# On the Water Masses of the Southern Ocean in the Section between Queen Maud Land and South Africa

Sadakiyo HORI*

# Queen Maud Land と南アフリカ間における南極洋の水塊について

堀　定清*

要　旨

第7次南極地域観測の海洋観測によって明らかにされた，Queen Maud Land と南アフリカの間における，南極洋の水塊の状態について記述した．また，DISCOVERY II (1933) および OB (1957 および 1962) の観測資料と比較した結果，特に底層水については，その性質にわずかではあるが年による差違が認められ，底層水の生成に示唆をあたえるものとして注目される．

## Introduction

Although a great number of serial observations have been made in the Southern Ocean, there are not very many observations which are deep enough and can be used for the synoptic investigation in a section, except those of the DISCOVERY II made in 1932–33 and of the OB in 1957–58. The Japanese Antarctic Research Expeditions (JARE) had carried out more or less oceanographic observation on board the SOYA and UMITAKA-MARU since 1956 until 1962 and the results were reported by the observers who were engaged in those Expeditions (KUSUNOKI, 1958; ISHINO, 1958; TORII, 1959; ONO, 1960; FUKASE, 1961 and 1962; HORI, 1962; KUGA, 1963). However, very few serial observations were made for the layer deeper than three thousands meters during these expeditions. In 1965 the Japanese Antarctic research was resumed as JARE–7 with the new ice-breaker FUJI which was capable to carry out serial observation to the depth about 6000 meters.

Some of the stations occupied by JARE–7 are in the section between Princess Astrid Coast of Queen Maud Land and Cape Town of South Africa (10°–15°E), where the hydrographic casts could reach the Antarctic bottom water. This portion of the Southern Ocean had been surveyed by the DISCOVERY II and the OB along nearly the same section (10°–15°E and 20°E, respectively), and is much likely to be repeated every year by JARE, so that it can be taken as a fixed line of obser-

* 海上保安庁水路部. Hydrographic Division, Maritime Safety Agency.

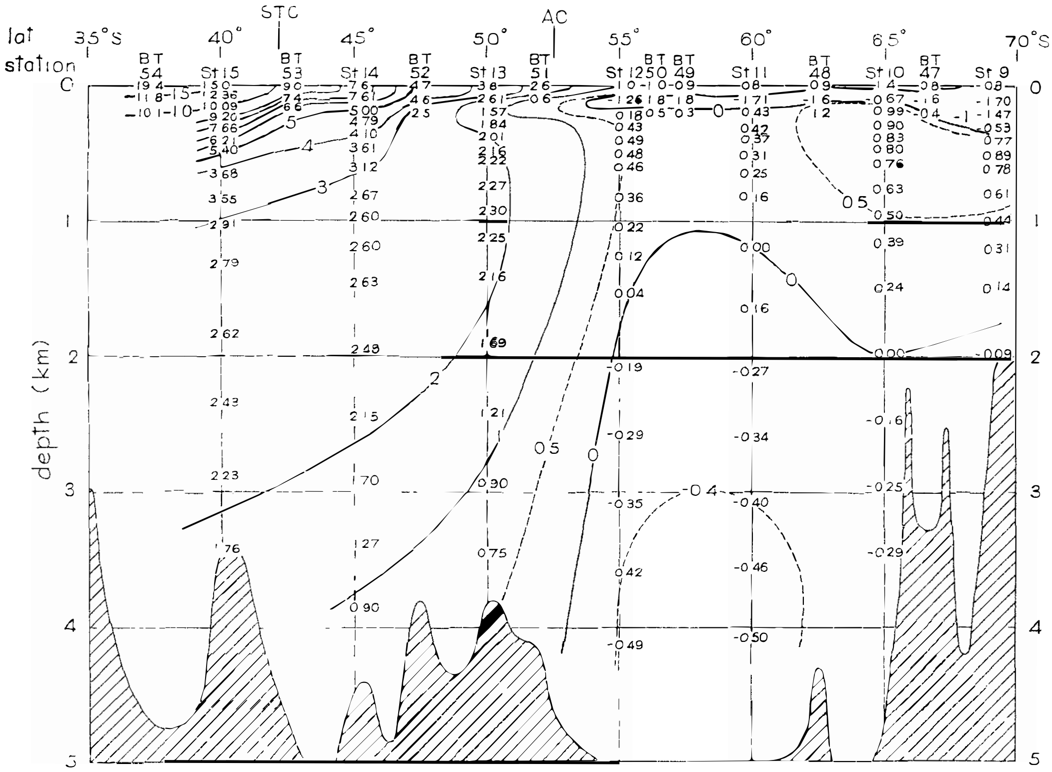


*Fig 1 Distribution of temperature (°C) along a section between Princess Astrid Coast and Cape Town, February 1966*

