographic effect of the Yamato Rise which restricts the exchange and mixing of the two Basin bottom waters.

By comparing the vertical profiles of dissolved oxygen in 1969, 1977, 1979 and 1984 in the Japan and the Yamato Basins, it was found that in both Basins the thickness of the bottom layer decreased by 400 m between 1969 and 1984, and the bottom oxygen concentration was also decreased by 5–7 μmol kg^{-1} between 1977 and 1984. These temporal variations were interpreted to be transient, probably caused by the recent reduction or cessation of new bottom water formation in the northern Japan Sea.

1. Introduction

The Japan Sea is a marginal sea surrounded by Japanese Islands, Siberia and Korean Peninsula (see Fig. 1). The deep water of the Japan Sea, whose maximum depth is about 3,700 m, is completely isolated from the Pacific deep water, because the Japan Sea is connected to the western Pacific by three shallow straits of the maximum depth of less than 150 m. It has been known that the deep water of the Japan Sea below 1,000 m depth has extremely low potential temperature of 0.0–0.2°C (salinity: 34.06–34.07) and has a high dissolved oxygen content of 220–230 μmol kg^{-1} (e.g.,

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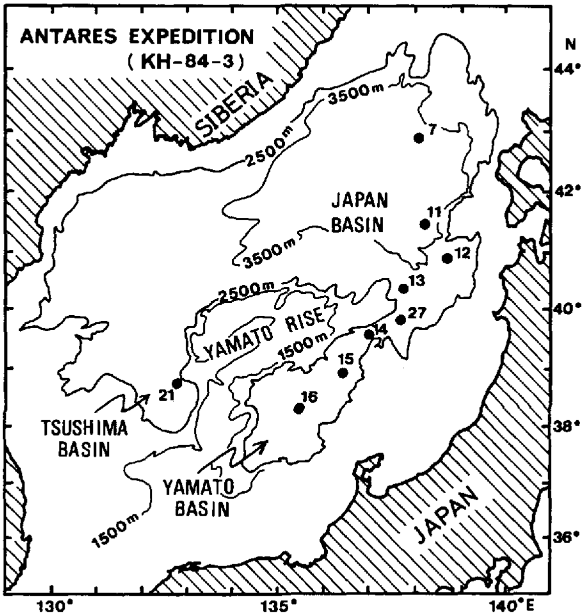

Figure 1. Map showing the locations of stations in the Japan Sea during the ANTARES Expedition.

Suda, 1932; Nitani, 1972; Moriyasu, 1972). This means that the deep water of the Japan Sea is not stagnant but has its own abyssal circulation system which refreshes the deep water.

Gamo and Horibe (1983) measured for the first time the continuous profiles of potential temperature with a Neil Brown CTD at 4 stations in the southeastern Japan Sea. They found that each profile has a marked boundary at about 2,000 m depth which is characterized by a sudden change in vertical gradient, suggesting that the Japan Sea below 1,000 m depth can be separated into the deep layer and the bottom layer by the boundary. The potential temperature of the bottom layer at each station was constant within the resolution limit of the CTD of ±0.0005°C. They applied a box model to the carbon-14 data in the bottom layer, revealing the mean residence time of the bottom water to be about 300 years. However, the mechanism of the abyssal circulation is almost unknown due to the lack of detailed data about the water properties of the bottom layer.

During KH-84-3 (ANTARES) Expedition of R.V. *Hakuho Maru* in August to October in 1984, we have made hydrographic studies at 9 stations in the southeastern Japan Sea. This paper analyzes the CTD and dissolved oxygen data in the bottom layers obtained in the cruise in order to discuss the abyssal circulation pattern in the Japan Sea. Furthermore, we will compare the dissolved oxygen profiles in the deep and bottom layers for the past 15 years, and the time variation of the profiles will be

Table 1. Locations and bottom depths of the stations of the ANTARES Expedition.

Station no.	Latitude	Longitude	Bottom depth (m)	Time
AN7	42° 50′ N	138° 05′ E	3,614	Sep. 11–12, 1984
AN11	41° 25′ N	138° 15′ E	3,641	Sep. 13–14, 1984
AN12	40° 51′ N	138° 42′ E	3,298	Sep. 14 , 1984
AN13	40° 20′ N	137° 43′ E	2,847	Sep. 14–15, 1984
AN27	39° 49′ N	137° 41′ E	2,768	Sep. 26 , 1984
AN14	39° 32′ N	137° 00′ E	2,547	Sep. 15 , 1984
AN15	38° 50′ N	136° 24′ E	2,653	Sep. 15 , 1984
AN16	38° 17′ N	135° 30′ E	2,926	Sep. 16 , 1984
AN21	38° 41′ N	132° 48′ E	2,821	Sep. 24 , 1984

discussed in terms of the mechanism of the abyssal circulation characteristic of the Japan Sea.

