On the Sea Water and Criculation in the North Pacific (1)

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In the North Pacific Ocean, the vertical circulation is not so active and the inflow the south to the northern area is small. In the northern area of the North Pacific Ocean, the surface salinity is too low for winter cooling to make the water dense enough to sink to any considerable depth.

In the Gulf of Alaska, the salinity is remarkably low at the sea surface, but it is higher in the intetrmediate layer than the water in the southern or the eastern area, though there is no appreciable source of salt in the interior of the area. The salinity values shown at the depths of 400m and 600m in the region of Alaska (in lat. 50°N, long. 140°W) are somewhat higher than those at the same depths in the western area of the Guif.

The Intermadiate Water is generally considered to be formed in the convergence area to the norteast of Japan, but it also seems to originate somewhere farther north, for instance in the Bering Sea and the Sea of Okhotsk. The Intermediate Waters which sink in the subarctic convergence area and in the more northern regions mentioned above, does not flow directly south but flows toward the east, sending branches off to the south. And waters travel the long distance to the west increasing in their salinity. The Waters cause a large clockwise circulation and upwell on the way of the circulation.

This phenomenon is suited to be called "the Intermediate Circulation".

Key words : The Gulf of Alaska. Low Salinity. Convergenct area. Inlermediate watar.

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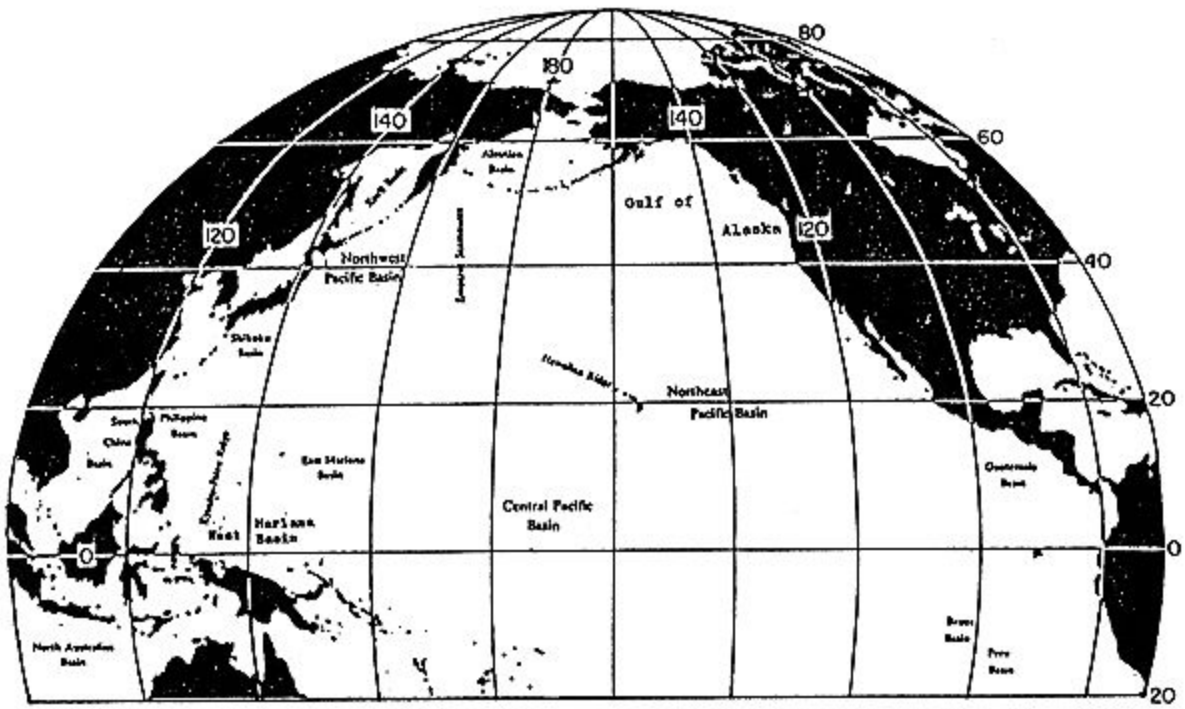

Fig.1 Morphological features of the North Pacific Ocean.

