Influence of the Pacific on the Circulation in the South-West Atlantic Ocean

By A. J. CLOWES, Scientific Staff, "Discovery" Committee

FOR some time the ships of the "Discovery" Investigations have been accumulating hydrographic data in the South-West Atlantic in connexion with whaling research, and it is considered that a preliminary account of some of the principal features would be of interest.

The surface water of this area is divided into two main types by two distinct convergence lines. The more southern of these has been named the Ocean Polar Front by Defant[1] and is called by us the Antarctic Convergence, while the more northern is called the sub-Tropical Convergence. Both Defant and Wüst[2] base the position of the Antarctic Convergence on a chart of the surface currents by Meyer, who places it at approximately 50° S. between 45° W. and 5° E., but between 40° W. and 60° W. it is considered that it forms the boundary between the Falkland and the Brazilian currents in about 40° S. Our intensive work in the South-West Atlantic shows, however, that this boundary is part of the sub-Tropical Convergence, and that the Antarctic Convergence is found in 58° 50′ S. south of Cape Horn, and that it continues to the north-east, being found in 49° 50′ S. at 40° W.

The waters of the South-West Atlantic may be summarised as consisting of a surface layer of either antarctic water (in the antarctic zone of the ocean) or of sub-antarctic water (in the sub-antarctic zone), below which is found an intermediate layer of relatively warmer and more saline water above the bottom layer, the Antarctic Bottom water. Wüst agrees with Merz that the intermediate layer of warmer and more saline water is of North Atlantic origin; he also states: "Just as Merz could trace the last vestiges of this water (*N. Atlantic Deep water*) as far as about 65° S. in the observations of Brennecke, so in the east the 'Meteor's' observations place the furthermost limit at 56° S."

The Atlantic Ocean is separated from the Pacific Ocean by the Drake Passage of approximately 450 miles, between South America and the northernmost point of Antarctica at Graham Land. The question arises, What influence has the Pacific on the circulation and composition of the water in the South-West Atlantic? Wüst states that the influence of the Pacific Ocean is of secondary importance. However, our data quickly showed that there is a considerable eastward flow through the Drake Passage on both sides of the Antarctic Convergence. Moreover, this flow is not confined to the surface layer only but is continuous to the very great depths of the Drake Passage. Thus no water of Atlantic origin passes into the Pacific. Lack of space precludes the reproduction of many diagrams, but the topographical chart for the 600 decibar surface in relation to the 3,000 decibar surface is given in Fig. 1. The chart is constructed by making use of the observed densities at 72 stations of which the greater part lie in the Scotia Sea, and gives the stream lines of the currents at the level indicated, assuming the velocity at 3,000 metres is zero, or so small that it does not affect the magnitude of currents at lesser depths. The level of 600 metres has been chosen because in the region of South Georgia the maximum temperature of the intermediate warm and more saline water occurs at 600 metres.

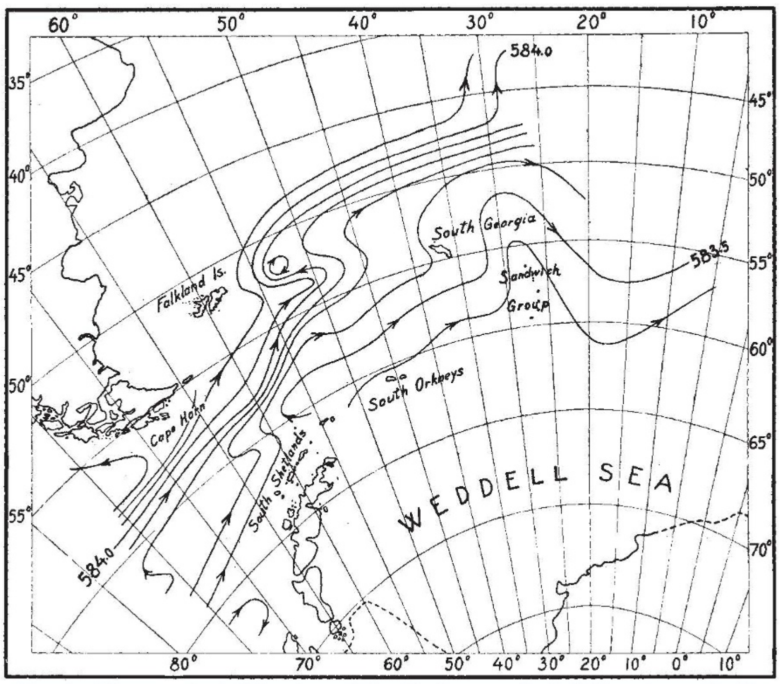

FIG. 1. The currents at 600 metres relative to the currents at 3,000 metres. The lines show the topography of the 600 decibar surface relative to the 3,000 decibar surface.