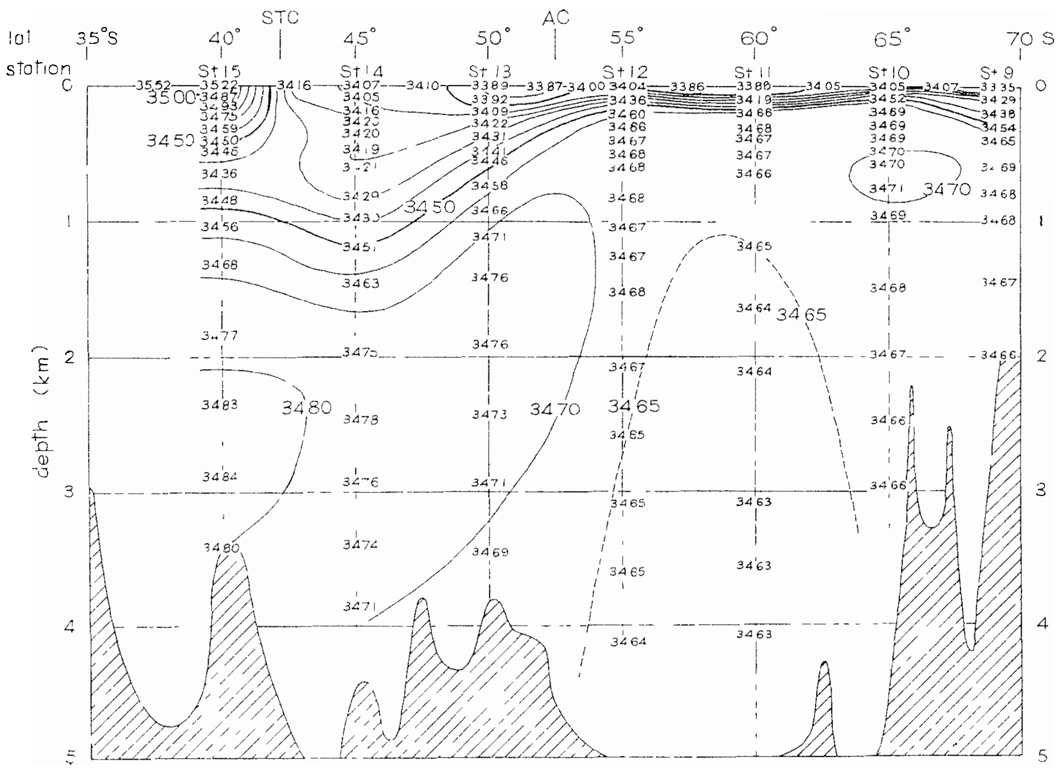


*Fig 2 Distribution of salinity (‰) along a section between Princess Astrid Coast and Cape Town, February 1966*