2. Area and location of stations

The locations of stations during the ANTARES Expedition are listed in Table 1 and also shown in Figure 1.

As shown in Figure 1, the topography of the southeastern Japan Sea is characterized by a rise (Yamato Rise) and three basins: Japan Basin, Yamato Basin and Tsushima Basin. The Japan Basin is the deepest basin in the Japan Sea, most part of which exceeds a depth of 3,500 m. On the surface of 2,500 m depth, the Japan Basin and the Yamato Basin are narrowly connected with each other, but the Yamato Basin and the Tsushima Basin are closed by the topographic barrier of the Yamato Rise. The Japan Basin and the Tsushima Basin are connected along the northwestern side of the Yamato Rise.

Stations AN7, AN11, AN12 and AN13 are in the Japan Basin, and station AN16 and station AN21 are in the Yamato Basin and in the Tsushima Basin, respectively. Stations AN27, AN14 and AN15 are located inside the narrow passage connecting the Japan Basin and the Yamato Basin.

3. Data

Potential temperature was calculated according to the polynomial by Bryden (1973) from the *in-situ* temperature and salinity obtained with the Neil Brown Mark III CTD.

Seawater samples were collected by using 23-liter PVC Niskin type samplers. Dissolved oxygen was measured by using the Carpenter's method (Carpenter, 1965) modified by Horibe and Gamo (1981). Samples were titrated in calibrated 50 ml oxygen-bottles with a 5 ml piston burette. The freshly prepared Sagami CSK standard

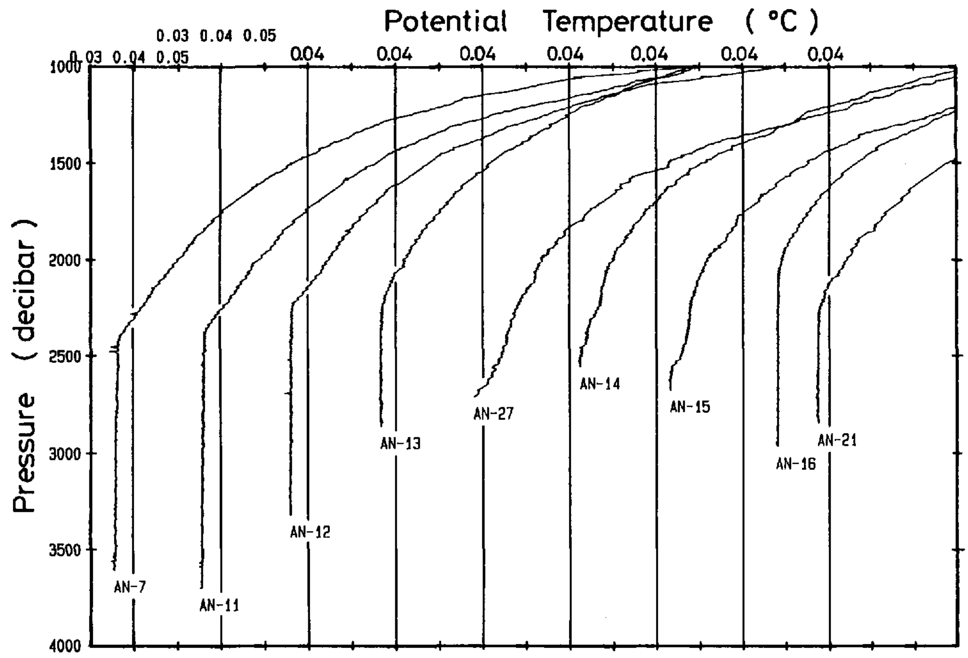

Figure 2. Vertical distributions of CTD potential temperature at stations AN7, 11, 12, 13, 27, 14, 15, 16, and 21. The abscissa is shifted by 0.02°C for every station.

of 0.01N potasium iodate solution was employed for the standardization. The effect of air contamination and the blank of added reagents were removed according to Horibe *et al.* (1972). The standard deviation for replicate analyses is less than 1 μmol kg^{-1}.

The oxygen data in the Japan Sea has been obtained three times since 1977 in the following expeditions of R. V. *Hakuho Maru*: the PEGASUS Expedition in 1977 (Horibe, 1981), the ALTAIR Expedition in 1979 (Horibe, unpublished) and the ANTARES Expedition in 1984 (Sakai, unpublished).