It can be seen from this chart that the water flows from the Pacific through the Drake Passage in a north-eastwards direction into the Atlantic, and continues northwards of South Georgia. The great bends of the dynamic isobaths in Fig. 1 between South Georgia and the Falkland Islands, between the South Sandwich Islands and South Georgia, and close to Graham Land are characteristic and permanent features and are related to the topography of the sea bottom, but several details may be due to the circumstance that observations from different years and seasons have been combined. At the 2,000 metres level the water flows in the same direction as at 600 metres, but the velocities are much smaller. Thus the maximum velocity at 600 metres is about 32 cm./sec. but at 2,000 metres it is about 8 cm./sec.

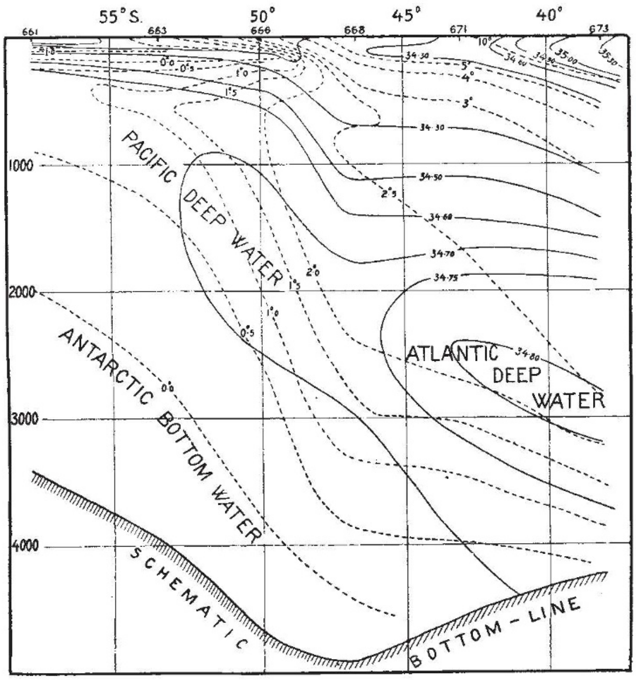

FIG. 2. Vertical section of salinity and temperature along 30° W. from 57½° S. to 43° S.

Fig. 2 is the vertical section of salinity and temperature along long. 30° W. At Station 666, the water of temperature between 1·99° and 1·02° and salinity between 34·62 and 34·73 per mille would have originated in the North Atlantic according to the conception of Wüst, whereas according to our view it came from the Pacific. It has been found by Helland-Hansen that there is a very distinct relationship between temperature and salinity of sea water. Briefly, it may be stated that water masses possessing the same temperature and salinity have a common origin. Thus if we examine the graphs of the relationship between temperature and salinity for a station in the Drake Passage and one or two north of South Georgia, it will be possible to determine the correctness of our view of the water movements in this area. In Fig. 3 the temperature-salinity diagrams for depths below 100 metres have been drawn for three stations, Station 647 in the Drake Passage, and Stations 666 and 671 both north of South Georgia. The agreement between the curves for Stations 647 and 666 is excellent, whereas there is a striking disagreement between the curves for the two former stations and that for 671. Only at depths below 2,000 metres is the water at 666 similar to that at 671 below 3,500 metres, thus showing the common influence of the Antarctic Bottom water from the Weddell Sea at both stations.

Thus the temperature-salinity diagrams agree with the topographical charts that the warm, more saline intermediate layer in the South-West Atlantic originates in the Pacific. It is only north of 46° S. that the deep water shows a southerly component and is of Atlantic origin; south of 46° S. it is of Pacific origin as far as about 55° S., where the influence of the Weddell Sea is predominant.

On the basis of the sections through the Drake Passage, it is possible to compute the total volume of water which flows from the Pacific to the Atlantic, assuming that the velocity is zero at a depth of 3,500 metres. Using data from two different years, 1929 and 1930, one finds nearly the same values, namely a transport of about 110 million cubic metres a second. This transport is more than four times as great as the total flow of water through the Strait of Florida. Considering water of a salinity of more than 34·65 per mille as Pacific deep water, one finds that more than one third of the water which flows through the Drake Passage is of this type, and it is evident that such a tremendous inflow of Pacific deep water to the Atlantic must have an appreciable influence on the character of the water masses in the southern part of the western Atlantic. There it is met with as an intermediate layer between the light surface water and the heavy Antarctic Bottom water.

In conclusion, it is of interest to consider the circulation of the Southern Ocean as a whole. All around the antarctic continent there exists one continuous current, flowing from west to east. Within the upper layer of this current one can

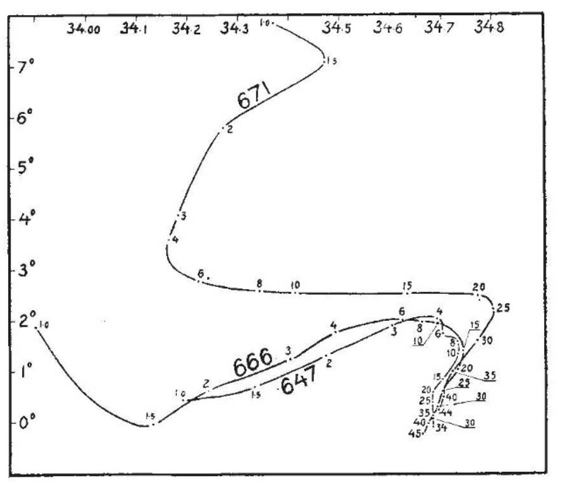

FIG. 3. Diagram of the relation of temperature and salinity for Stations 647 (59° 29½′ S., 58° 39¾′ W.), 666 (49° 58¾′ S., 29° 52½′ W.), 671 (43° 08′ S., 30° 15¾′ W.). The numbers alongside the curves represent the depths of the observations in hectometres.