1 Introduction

Sverdrup (1946)[1] suggested that Intermediate water is formed in the west near Japan by sinking at the convergence of the Oyashio and the Kuroshio Extension.

Reid (1969)[2] has pointed out that the salinity minimum of the North Pacific Intermediate Water occurs on a surface of constant density σ_t=26.8 and that water of this density does not occur at the surface in the North Pacific at any season. He concluded that this water attains its properties below the surface by vertical mixing in the subarctic region where the paticular density surface is shallow and the surface waters above are cold, low in salinity and high in oxygen content.

It is one of the few exceptions to the general rule that subsurface water masses acquire their TS characteristics at the surface of the sea. Both to the north and to the south of 36 °N an Intermediate water is present, characterized by a salinity minimum. Below the mixed water to the north of 36°N the salinity minimum is found at a depth of 300m. the lowest salinities being less than 33,8 ‰[1].

As mentioned above, it is thought that no saline water in the northern North pacific should be produced at the surface due to brine (salt) rejection during ice formation, so the sinking does not occure to large depth.

In the northern area, the surface salinity is too low for winter cooling to make the water dense enough to sink to any considerable depth.

North of the North Pacific Central water is a Pacific Subarctic water which extends across the greater salt of the ocean. Its characteristic properties are low salinity and relatively low temperature.

In the Labrador Sea, deep sinking occurs to depth of 1,500-2,000m or more in Lats, 56～57°N, and there is no geometrical reason why similar deep sinking should not occur at comparable

latitudes in the North pacific (warren, 1983)[3]. The immediate reason why sinking does not occur to great depth in the northern North Pacific is that the surface is too fresh. In this region, the average surface salinity is about 32.7 ‰ according to Rebinson's map (1976)[4] of annual-mean surface salinity, while according to Reid's (1969)[2] the winter average is about 32.9‰.

These values cannot be made dense enough to sink very deep even when the surface temperater is reduced to the freezing point. In the northern North Atlantic, on the other hand, the average surface salinity is about 34.9 ‰ (Robinson et al., 1979)[5], much closer to the deep-water values. In this paper the sea water and the circulation in the intermediate layer especially in the subarctic region, will be discussed.

2 The water of the northern area

In Fig.2 and 3 a Subarctic waters (curves at left side) which are characterized by a low temperature and by a salinity which at the surface may be as low as 32 ‰ but increase rapidly in the intermediate layer and below the layer increase slowly in deep layer.

Fig.2 shows meridian profiles from the inner area in the gulf of Alaska to the south along 140°W of specific volume-salinity diagram. The salinity values of the surface waters increase regularly, from the north to the south, reaching 35 ‰ in tropical water at 20°N. The salinity minima found in another three curves upper left parts within the dashed rectangle show the Subarctic Intermediate waters.

The salinity values shown at the depths of 400m and 600m in the region of Alasa (in lat. 50 °N, long. 140 °W) are somewhat higher than the values of same depths in another curves. The curves off the Gulf of Alaska increase rapidly its salinity from the surface to the intermediate layer.

Fig.3 shows the vertical profiles from the data of NORPAC. In the subarctic water on the surface in the Bay of Alaska (dashed curve), no salinity minimum is present, and its salinity increses gradually in the underlaying deep waters. The salinity value at the depth of 800m is 34.13 ‰ which is higher than the value at the same depth in Ogasawara area. The specific volume-salinity relations between Ogasawara area and Shikoku Basin showing salinity minima are similar. The salinity minima are found in the both two curves of the Ogasawara area and the Shikoku Basin at the depths of about 600m and 800m respectively.

In the west of the North pacific, the salinity minimum is deep but rise to the east.

Fig.4 shows salinity distributions for different depths and each stations from the southwest to the northeast directions in the North Pacific. The salinity values in the upper layer shallower than 1,000m vary widly between 20 °N and 40 °N, and salinity minima are found around at lat. 30 °N, long. 140 °E.