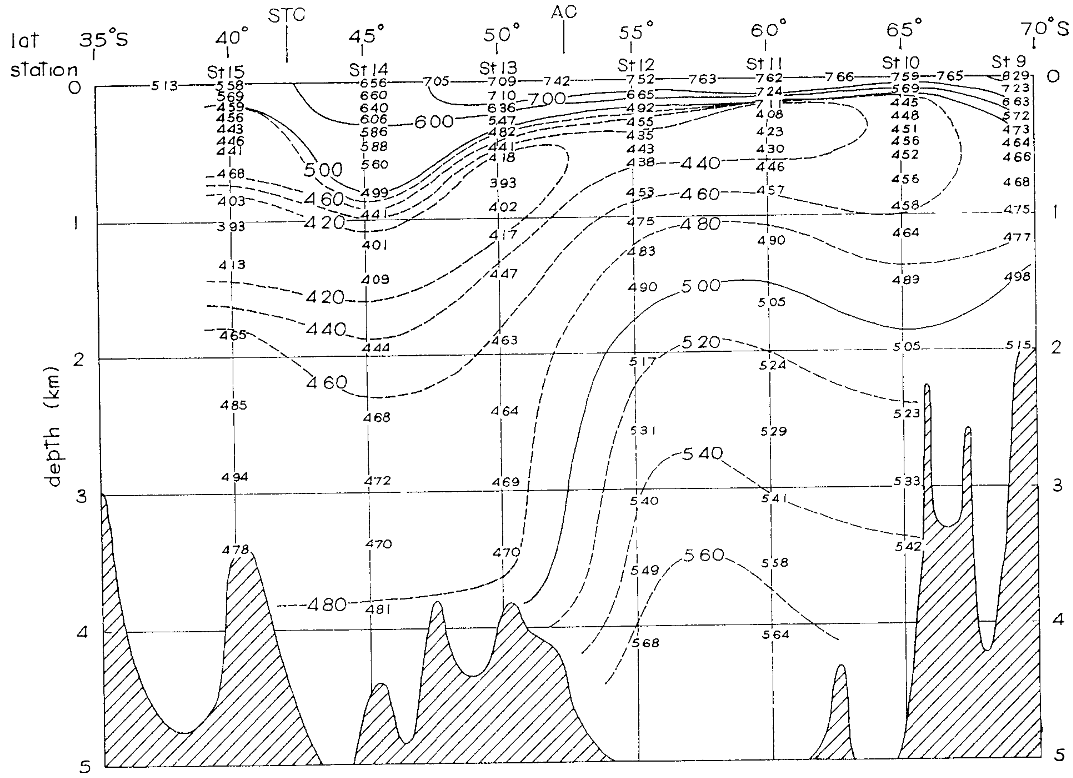


*Fig 3. Distribution of dissolved oxygen (cc/L) along a section between Princess Astrid Coast and Cape Town, February 1966*

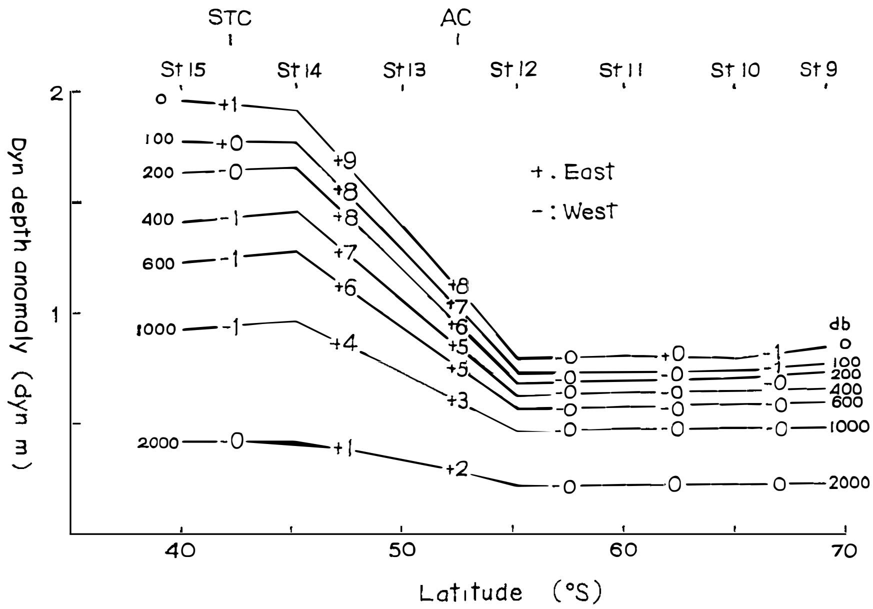


*Fig. 4. Dynamical topography of isobaric surfaces and geostrophic current, relative to 3000 db surface, with reference to a sea of uniform temperature 0°C and salinity 35 00‰*

vation to investigate annual variation of the water masses along it.

The comprehensive description of the Southern Ocean was already given by DEACON (1937a and 1963) and by SVERDRUP (1942). This report describes the water masses along the section as observed by JARE-7, with reference to the previous observations mentioned above. The distributions of temperature, salinity and dissolved oxygen in the summer of 1966, which are referred in the following description, are shown in Figs. 1, 2 and 3, respectively, while the numerical data of JARE-7 are given in another report by the present author (HORI, 1966).