4. Spacial variations of potential temperature and oxygen profiles

The profile of bottom potential temperature is a good indicator for estimating bottom water movements. Figure 2 shows the vertical profiles of potential temperature below a pressure of 1,000 decibars to the bottom. For easier comparisons among the stations, each profile is successively shifted horizontally by 0.02°C.

A layer of constant potential temperature or "the bottom layer," which is presumably maintained by an active vertical mixing, can be observed at stations AN7, AN11, AN12, AN13, AN16 and AN21. These stations are located within any one of the three basins, and all the stations in the basins have the bottom layers. On the contrary, stations AN27, AN14 and AN15 have no clear bottom layer.

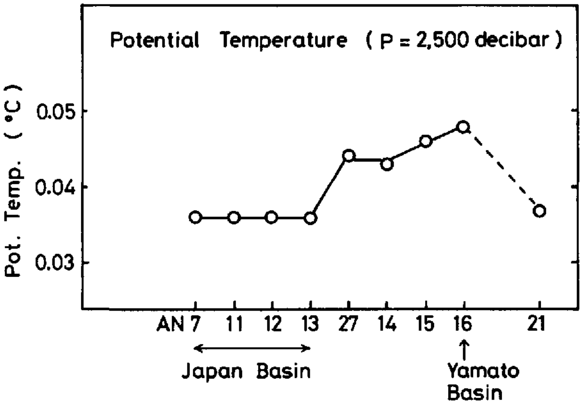

Figure 3. Potential temperature values at stations AN7, 11, 12, 13, 27, 14, 15, 16, and 21 at a depth of $P = 2{,}500$ decibars.

The bottom potential temperatures at a depth of $P = 2{,}500$ decibars are compared in Figure 3. Stations AN7, AN11, AN12 and AN13 in the eastern Japan Basin have almost the same value of 0.036°C while station AN16 in the Yamato Basin has a higher value of 0.048°C. These data mean that the bottom water in the eastern Japan Basin is horizontally (as well as vertically) well-mixed and is probably younger than that in the Yamato Basin. The bottom potential temperature at AN21 (0.037°C) in the Tsushima Basin is significantly lower than that at AN16, indicating that the bottom water in the Tsushima Basin is supplied not from the Yamato Basin but from the Japan Basin; the topographic barrier between the Yamato Basin and the Tsushima Basin blocks the bottom water exchange between them.

Dissolved oxygen is another good indicator for tracing bottom water movement, and was measured at stations AN7, AN11, AN14 and AN16. The results are shown in Figure 4. The average bottom oxygen value at AN7 and AN11 was higher by about 5 μmol kg^{-1} than that at AN16. This means that the bottom water of the eastern Japan Basin is younger than that of the Yamato Basin, which is consistent with the result from the potential temperature data. It can be assumed that the direction of bottom current should be from the Japan Basin to the Yamato Basin, though future studies with current meters are necessary to confirm this assumption.

It is worth noting that the potential temperature profiles differ drastically between AN13 and AN27. As shown in Figure 2, the bottom layer is observed at AN13, but it suddenly disappears at AN27. Furthermore, the value of potential temperature at a depth of $P = 2{,}500$ decibars rapidly increases from 0.036°C at AN13 to 0.044°C at AN27 as shown in Figure 3. Just between these stations, the rift of the Yamato Rise extends eastward (see Fig. 1). It is quite likely that this topographic effect restricts the bottom water exchange between the Japan Basin and the Yamato Basin.

