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Abyssal Circulation in the Atlantic near the Poles and Abyssal Circulation in the Pacific and other Oceans in relation to the Former*

Jiro FUKUOKA**

Abstract: H. Stommel's idea about the abyssal circulation in all the world has theoretically departed from the existence of the sources (areas of sinking motion) in the northern part of North Atlantic and in Weddell Sea, and the steady ascending motion in deep layer in sea areas of middle latitudes. The present author has researched into the abyssal circulation from the viewpoint of data analysis.

The authors study resulted in the following: The sinking motion of the northern part of North Atlantic is superior to it of Antarctic Ocean on an average. According to the distribution of oxygen, it may be seen that there is an area of sinking motion in Ross Sea. From the horizontal distribution of phosphate-p at deep layer, we can find that abyssal circulation is similar to chart of Stommel.

1. Abyssal circulation in the both polar seas of the Atlantic.

Hitherto it has been supposed that the sources (the areas of sinking motion) exist in the northern part of North Atlantic near Greenland and in the Antarctic Ocean. The supposition of sinking motion in the source area should be based upon the fact that the vertical distribution of oxygen is uniform from upper to deep layers. So the vertical distribution of oxygen in the seas around Antarctica is researched in the first place. We define the northern part of North Atlantic as the area north of 65°N and the Antarctica Ocean (the seas around Antarctica) as the area south of 65°S. In Fig. 1a the vertical distribution of oxygen is shown for the seas around Antarctica. At a glance it is seen that oxygen values are 8-10 cc/L at the surface layer, and then decreasing, about 5 cc/L at 500-m layer. These vertical distributions in Fig. 1 are drawn from the data of recent years.

The trend that oxygen values at deep layer are lower than those of surface layers is seen not only from the recent data, but also from the old observational data reported by ships, the Discovery II and the Norvegia. Fig. 2 represents the observational results of the

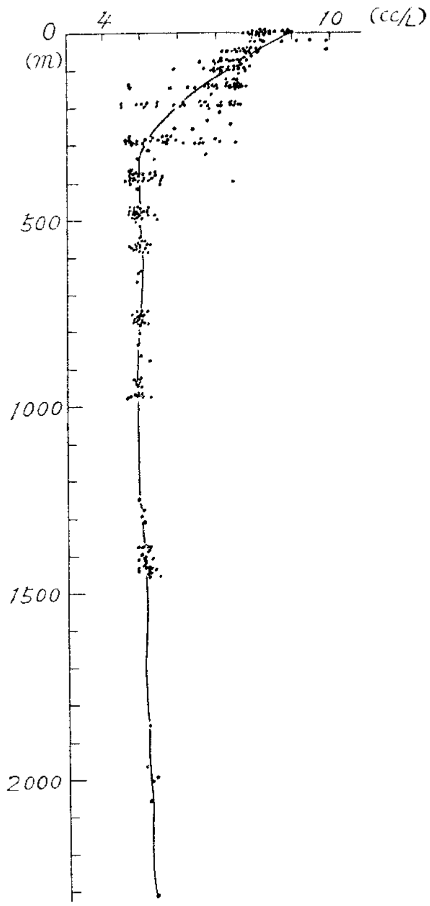

Fig. 1a-1 Vertical distribution of O_2 (cc/L) in summer (Umitaka-maru, Jan.-Feb., 1957)

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** Meteorological Research Institute.

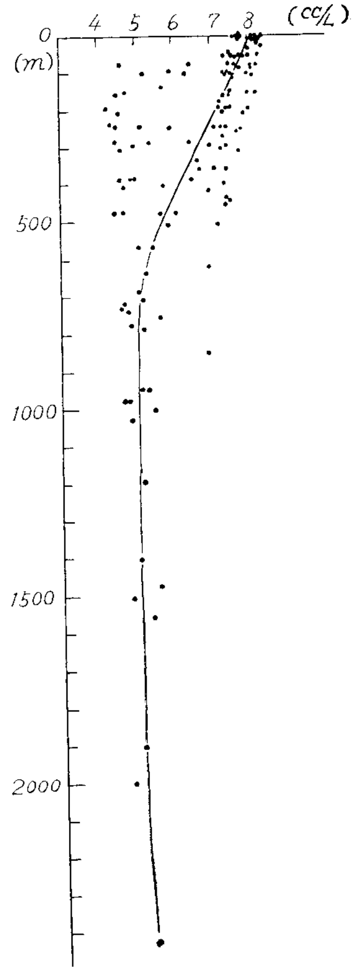


Fig. 1a-2 Vertical distribution of O_2 (cc/L) in summer (Ob, Jan.-Feb., 1956)

Discovery II in the northern part of Weddell Sea. At the southern boundary of this part also we can see that the oxygen values are large in upper layers and small in deep layers.