discriminate between two typically different water masses, the antarctic water, and the sub-antarctic water of the west wind drift. These two water masses are separated by a boundary surface which at sea level is recognized as the line of Antarctic Convergence. To the south of the broad easterly current a series of whirls are probably formed. These circular movements, of which the greatest is found in the Weddell Sea, are stationary and dependent upon the topographic features of the bottom of the sea, and of the coast line of the antarctic continent. In the regions of these whirls the places have to be sought where the Antarctic Bottom water is formed. To the north of the easterly current one finds the sub-Tropical Convergence representing the boundary between the warm and saline water from the Atlantic or Indian Oceans and the sub-antarctic water. Along this boundary surface, whirls are probably also developed, but these are not stationary but represent travelling disturbances which uphold processes of mixing. Through this mixing, the character of the eastward-flowing water slowly changes. The water in 65° S. and approximately 28° W., which Merz and Wüst have considered as being of Atlantic origin, belongs according to our view to the great whirl of the Weddell Sea, which, however, represents a closed system to the south of the current from the Pacific, and therefore the warm and saline intermediate water of the Weddell Sea is for the most part of Pacific and not of Atlantic origin. The so-called Indian Ocean intermediate warm and saline water found in the southern part of the Weddell Sea is no doubt typical water of the circumpolar system.

I have had the advantage of discussing these results with Dr. H. U. Sverdrup, to whom I wish to express my grateful thanks.

[1] Defant, Z. Gesell. Erdkunde, Berlin, 1928.
[2] Wüst, *ibid.*, p. 506, *et seq.*

Helium Liquefaction Plant at the Clarendon Laboratory, Oxford

By Prof. F. A. LINDEMANN, F.R.S., and T. C. KEELEY

THE main properties of liquid helium have been familiar to men of science for a great many years. The only object therefore in liquefying it is in order to cool other substances the characteristics of which it is desired to study in the neighbourhood of the absolute zero. It has long been known that the heat capacity of solids becomes extremely small at low temperatures. Thus the latent heat of evaporation of 20 mgm. of liquid helium is sufficient to cool 60 gm. of copper from the temperature to be attained with liquid hydrogen boiling under a reduced pressure to the boiling point of helium.

It is easy to design apparatus so that the substances the properties of which at low temperatures are under investigation, are cooled to the temperature of the surrounding liquid or solid helium and maintained at this temperature with a minimum of waste. It seemed preferable, therefore, to instal a small inexpensive apparatus requiring comparatively little liquid hydrogen, which can therefore be operated frequently or duplicated at comparatively small cost, rather than to indulge in a plant designed to produce liquid helium in large quantities. In any event, the financial resources available would have imposed this choice, even had the alternative procedure been considered desirable.

The apparatus which has been installed at Oxford is of a type developed by Prof. Simon and Dr. Mendelssohn in Berlin and Breslau. Two concentric cylinders capable of withstanding a pressure of some 150 atmospheres surround the space in which the substance under investigation is placed. Helium under a pressure of about 100 atmospheres is introduced into the space between the cylinders. The upper part of the annular space between the cylinders is separated from the lower, in which the helium is compressed, by a metal sheet, thus forming a small metal container which is joined by a spiral of thin copper tubing to a source of pure hydrogen. The whole is held in position on a German silver tube in the centre of a larger metal vessel containing hydrogen or helium gas at low pressure which can be evacuated by means of a mercury vapour pump. This outer vessel together with the copper spirals through which the hydrogen and helium are introduced is immersed in a Dewar flask containing liquid hydrogen.

When temperature equilibrium has been attained, hydrogen is introduced into the top vessel under a pressure of two or three atmospheres. Passing through the copper spirals, this liquefies owing to the excess pressure and runs down into the metal container over the double-walled helium cylinder. A tap to the mercury vapour pump is now turned on and a high vacuum produced in the metal box, so that the helium container with its superposed pot of liquid hydrogen is thermally insulated save for the necessary connecting tubes.

The yield of liquid helium is improved if the compressed helium is further cooled by boiling the hydrogen in the inner container under reduced pressure. If the helium is now allowed to expand, about half of it liquefies and the central space with the experimental substances it contains is cooled to the temperature of the surrounding helium. By evacuating the space above the liquid, that is, causing it to boil under reduced pressure, one can, of course, reduce the temperature to within one or two degrees of the absolute zero.

In the apparatus used at Oxford the helium lasts for about an hour and a half. If the experiment is not finished in this time, one can repeat the process in a few minutes at very small cost in liquid hydrogen. The helium expands into a rubber bag and is recompressed into a cylinder so that very little gas is lost. The temperature during the experiment can be observed on a large-