At station AN27, a thermocline can be seen between 200 and 50 m above the

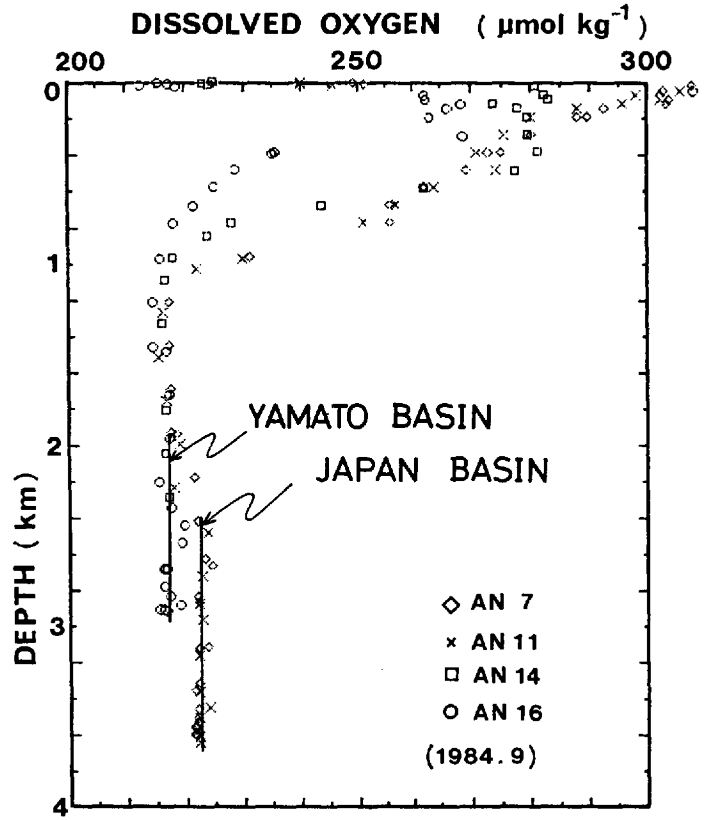

Figure 4. Vertical distribution of dissolved oxygen at stations AN7, 11, 14, and 16.

bottom, and below the thermocline, potential temperature is slightly below 0.04°C as shown in Figure 2. It is implied that two bottom waters with different potential temperature values might intersect at AN27: the bottom 50 m water derived from the Japan Basin bottom water (possibly southward current), and the bottom water above the thermocline which is affected by the Yamato Basin bottom water (possibly northward current). This implication should also be verified by the future current measurements.

5. Temporal variations of oxygen profiles

Temporal variations of water properties, if any, would given much information about the abyssal circulation mechanism as well as the spacial variations discussed above. Unfortunately, CTD potential temperature data in 1979 (Gamo and Horibe, 1983) and in 1984 (this work) could not be compared with each other because no calibration was done between both CTD measurements. The temperature data in the bottom layer by reversing thermometers are available between 1969 and 1984, but they have too low precision for the purpose.

Dissolved oxygen is a good substitute for potential temperature because the bottom oxygen-constant layer agrees well with the bottom layer defined by CTD potential temperature. At stations AN7 and AN11, for example, the bottom layer was observed below 2,400 m depth as shown in Figure 2, and the concentration of dissolved oxygen was correspondingly constant in this depth range as shown in Figure 4. The similar agreement was also observed during the ALTAIR Expedition in 1979 (Gamo and Horibe, 1983).

We compared the vertical profiles of dissolved oxygen measured since 1969 at two regions, one in the eastern Japan Basin and the other in the Yamato Basin as shown in Figure 5a and b. Data are listed in Table 2a and b. For each region, the locations of stations of the different expeditions were nearly the same as in Table 2.

Data at stations C-3, C-4, D-5 and D-6 in Figure 5a and those at station G-4 in Figure 5b were obtained in 1969 by the Japan Meteorological Agency (1971). The measurement was done by using the classical Winkler's method. There is a fear of systematic deviation of oxygen value between the Winkler's method and our Carpenter's method, because the former method was shown to have a tendency to give less oxygen value mainly due to the evaporative loss of iodine during titration (Carritt and Carpenter, 1966; Horibe and Gamo, 1981). Therefore, we avoided comparing the absolute concentration in 1969 with our data since 1977. But it was possible to compare other properties such as the thickness of the bottom layer and the depth of oxygen minimum layer among all data since 1969.

The following three characteristics can be seen from Figure 5a and b. CTD potential temperature data in 1979 (Gamo and Horibe, 1983) and in 1984 (Fig. 2) were also referred to for determining the thickness of the bottom layer.

(1) The oxygen value in the bottom layer has been decreasing since 1977. The amounts of decrease are significant beyond the analytical error of oxygen measurement.

(2) The thickness of the bottom layer has been decreasing since 1969.

(3) The depth of the oxygen minimum layer has been deepening since 1969, though it became increasingly difficult to determine its correct depth because the minimum layer became broader and less clear as time passed by.

Since these three points were commonly observed both in the eastern Japan Basin and in the Yamato Basin, it can be said that the temporal variation of the oxygen profile is not a local but rather a universal phenomenon in the Japan Sea.