With reference to these data, it is sure that the vertical distribution of oxygen in the seas around Antarctica shows fairly different values of oxygen in upper and deeper layers. Investigation on the vertical distribution of density (σ_t) gives Fig. 1b, where a remarkable vertical gradient of density is seen. It is supposed that these density differences along the vertical will exert some influence upon the vertical distribution of oxygen.

Now, we must research the vertical distribution of oxygen in the northern part of North

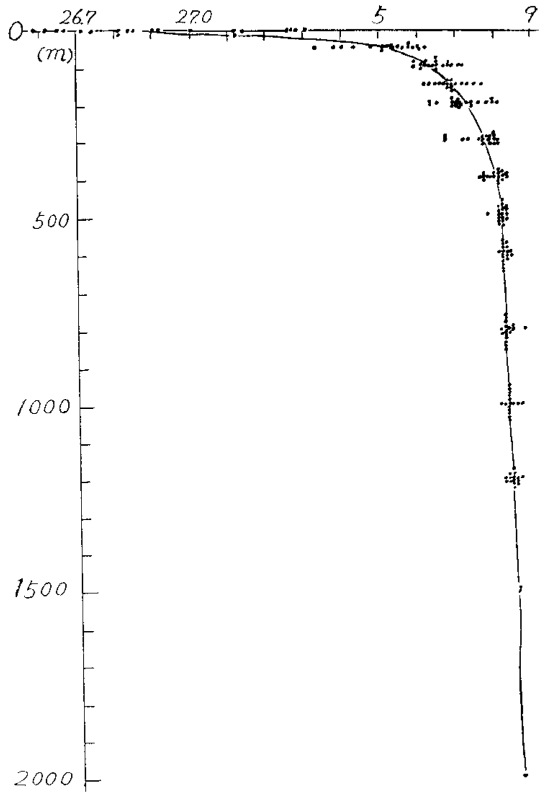


Fig. 1b-1 Vertical distribution of density (σ_t) in summer (Umitaka-maru)

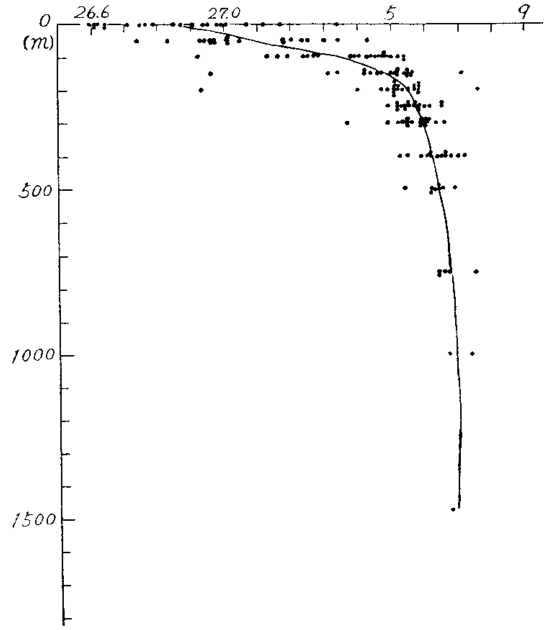


Fig. 1b-2 Vertical distribution of density (σ_t) in summer (Ob)