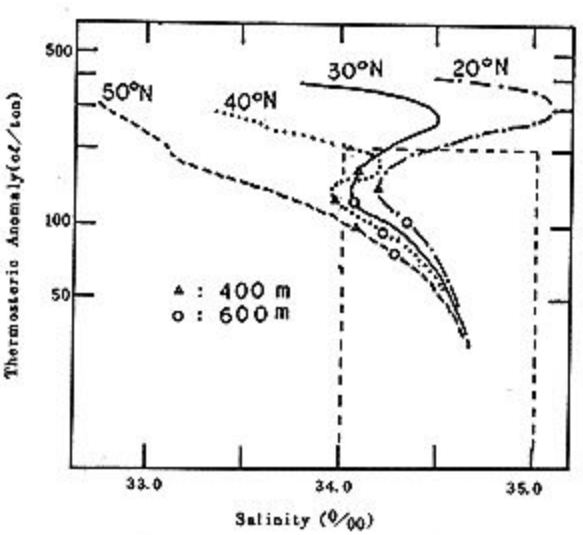

Fig.2 South-North longitudinal profiles along 140°W of specific volume-salinity diagram from the data of Oceanographic atlas[6]. 90% of the world ocean has density and salinity values within the dashed rectangle (Pond and pichard)[7].

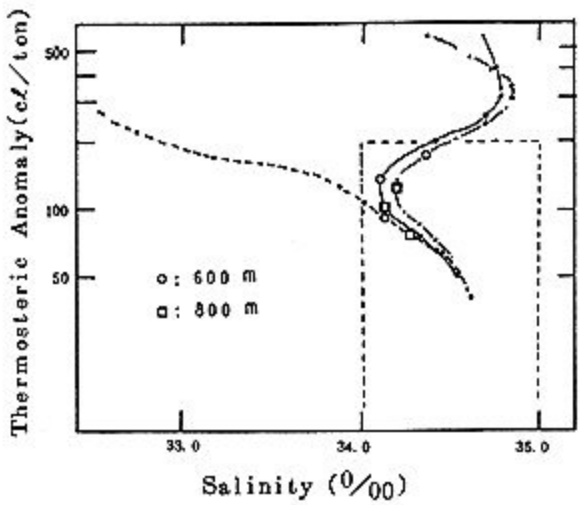

Fig.3 Specific volume-salinity diagram from the data of NORPAC.[8] Dashed line shows from the data of Alaska Bay (58° 54' N, 142 °01' W), solid curve of Ogasawara area (25°05' N, 143 °28' E) and another one of Shikoku Basin (30°10' N, 134 °10' E).

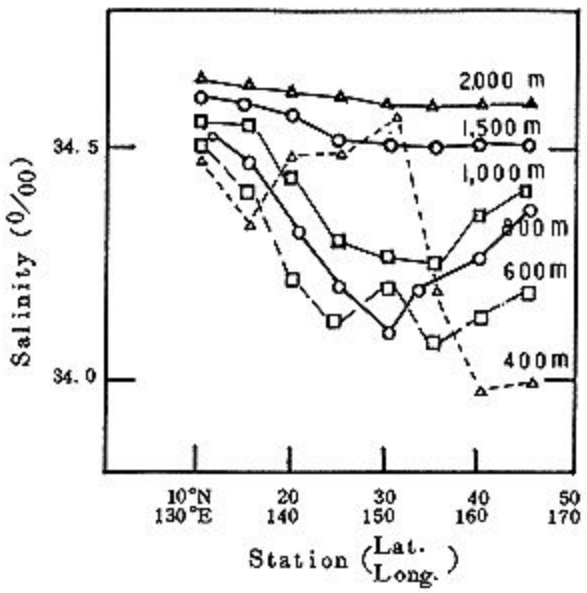

Fig.4 Salinity distributions for different depths and each stations from S-W to N-E directions in the western North Pacific (from the data of Japan Hydrographic Association).[9]

The salinity of the layer being deeper than 1, 500m scarcely changes. The salinity values of the intermediate water at the depths of 600, 800 and 1,000m increase rapidly in the area from lat. 30 °N, long 150 °E to lat.50 °N long. 170 °E.