The unreliability of oxygen analysis among different expeditions could cause a false temporal variation of oxygen profiles. However, this possibility can be rejected by the following reasons. As mentioned before, our analytical procedure for oxygen determination, including the method of titration (modified Carpenter's method), concentrations and volumes of reagents to be added to samples, the standard solution (Sagami

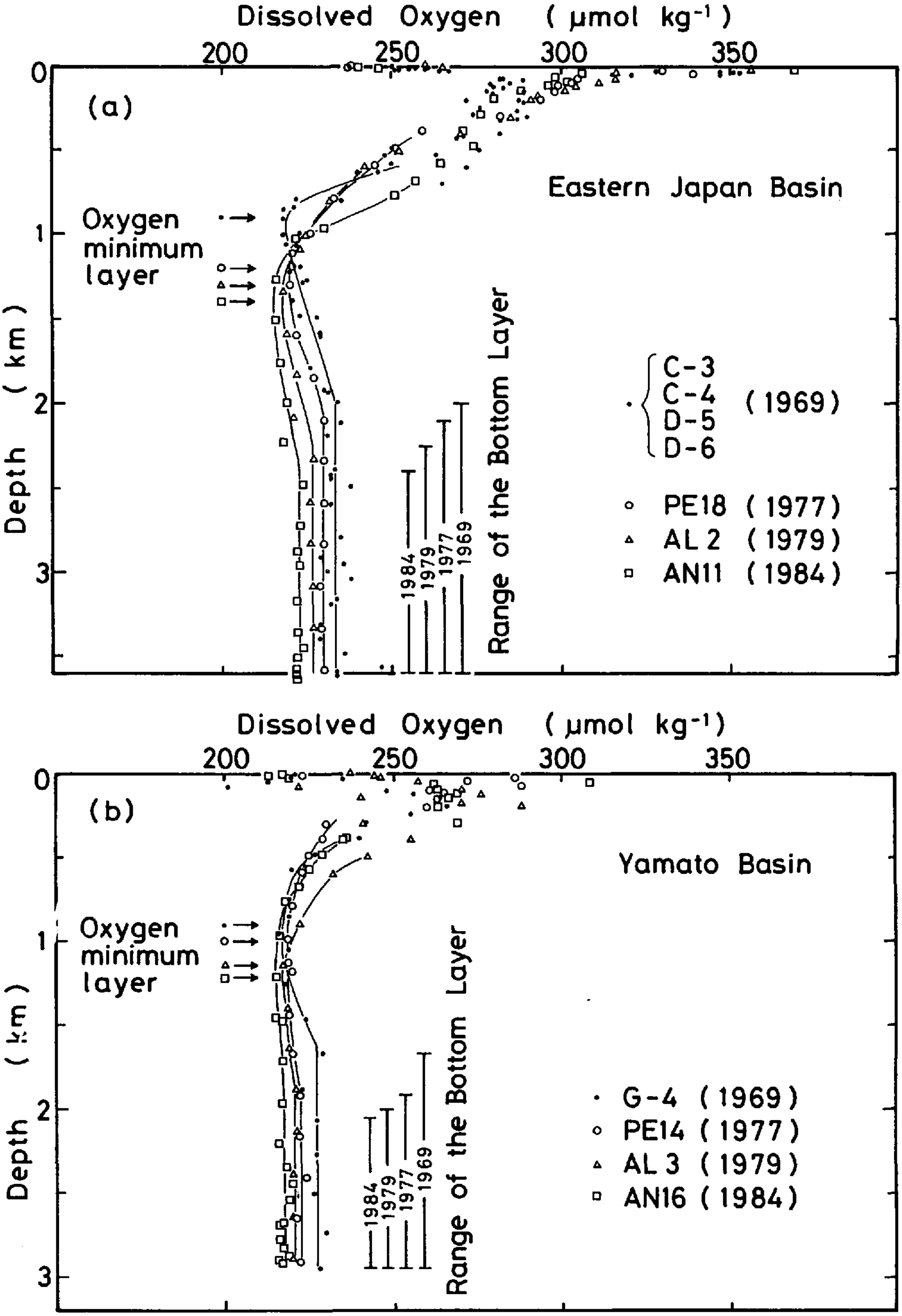

Figure 5. Temporal variations of dissolved oxygen profiles in (a) the eastern Japan Basin and in (b) the Yamato Basin between 1969 and 1984.

Table 2. (a) and (b). Average oxygen concentrations in the bottom layer (B.L.), thickness of the B.L., and depth of the oxygen minimum layer from 1969 to 1984; (a) in the eastern Japan Basin and (b) in the Yamato Basin.