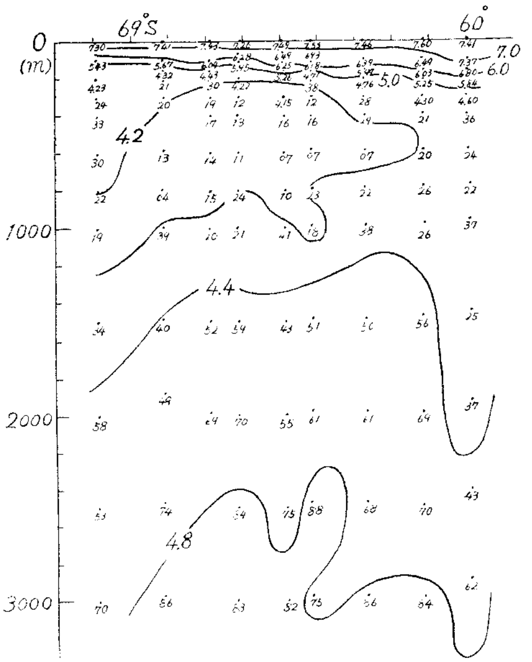
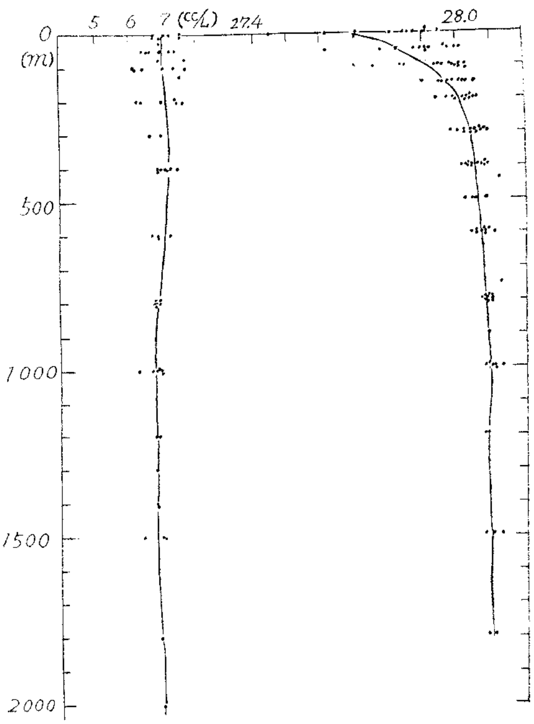


Fig. 2 Vertical distribution of O_2 (cc/L) along 20° W in summer (Discovery II, Jan., 1932)



(a) (b)

Fig. 3 Vertical distributions of O_2 (cc/L) and density (σ_t) in the North Atlantic in summer

Atlantic, the area of another source. For this research the data published in Bulletin Hydrographique 1950–53 have been used, and the vertical distribution of oxygen is shown in Fig. 3a.

The oxygen value of 2000-m layer is not very different from that of surface layer. When we think that the surface water is rich in oxygen because of its exposure to the atmosphere, the deep-layer water which is rich in oxygen may surely indicate the sinking motion. In order to compare the vertical distribution of oxygen with the vertical stability, the vertical density distribution is also shown in Fig. 3b. When we compare the density distribution of Fig. 1 with that of Fig. 3, the difference in density distribution is clearly recognized between the northern part of North Atlantic and the seas around Antarctica (Antarctic Ocean).

The density difference between the surface and 200-m layers is shown in table 1. From this table it is seen that the vertical stability is greater in the Antarctic Ocean than in the northern part of North Atlantic.

It may be reasonable to consider that the difference of vertical stability between the northern part of North Atlantic and the Antarctic Ocean will exert some influence upon the difference of oxygen distribution. By what reason will be caused the difference of

Table 1. Density distribution in the northern part of North Atlantic and the Antarctic Ocean (in summer)

Depth \ Sea	Northern part of North Atlantic	Antarctic Ocean	
0	27.70	26.87	27.14
200	28.02	27.71	27.71
		(Umitaka-maru)	(Ob)

Table 2. Salinity distribution in the northern part of North Atlantic and the Antarctic Ocean (in summer)

Depth \ Sea	Northern part of North Atlantic	Antarctic Ocean	
0	34.81	33.79	33.43
200	34.89	34.58	34.47
		(Discovery II)	(Umitaka-maru)

vertical density distribution? In order to know this reason, we must research the vertical distributions of water temperature and salinity.