## Antarctic surface water

In summer, the surface of the Antarctic region south of about 55°S, is covered by a very thin layer of warm, less saline water which is formed by the melting of ice and by the solar radiation. The temperature of the water is nearly 1°C, the salinity is less than 34.00‰, except in the vicinity of 65°S, and the thickness of the layer is about 50 meters. Under this layer the main body of Antarctic surface water exists again in a thin layer of very low temperature. The Antarctic surface water in summer is characterized by the temperature minimum of nearly freezing point between the warm surface water and the deep warm water. The salinity increases downwards from 34.00‰ to 34.60‰ within this thin layer, suggesting stableness at the lower boundary of the layer. The thickness of the layer is about 100 meters and the depth of which changes slightly from 60 meters at 65°S to 100 meters at 55°S, but the cold surface water reaches the depth of about 400 meters near the Antarctic coast where the warm deep water with its decreased density is a weaker barrier for the surface water to sink. The frontal zone of this penetrating cold water is called the interwater convergence zone by LEDENYOV (1966) and is also seen in the OB's section but not in the DISCOVERY's, suggesting its local variation. In the vicinity of 65°S the iso-haline rises to the surface showing an upwelling feature and this seems to be caused by divergence at the surface which can be expected in the boundary region between the east and west wind drift.

## Antarctic convergence, sub-Antarctic region and sub-tropical convergence

At about 52.5°S the Antarctic surface water which spreads to the north starts to descend and the Antarctic convergence develops at the surface layer. According to DEACON (1937a) the convergence is closely related with the vertical circulation and is formed to the north of the region where the warm deep water climbs up over the Antarctic bottom water and where the Antarctic surface water is free to sink. Thus the position of the convergence can be determined from the vertical distribution of observed properties, but is marked only by a gradual temperature increase at the surface.

The Antarctic surface water spreads further north in deeper layer as the Antarctic intermediate water after passing the convergence. The path of the intermediate water can be traced by the temperature minimum near the Antarctic convergence and by the salinity minimum near the sub-tropical convergence where it reaches a depth about 700 meters from the surface. In the upper layer of the sub-Antarctic region north of the Antarctic convergence, the temperature and salinity increase to the north, from 2°C to 10°C and from 33.9‰ to 34.4‰, but the increase is rather gradual and the surface water in the region is much likely to be of Antarctic origin carried by the northward component in the west wind drift.

The sub-tropical water of high temperature and high salinity forms the sub-tropical convergence with the sub-Antarctic water at about 42°S, where the surface temperature rises from 10°C to 15°C and the salinity from 34.5‰ to 35.0‰ within a short distance of about 100 miles. In the south of the sub-tropical convergence a southward bend of the iso-haline is seen between the surface and the intermediate water, and suggests a returning flow of the water which sunk at the convergence. This southward movement of the sub-surface water causes a vertical closed circulation with the northward spread at the surface and seems to contribute to the southward movement of the sub-tropical water.

## Warm deep water

The deeper portion of the sub-Antarctic and sub-tropical region is occupied by the large volume of the warm deep water, the center of which lies at the depth of about 3000 meters in the south of Africa characterized by the higher salinity of 34.84‰ and the temperature slightly above 2°C. The warm deep water spreads to the south, being mixed with the Antarctic intermediate water in upper layer and with the Antarctic bottom water in the lower part, and starts to ascend at about 50°S, where the bottom topography shows the existence of a submarine ridge*. Then it ascends to the depth of about 1000 meters, along the northern side of the Antarctic bottom water, where its salinity decreases to about 34.70‰. The warm deep water is originated far north in the north Atlantic Ocean and characterized by the deficiency of dissolved oxygen in the Southern Ocean, however, the oxygen minimum appears in the rather stable layer between the intermediate and the deep water, where the oxidation of the organic matter is to be more active.

The warm deep water seems to be better represented in the salinity section

* The bottom profile was not surveyed by JARE-7 due to a trouble in the echo-sounder The topography shown in the figures is obtained from a nautical chart and shows an approximate feature.

and the iso-haline of 34.70‰ is taken as a good indicator of it, while in the temperature section it is obscure due to the smaller difference from the other water masses. In the Antarctic region the warm deep water occupies the upper part of the section, the center of which lies in the depth of about 600 meters. The 34.70 ‰ iso-haline makes a closed line at about 65°S and there is no direct continuation to that in the sub-Antarctic region. This discontinuity of the deep water in the section can be explained by the large scale cyclonic circulation which is reported by DEACON (1937a) to exist in this part of the Southern Ocean. That is, the deep water in the Antarctic region is in a westward flow and forms, with the eastward flow in the sub-Antarctic region, the large divergence region in the intermediate depth which causes upwelling of the bottom water.