(a) Eastern Japan Basin

Station no.	Position		Time	Average O_2 in the B.L. (μmol kg^{-1})	Thickness of the B.L. (m)	Depth of O_2 mim. (m)
C-3	42° 01′ N	137° 56′ E	Sep. 1969	233	1,600	900
C-4	42° 00′ N	137° 00′ E	Oct. 1969			
D-5	40° 59′ N	137° 58′ E	Oct. 1969			
D-6	40° 59′ N	137° 03′ E	Oct. 1969			
PE18	41° 20′ N	137° 21′ E	Sep. 1977	229.9 ± 0.6 (7)	1,500	1,200
AL 2	41° 21′ N	137° 20′ E	Jun. 1979	226.6 ± 0.5 (5)	1,350*	1,300
AN11	41° 25′ N	138° 14′ E	Sep. 1984	222.7 ± 0.7 (11)	1,200**	1,400

(b) Yamato Basin

Station no.	Position		Time	Average O_2 in the B.L. (μmol kg^{-1})	Thickness of the B.L. (m)	Depth of O_2 mim. (m)
G-4	38° 03′ N	134° 57′ E	Oct. 1969	227	1,300	900
PE14	37° 44′ N	135° 12′ E	Sep. 1977	222.2 ± 0.9 (5)	1,000	1,000
AL 3	37° 44′ N	135° 14′ E	Jul. 1979	220.4 ± 0.2 (4)	950*	1,200
AN16	38° 17′ N	135° 30′ E	Sep. 1984	217.2 ± 1.4 (12)	900**	1,250

Figures in parentheses are the numbers of data averaged.
*from CTD profile by Gamo and Horibe (1983).
**from CTD profile in Figure 2.

CSK standard), and the correction for oxygen contamination by added reagents, is perfectly common for all the oxygen values since 1977. Therefore, there is no possibility to cause a systematic deviation of oxygen data among the different expeditions. This is confirmed by the fact that the same oxygen profiles were obtained in the northern Philippine Sea deep water in 1977, 1978 and 1979 (PEGASUS, VEGA and ALTAIR Expeditions) as shown in Figure 6. Furthermore, the temporal decrease of oxygen in the bottom layer of the Japan Sea was supported by the accompanying increases of nutrients (silicate, phosphate and nitrate) as shown in Figure 7.

The material balance of oxygen in the bottom layer is probably controlled by the following three processes. The first process is the supply of new oxygen-rich bottom water. It has been suggested that the bottom water should be formed along the northern or northwestern shores of the Japan Sea, where evaporation and freezing in winter seasons make the surface water dense enough to sink (Suda, 1932; Nitani, 1972; Moriyasu, 1972). The second one is an *in-situ* oxygen consumption by oxidation of organic materials falling from the surface. And the third one is a vertical water mixing

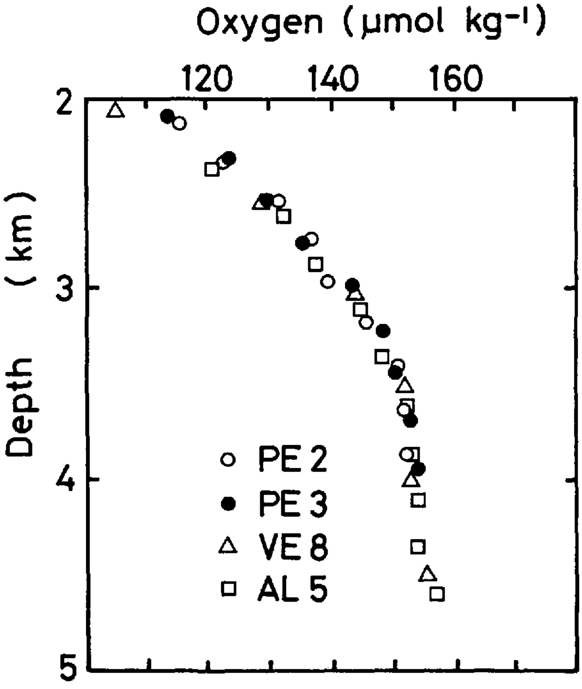

Figure 6. Comparison of vertical oxygen profiles in the northern Philippine Sea in 1977–1979. Data were obtained at PE2 (30°44′N, 136°10′E) and PE3 (31°21′N, 133°46′E) during PEGASUS Expedition in 1977 (Horibe, 1981), at VE8 (30°31′N, 134°02′E) during VEGA Expedition in 1978 (Horibe, unpublished), and at AL5 (29°58′N, 135°00′E) during ALTAIR Expedition in 1979 (Horibe, unpublished).

between the bottom layer and the deep layer; the latter has lower oxygen content than the former. The temporal decrease of oxygen concentration is, therefore, thought to reflect either of the three possibilities: the reduction or cessation of the supply of the new bottom water, the increase of falling organic materials, and the enhancement of vertical mixing between the bottom layer and the deep layer.