In the sea areas of low water temperature at high latitudes, the density distribution is more strongly affected by salinity than by temperature. The salinity distributions are shown in table 2, and while the salinity of surface water is rather low in the seas around Antarctica, it is rather high in the northern part of North Atlantic. (As for the general distribution, refer to the chart of salinity distributions in the Oceans after H. U. Sverdrup)

Next, we should research the difference in salinity distribution between the northern part of North Atlantic and the seas around Antarctica. When we glance at the pilot chart of the Atlantic, we can consider that precipitation and evaporation in both of the two sea areas may be similar to each other, respectively, and that the salinity distribution in both the sea areas will be strongly affected by the land water transported from the continents or large islands.

The land water supply form rivers and glaciers to the northern part of North Atlantic must be studied, but we cannot see the value of this supply exactly. On the other hand, the amount of water supplied by glaciers into Weddell Sea is said to be about 0.6×10^{18} gr/year, but this value also is not very exact, because it was made known to the author by personal communication from K. Kusunoki, Low Temperature Institute, Hokkaido University, together with other data. Areas covered by ice in Greenland and Antarctica seem to affect the salinity distribution (table 3). If the thickness of ice is equal in both the regions, the ratio of the volumes of ice in the regions is 1 : 10. The ice volume which has a direct effect on the salinity distribution in the northern part of North Atlantic may be about 1/3 of the total ice volume of Greenland, and the effective ice volume for the Altantic sector of Antarctic Ocean may be about 1/3 of the total ice of the Antarctica. The largest glacier in Greenland, Humboldt Glacier, flows to the north coast and may have no effect on the salinity distribution of the northern part of North Atlantic, and on the other hand, the glaciers facing to Weddell Sea may have about 1/3 of the total ice of Antarctica. So it is considered that the water supply to Weddell Sea is about 10 times larger than that from Greenland to the northern part of North Atlantic. Smaller salinity, i. e., lower density of the surface water in the Antarctic Ocean might be due to this. Such consideration is based upon supposition, but in view of the fact that in the recent IGY many observations of glaciers were carried out, the water supply from glaciers to the Atlantic will be hereafter more and more examined.

Table 3. The area of glaciers

In Antarctica	13,500,000km²
In Greenland	1,650,000

The vertical distributions stated above are obtained only for the summer season, and it is necessary to investigate for the winter season so that we may know the mean abyssal circulation distinctly. As the cooling and freezing of the surface water layer is generally active in winter, the surface water sinks and the convec-

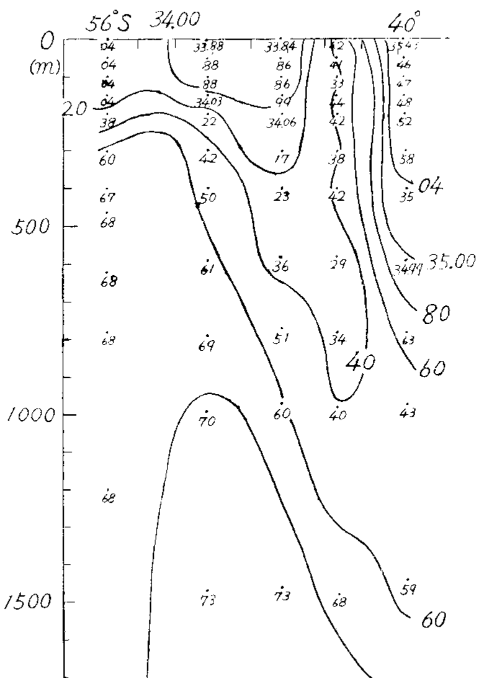


Fig. 4 Salinity distribution along 21°E in winter (Discovery II, July 1938)

tion is brisk, it is said. But the data of active sinking in support of this concept are not very numerous in the Antarctic Ocean, because oceanographical observations in winter are very difficult.

When we refer to the data of Discovery II from among the scanty data of winter, the vertical distribution of oxygen in June and July shows a difference between the surface and deep layers in the seas around Antarctica, and the vertical distribution of salinity also shows a small difference between the surface and deep layers, although the difference is not so remarkable as in summer (Fig. 4). These vertical distributions may indicate a fact that even in winter the convection current is not predominant. The data of Fig. 4 are observed at 56° S, and in more southern areas the sinking motion may be striking.