3 The Intermediate Water in the subarctic region

It is hardly thought that the salinity of the Intermediate water in the subarctic region is supplied by vertical mixing with deep water. In the Gulf of Alaska, the salinity is remarkably low at the sea surface, but it gets a higher salinity in the intermediate layer than the water in the southern or the eastern area (fig.3), though there is no appreciable source of salt in the interior of the area.

The Intermediate Water is interpreted to be formed in the convergence area to the northeast of Japan to these days, but it also seems to originate somewhere in the more northern area, for instance in the regions of Gulf of Alaska, the Bering sea and the Sea of Okhotsk. Since, the surface water of these regions (mainly last two regions) freeze ever in winter season. The freezing of the sea water concentrates salt in the surface layer so that water of higher salinity tends to form and sink. It is thought that the Intermediate Water in the northern ares is produced by ice formation and addition of salt, and it gets a higher salinity by concentration.

4 The circulation of the Intermediate Water

The Intermediate Water of lower salinity which to the north of the convergence between the Kuroshio and the Oyashio is found at depths of 300m or less, does not flow directry south but flows toward the east, sending branches off tc the south. A large clockwise gyre consequently

appears to be present in the Western Pacific approximately between 160°W and the coast of Asia, with a whirl rotating in the same direction directly off the coast of Japan[1].

Fig.5 shows sectional distribution of salinity and depth, plotted as function of sigma-t, along latitude 11 °N from the Philippine Basin to the Northeast Pacific Basin. The washy salinity waters on the surface of eastern area attaine a relatively higher salinity and tends to sink. The Intermediate Waters, being to sink and tear to pieces, travel to the west and reach nearly off the coast of Mindanao Island.

These intermediate waters produced in the northern regions, near convergence area are found at the depth of 300m or less, flow toward the east and branch away to the south. Below the Kuroshio water the salinity minimum is found at a depth of about 800m, and the values are between 34.00 ‰ and 34.10 ‰, whereas the northern area the salinity minimum is found at a depth of 300m, the values being less than 33.8 ‰.

In lat. 10°N, the layer of salinity minimum appers to be divided, and one branch sinking and approaching the minimum layer of the Equatorial Water[1]. Specific volume-salinity curves in Fig.2 and 3 except the curves of the Subarctic waters show the both characterestics of the Subarctic water and the Equatorial water.

5 Conclusion

In the North Pacific Ocean, the vertical circulation isn't so active and the inflow from the south to the northern area is small which may be due to its configulation.

It is found that the anomalously low surface salinity in the northern North Pacific is mainly due to the relatively low surface temperature, which seems to be caused by the same origine as the evaporation on the surface of a cold eddy. The low salinity water is extended on the surface of the Mindanao Eddy, and there is not such a low salinity water in the surroundings of the eddy (Midorikawa, et al., 1990; Nakano, et al., 1990).

This phenomenon is appreciated that the precipitation exceeds the evaporation in consequence of the low temperation on the surface of the eddy. It means that a high temperature of the surface water is a more effective factor for

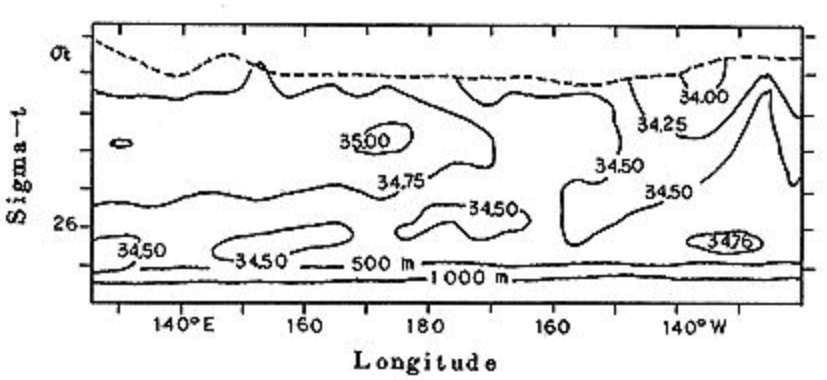

Fig.5 Salinity and depth, plotted as functions of sigma-t, along latitude 11 °N from the Philippine Basin to the Northeast Pacific Basin. Dashed line shows sigma-t at 10 meters in August (from Oceanogr. attlas).[6]

evaporation than the breeze or the atomospheric temperature. This fact is one useful evidence to explain the root of low evaporation in the northern North Pacific.