The third case would result in an increase of oxygen content of the deep layer as expected from the material balance between the deep and bottom layers. Actually, the oxygen of the deep layer has also been decreasing since 1977 as shown in Figure 5, so the third case should be erased. The second possibility seems to be unlikely because there has been no remarkable increase of biological activity as deduced from the records of chlorophyll *a* and phaeophytin concentrations and of wet weight values of plankton in the southeastern Japan Sea surface water for the past several years (Maizuru Marine Observatory, 1977–1984).

The first possibility is thought to be appropriate. The idea of the reduction or cessation of the bottom water supply is consistent with the other two situations: the temporal decrease of the thickness of bottom layer and the deepening of the oxygen

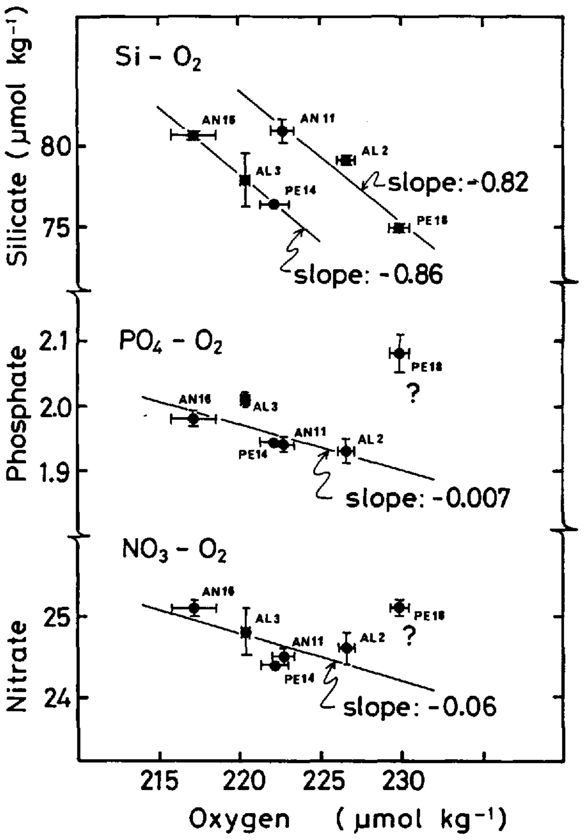

Figure 7. Nutrients vs. oxygen relationships in the bottom layer of the Japan Sea from 1977 to 1984.

minimum layer. If the supply of new bottom water is reduced, the thickness of the bottom layer is expected to decrease because the new bottom water supply is thought to be the main energy source for keeping the bottom layer in a well-mixed condition over the thickness of more than a kilometer. If the rate of bottom water supply becomes smaller, water upwelling velocity in the deep layer should also become smaller. This would result in a deepening of the oxygen minimum layer, if it is assumed that consumption of oxygen as a function of depth remains constant.

If the bottom water supply was completely ceased, the oxygen content of the bottom layer would decrease according to the oxygen consumption rate in the bottom layer. Therefore, the reduction rate of dissolved oxygen in the bottom layer can be taken as the lower limit of the oxygen consumption rate. This is 0.7 μmol kg^{-1} y^{-1} in the Yamato Basin and 1 μmol kg^{-1} y^{-1} in the eastern Japan Basin from Table 2. These values are almost the same order of the value of 0.4 μmol kg^{-1} y^{-1} obtained by dividing the AOU of the bottom water by its mean residence time (Gamo and Horibe, 1983). Compared

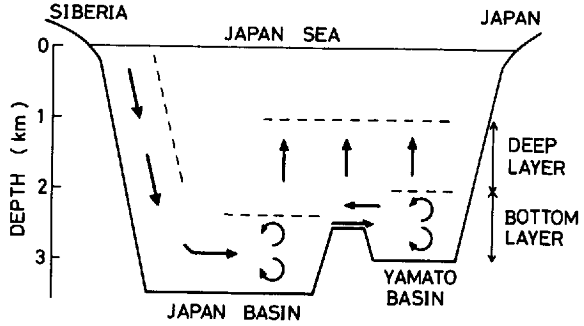

Figure 8. Simplified vertical section of the Japan Sea with a schematic flow pattern of the abyssal circulation. Eddy-like arrows stand for the concept of active vertical mixing, not for real direction of water currents.

with the oxygen consumption rate of about 0.1 μmol kg^{-1} y^{-1} estimated for the open ocean deep water (e.g., Kroopnick, 1980), that of the Japan Sea bottom water is an order of magnitude greater.