In the northern part of North Atlantic the vertical distributions of oxygen, salinity and density are fairly uniform in winter. If we suppose sinking motions in the northern part of North Atlantic (north of 65° N) and in the seas around Antarctica (south of 65° S), the sinking motions in both areas will be the same in winter, but in summer sinking motion will be more predominant in the northern part of North Atlantic than in the seas around Antarctica. The author thinks the difference of sinking motion in both the areas to be very important for future study. Recently H. Stommel has published a report of the abyssal circulation, supposing that the water amounts transported by sinking motion in both the said source areas are approximately equal, and has drawn a block diagram which indicates the system of abyssal circulation in all the world. If the amounts were so, and if we take into consideration the difference in sinking speed stated by the present author, then it would be reasonable to assume a difference in the areas of sinking motion at the north and south ends of Atlantic Ocean, and we should have to grasp the actual states of the source areas in the northern part of Atlantic Ocean and Weddell Sea.

2. The abyssal circulation around Antarctica

Hitherto, a remarkable sinking motion in Weddell Sea due to the vertical distribution of oxygen has been pointed out. But in the former chapter of the present paper it is stated that the sinking motion is generally weaker in the seas around Antarctica than in the northern part of North Atlantic. A study on the horizontal distributions of oxygen and salinity at 2000-m and 3000-m layers gives the map of Fig. 5. From Fig. 5, it is seen that an area of high concentration of oxygen or salinity lies in the Atlantic Ocean to the north of Weddell Sea.

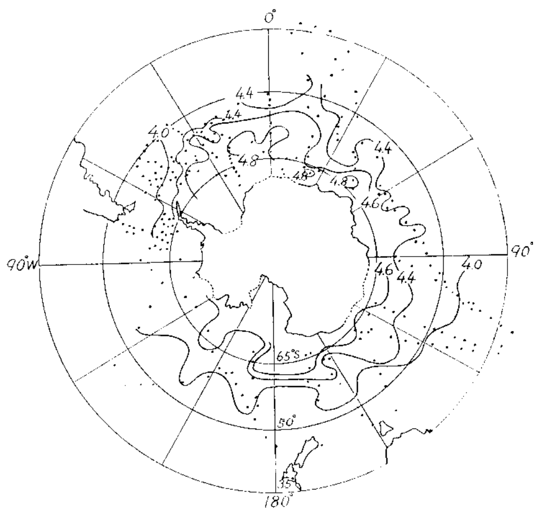


Fig. 5 O_2 at 2000-m layer (Discovery II and Umitaka-maru)

and starting from this area the concentration becomes lower in the seas near Antarctica. From the horizontal distributions it can be estimated that the source area in the Antarctic Ocean may be situated in the vicinity of Weddell Sea.

Though an uniform vertical distribution of oxygen cannot be seen in the seas where the Discovery II carried out observations (northern part of Weddell Sea), such distribution is seen, according to the recent data of the USN icebreaker Atka, in the southern part of Weddell Sea (Fig. 6). It may be deduced that the area of sinking motion of Weddell Sea has a trend to occupy the southern part of Weddell Sea, that is, the part near the

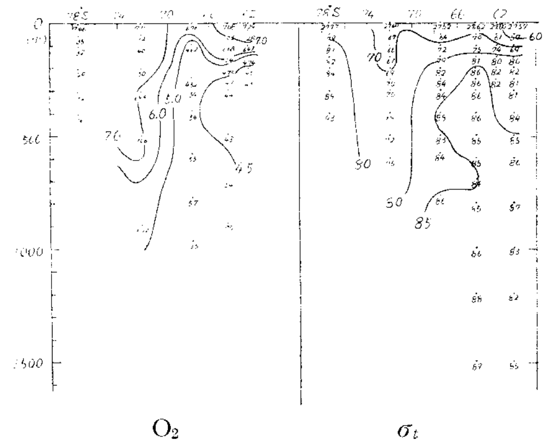


Fig. 6 Vertical distributions of O_2 and σ_t in Weddell Sea (Atka, Dec., 1956)

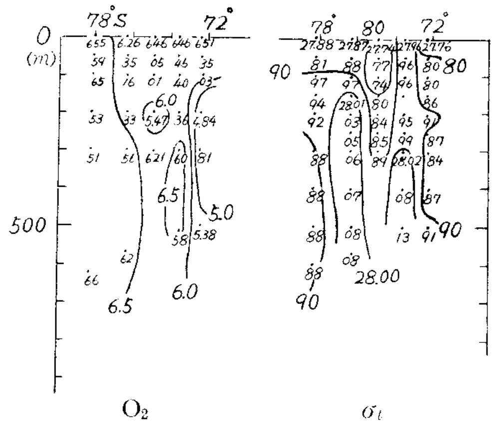


Fig. 7 Vertical distributions of O_2 and σ_t in Ross Sea (Atka, Nov., 1956)

Antarctica, as Stommel and Wüst and others have stated before. From Fig. 6 also, it is seen that the sinking motion is prevailing in the seas south of 72°S, and the area is considered to occupy 60°W-20°W, 72°S-77°S.