In the Gulf of Alaska, the salinity is remarkably low at the sea surface, but it gets a higher salinity in the intermediate layer than the water in the southern or the eastern area of the gulf. The Intermediate waters also seem to originate somewhere in the more northern area (may be in the Bering Sea) by freezing in winter season. The Intermediate waters sank in the subarctic convergence area and in the more northern regions, flow toward the east and branche away to the south. And the waters travele the long distance to the west increasing in their salinity shown in Fig.5. These waters cause a large clockwise circulation as like mentioned above and upwell somewhere on the way of the circulation. It is suited to give the name "Intermediate Circulation" for such a phenomenon.

Reference

1) Sverdrup, H. U., M. W. Johnson and R. H. Tleming : The Oceans, chap. xv, Prentice Hall, New York (1946)

2) Reid, J. L., Sea-surface temperature, salinity, and density of the Pacific Ocean in summer and in winter. Deep-Sea Res., 16, 215-224, (1969)

3) Warren, B. A. : Why is no deep water formed in the North Pacific ?. J.Mar.Res., 41, 327-347, (1983)

4) Robinson, M. K. : Atlas of North Pacific Ocean Monthly Mean Temperatures and Mean Salinities of the Surface Layer. Naval Oceanographic Office, Dept. Navy, Washington, D. C., 19pp. (1976)

5) Robinson, M. K., R. A. Bauer and E. H. Schroeder : Atlas of North Atlantic Indian Ocean Monthly Mean Temperatures and Mean Salinities of the Surface Layer. Naval Oceangrephic Office, Dept. Navy, Washington, D. C., 20pp. (1979)

6) Barkly, R. A. : Oceanographic Atlas of the Pacific Ocean. Univ. of Hawaii, Honolulu, (1968)

7) Pond, S. & Pickard, G. L. : Introductry Dynamical Oceanography, 2nd edi., Pergamon Press, Chap. 2 (1983)

8) 1955 The NORPAC Data : Oceanic Observations of the Pcific Univ. of California, (1969)

9) Marine Environmental Atlas, Northwestern Pacific Ocean : Japan Hydrographic Association, (1975)

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北太平洋の水質と循環について

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北太平洋ではその地理的条件から鉛直循環が他の海洋に比べて不活発で，特に，北部の海面の水温が低い。そのため北部海域の表層の塩分は低く，冬季においても表層水が沈降するのに十分な密度は得られないと考えられている。

NORPACの資料によるとアラスカ湾の表層水の塩分はかなり低いが，中層になると塩分は増加し，西部北太平洋の処々の海域の同じ深さ（たとえば400mや600m）の塩分値に比べて高い。今日，北太平洋の中層水の生成域は本邦の北東に連なる極前線と呼ばれる収束帯付近といわれているが，上記海域のもっと近く，すなわちさらに北部のベーリング海などにおいても，冬季にその生成が行われるものと考えられる。その理由の一つに，アラスカ湾の表層には塩分を増加させる源がないことで，隣接海域からの移動と高緯度における冷却がその成因であろうと考えられる。

北太平洋の中層水は，西部あるいは北部の海域で生成されて沈降しつつ東へ，そして分岐して南へと流れ，さらに長い道程を西へ，そして北上と，徐徐に塩分を増大させ，あるいは途中で湧昇を生じたりして移動を続ける。これは北太平洋の中層における一つの大きな循環，すなわち中層循環である。

キーワード：アラスカ湾，低塩分，収束帯，中層水

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