6. Abyssal circulation pattern: a hypothesis

The temporal variations of oxygen profiles lead to the conclusion that the abyssal circulation in the Japan Sea is in not a steady but a transient state for these 15 years. Nitani (1972), who found the temporal variations of temperature and oxygen profiles in the Japan Sea from 1930 to 1970, also discussed about the unsteadiness of the bottom water formation. He proposed the idea that the sinking of dense surface water to the bottom in the northwestern shore does not occur in every winter but it occurs in especially cold winters.

Our results of this study, together with those by Nitani (1972) and Gamo and Horibe (1983), can lead us to the following hypothesis about the abyssal circulation system in the Japan Sea.

In especially cold winter, the surface water in the northern or northwestern Japan Sea becomes dense enough to sink to the bottom due to cooling and freezing. For the initiation of the deep convection, an appropriate combination of the surface conditions (wind, precipitation, surface circulation pattern etc.) would be necessary. The newly formed bottom water would have kinetic energy and drive the bottom layer to maintain active vertical mixing. It may be likely that the enormous supply of new bottom water should increase the oxygen content in the bottom layer, increase the thickness of the bottom layer, and shallow the depth of the oxygen minimum layer. On the other hand, the bottom water is little formed in relatively warm winter.

There is a transport of bottom water from the Japan Basin to the Yamato Basin which is restricted to some extent by the topographic effect of the Yamato Rise. In the deep layer, water upwells to balance the supplied bottom water. The repetition of these processes forms a closed abyssal circulation system. This is illustrated in Figure 8.

Little is known about the spacial and temporal variations of water properties in the northern Japan Sea which is regarded as a source region of the bottom water. In order to prove the above hypothesis, it is desirable to research in the northern and northwestern Japan Basin especially in winter season, as well as to continue monitoring the temporal variations in the eastern Japan Basin and in the Yamato Basin through detailed physical and chemical observations.

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REFERENCES

Bryden, H. L. 1973. New polynomials for thermal expansion, adiabatic temperature gradient and potential temperature of sea water. Deep-Sea Res., *20,* 401–408.

Carpenter, J. H. 1965. The accuracy of the Winkler method for dissolved oxygen analysis. Limnol. Oceanogr., *10,* 135–140.

Carritt, D. E. and J. H. Carpenter. 1966. Comparison and evaluation of currently employed modifications of the Winkler method for determining dissolved oxygen in seawater; a NASCO report. J. Mar. Res., *24,* 286–318.

Gamo, T. and Y. Horibe. 1983. Abyssal circulation in the Japan Sea. J. Oceanogr. Soc. Japan, *39,* 220–230.

Horibe, Y. (ed). 1981. Preliminary Report of the *Hakuho Maru* Cruise KH77-3 (PEGASUS Expedition). Ocean Research Institute, Univ. of Tokyo, 55 pp.

Horibe, Y. and T. Gamo. 1981. Modified Carpenter's method, *in* Preliminary Report of the *Hakuho Maru* Cruise KH77-3 (PEGASUS Expedition), Y. Horibe, ed., Ocean Research Institute, Univ. of Tokyo, 53–55.

Horibe, Y., Y. Kodama and K. Shigehara. 1972. Errors in sampling procedure for the determination of dissolved oxygen by Winkler method. J. Oceanogr. Soc. Japan, *28,* 203–206.

Japan Meteorological Agency. 1971. The results of marine meteorological and oceanographical observations No. 46, 270 pp.

Kroopnick, P. 1980. Isotopic fractionations during oxygen consumption and carbonate dissolution within the north Atlantic deep water. Earth Planet. Sci. Lett., *49,* 485–498.

Maizuru Marine Observatory. 1977–1984. Oceanographic Prompt Report: The result of the oceanographic observations in the Japan Sea Nos. 311–349 (in Japanese).

Moriyasu, S. 1972. The Tsushima Current, *in* Kuroshio: Its Physical Aspects, H. Stommel and K. Yoshida, eds., Univ. of Tokyo Press, 353–369.

Nitani, H. 1972. On the deep and bottom waters in the Japan Sea, *in* Research in Hydrography and Oceanography, D. Shoji, ed., Hydrographic Department of Japan, 151–201.

Suda, K. 1932. On the bottom water in the Japan Sea (preliminary report). J. Oceanogr., *4,* 221–241 (in Japanese).

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