On the other hand, the area of sinking motion in the northern part of North Atlantic occupies a rather narrow part, 20°W-10°W, 67°N-73°N. The difference between the two areas of sinking motion may be apparent, but the above-stated values are not very accurate. It is desirable that the difference will be much more investigated in future.

Weddell Sea, where the observations were made at comparatively shallow layers, may be tentatively admitted to be an area of sinking motion, but still then there remains a question.

Uniform vertical distribution of oxygen is also seen in Ross Sea (Fig. 7). In the interior of Ross Sea the sinking motion is prevailing, according to the data of oxygen (Fig. 7). The sinking motion in Weddell Sea and Ross Sea, may have some influence upon the abyssal circulation in the Pacific. From the viewpoint of abyssal circulation we must arrange the oceanographical data in the seas around Antarctica. It is said that an area of remarkable sinking motion was recently discovered near Antarctica by the oceanographical observations of the research ship "Ob" of USSR. Many problems are left to be solved. The author thinks that from a standpoint of descriptive oceanography it is necessary to determine exactly the area of sinking motion (source area) near Antarctica, on the basis of all oceanographical data obtained by many countries, if possible. It is also important to compare the source area in the northern part of North Atlantic with that in the seas around Antarctica.

3. The abyssal circulation in the Pacific and other oceans.

As for the abyssal circulation of the Pacific, it is said that the deep-layer water of South Pacific moves northwards. In order to make

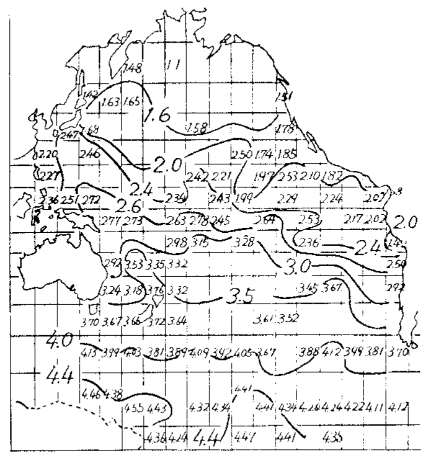


Fig. 8 O_2 at 2000-m layer in the Pacific

clear this concept, the horizontal distiribution of oxygen at 2000-m layer is shown in Fig. 8. The data are taken from a Russian book "Основные Черты Гидрологии Тихого

Океана" (Main characteristics of hydrography in the Pacific Ocean) after A. M. Muromzef.

In Fig. 8, high concentration of oxygen is seen in the southern part of Pacific Ocean, and the oxygen value gradually decreases towards north. The values of oxygen are larger in the western half of Pacific Ocean than in the eastern half. This trend is similar to the distribution of oxygen at 3000-m layer. It is supposed that the abyssal circulation of the Pacific is in a clockwise direction. For reference the oxygen distribution at 2000-m layer in Indian Ocean is shown in Fig. 9. The data are taken from "Основные Черты Гидрологии Индийского Океана" (Main characteristics of hydrography in the Indian Ocean) by A. M. Muromzef.

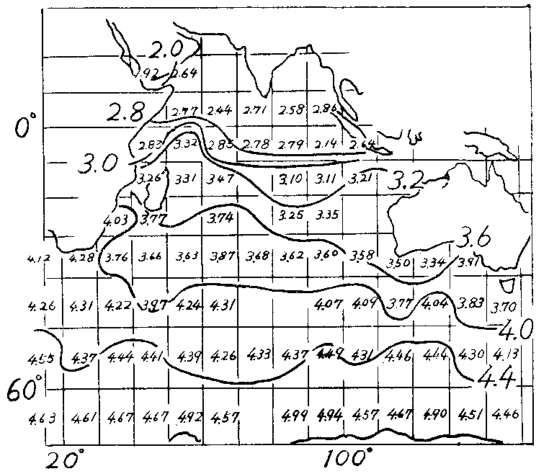


Fig. 9 O_2 at 2000-m layer in the Indian Ocean

The distribution of oxygen in the Indian Ocean is similar to that in the Pacific, that is, the values of western side of the Indian Ocean is higher than the values of eastern side. But in general the oxygen values of the Indian Ocean is higher than those of the Pacific Ocean.