## Antarctic bottom water

In the section the Antarctic bottom water has its central portion in the depression of the topography which is part of the Atlantic basin between the Atlantic-Indian Cross Ridge and the continent, and at the depth of 4000 meters it has the temperature of −0.5°C, the salinity 34.63‰ and the oxygen content higher than 5.6 cc/L. The bottom water shows a rather distinct boundary at its northern side with the warm deep water, while its upper boundary is not so clear, having a large volume of water of transitional character in them. The heaving of the isopleths around 58°S indicates an ascending motion due to the cyclonic circulation in the intermediate layer already mentioned.

*Table 1 An example of the variation in the Antarctic bottom water (below 4000 meters)*

| Ship | DISCOVERY II | OB | | FUJI |
|---|---|---|---|---|
| Year | 1933 | 1957 | 1962 | 1966 |
| Month | Mar ∼Apr | Feb | Apr | Feb |
| Approx longitude | 15°E | 20°E | 18°E | 11°E |
| Temperature (°C) | −0.45∼−0.49 | −0.34∼−0.46 | −0.30∼−0.36 | −0.50 |
| Salinity (‰) | 34.66 | 34.61∼34.70 | 34.69 | 34.63 |
| Dissolved oxygen (cc/L) | 5.17∼5.21 | 5.61∼5.80 | 5.25∼5.58 | 5.64∼5.68 |
| Nos of measurement/nos of station | 2/1 | 10/4 | 3/1 | 2/2 |

The property of the bottom water in the figures seems to differ from those obtained by other ships, although the difference is not very large. Table 1 shows the three elements in the bottom water below 4000 meters. As is shown in the table the values of the elements vary even in the central part of the bottom water and there seems to exist significant differences among them, especially in the salinity and the oxygen content. According to DEACON (1937a) the Antarctic bottom water, formed in the Weddell Sea, increases its temperature and salinity, and decreases the oxygen content as it spreads towards the east, being mixed with the deep water. The numerical values in the table, however, do not show such tendency, although the differences in longitude are not very large. Concerning the oxygen content the difference of such amount can be possibly be explained by the fact that the water bottles used in early days cause oxygen consumption of appreciable amount before the sample water is drained because of their uncoated inside (UNESCO, 1962). FOFONOF (1956) derived a strict restriction on the formation of the Antarctic bottom water based on the density analysis, and said that seasonal variations in the properties of the bottom water are not expected, while LEDENYOV (1966) reported that the bottom water formation takes place all the year round in the vicinity of the Antarctic coast within the interwater convergence zone at the depth of about 500 meters which is already mentioned with respect to the Antarctic surface water. Should LEDENYOV's conclusion be accepted, two types of the bottom water, the Weddell and the coastal origin, are possibly to exist in the region, and this might explain the difference among the values in the table. Furthermore, the properties and the abundance of the surface water near the continent (the shelf water) must change according to the weather and the ice condition of the year, and the bottom water may reflect such changes in its property. The salinity determination of JARE-7 was made by using an inductive salinometer and such small differences as given in the table should also be examined from the technical point of view. There are many questions left for the future as to the formation of the bottom water, and closer obsevations are needed before a more definite conclusion is derived.

## Dymanical topography of isobaric surfaces

As to the current system in the Southern Ocean, DEACON (1937b) showed that the geostrophic flow computed from the density distribution does not agree with some features which are derived from the distribution of the observed elements, and he attributed the disagreement to the existence of the vertical acceleration. SVERDRUP (1933) discussed the readjustment of the density field by the wind and showed that the other factors which cause the density change are also of equal importance to the horizontal current as is the wind. Fig. 4 shows the dynamical topography of the isobaric surfaces, relative to the 3000-decibar surface with reference to a sea of uniform temperature 0°C and salinity 35.00‰, and the geostropic current computed from it. The reference level was chosen at the lower portion of the deep water, according to DEACON's consideration, where meridional movement of the water is considered to be weakest. The larger geopotential gradient appears in the sub-Antarctic region where the computed mean surface velocity is 8 cm/sec (0.16 knots) to the east, while in the Antarctic region the major part of the water is actually at rest and only a sign of westward flow is seen to the south of 65°S. Some aspects of the computed current do not seem to differ very greatly from the general feature of the current system, however, the contribution of the geostrophic flow to the total current system is known very little, and should be examined against direct current measurement of sufficient accuracy in the future.

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