On the other hand, the values of phosphate-p become gradually higher, starting from the northern part of North Atlantic Ocean through the Indian Ocean until the Pacific Ocean (Fig. 10). Besides the discussions of oxygen and phosphate-p, biochemical consideration should be made, but the present author has not conducted it, because the difference in distribution of plankton between the northern part of North Atlantic and the Antarctic Ocean is not seen in the report of Sverdrup, and the study of abyssal circulation from the viewpoint of biochemistry remains as a future problem.

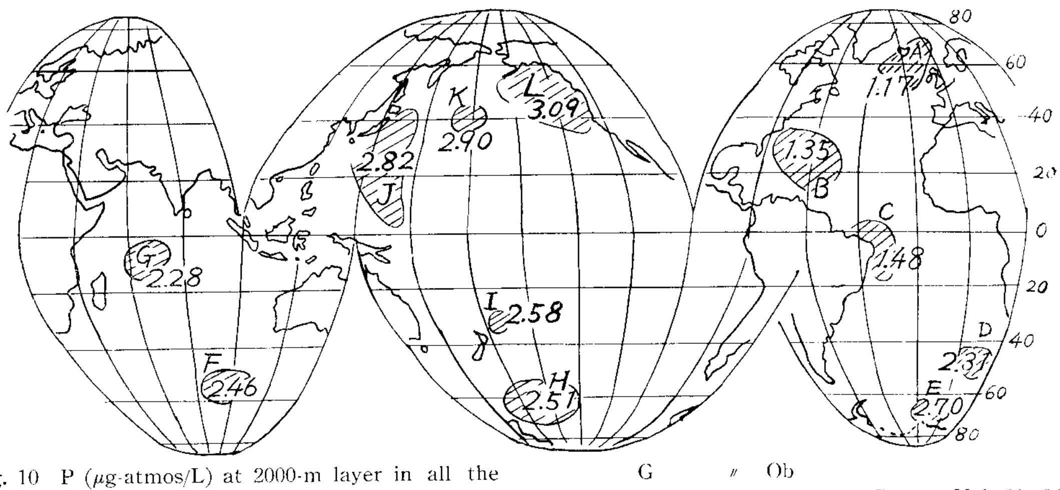


Fig. 10 P (μg-atmos/L) at 2000-m layer in all the world

A,B,C from Bulletin Hydrographique 1950-53
D, E 〃 Discovery Report Vol. 21, 24
F 〃 Discovery Report Vol. 21, 24 and Ob
G 〃 Ob
H 〃 Discovery Report Vol. 21, 24
I 〃 Vitiaz
J 〃 Ryofu-maru (JEDS and NORPAC)
K 〃 Vitiaz
L 〃 Washington Univ., (NORPAC)

On the basis of the sketch map of abyssal circulation by Stommel, we can expect a strong northward current from the western boundary of the Pacific Ocean. But the information about abyssal circulation in the Pacific is not at all known except for Japan and vicinity, and a part of equatorial zone. We are in hopes of observing an abyssal current in the western part of the South Pacific and in the wide low latitudes of Pacific.

In the seas adjacent to Japan the observation of deep current has been carried out since 1960 by members of Meteorological Research Institute and Japan Meteorological Agency. These data are valuable for the study of deep current in the Pacific Ocean.

4. Future problems.

It is necessary to know the difference of mechanism in the source area between the northern part of North Atlantic Ocean and the Antarctic Ocean, and to make a detailed study of the oceanographic structure of Ross and Weddell Seas in order to find the source area.

We should study on the water supply from glaciers to the seas near Greenland and Antarctica. Next, it is important to pursue the abyssal circulation by using the data phosphate-p also. The author is now planning to collect and arrange the oceanographical data of the Antarctic Ocean.

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