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Seasonal Fluctuations in the Surface Salinity off the North Coast of Java

by

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**The Subtropical Lower Water between the Philippines
and Irian (New Guinea)**

by

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**THE SUBTROPICAL LOWER WATER BETWEEN THE PHILIPPINES
AND IRIAN (NEW GUINEA).**

(Comparative considerations of the results of three expeditions)

by

KLAUS WYRTKI

SUMMARY:

Oceanographic observations are published, taken by the research vessel Siboele in 1949 at 57 stations in the Celebes Sea and around Halmahera. Basing on these observations, an analysis is made of the Subtropical Lower Water (salinity-Maximum) in this region and is compared with the observations of the Snellius and the Dana in 1929. The distribution of the oxygen content allows a distinction of the Lower Water into a northern and a southern water type, which regions of origin are situated in 23°N between 165°E and 165°W and in 15°S between 120° and 150°W respectively. It is shown that the temperature of the salinity maximum in 1949 is 1,4° higher and the salinity 0.11‰ lower than in 1929. The topography of the salinity maximum, which lies in about 100 to 200 m, is closely correlated with the surface currents.

ZUSAMMENFASSUNG:

Ozeanographische Beobachtungen des Forschungsschiffes Siboele aus dem Jahre 1949 an 57 Stationen in der Celebessee und den Gewässern um Halmahera werden veröffentlicht. Auf Grund dieser Beobachtungen wird eine Analyse des Subtropischen Unterwassers (Salzmaximum) durchgeführt und mit den Beobachtungen der Snellius und Dana in diesem Gebiet aus dem Jahre 1929 verglichen. Die Verteilung des Sauerstoffgehaltes ermöglicht eine Unterteilung des Unterwassers in eine nordliche und eine südliche Wasserart, deren Entstehungsgebiete in 23°N zwischen 165°E und 165°W und in 15°S zwischen 120° und 150°W liegen. Es wird gezeigt, dass die Temperaturen im Salzmaximum im Jahre 1949 um 1,4° höher und der Salzgehalt um 0.11‰ niedriger sind als 1929. Die Topographie des Salzmaximums, das in etwa 100 bis 200 m liegt, steht in enger Beziehung zu den Stromungen an der Oberfläche.

ICHTISAR:

Penjelidikan mengenai oceanografi jang diselenggarakan oleh kapal penjelidikan laut dalam tahun 1949 di-57 setasion di laut Sulawesi dan disekitar Halmahera, telah diumumkan.

Berdasarkan penjelidikan ini, dibikinlah suatu analisa dari lapisan air laut subtropis (maksimum kadar garam) didaerah ini dan dibandingkan dengan penjelidikan² dari Snellius dan Dana dalam tahun 1929. Keadaan kadar zat pembakar memungkinkan suatu perbedaan dari lapisan air laut mendjadi djenis air daerah Utara dan daerah Selatan, daerah-daerahmana masing-masing asalnja berada di 23° L.U. antara 165° B.T. dan 165° B.B. dan di-15° L.S. antara 120° dan 150° B.B. Telah diperlihatkan, bahwa suhu dari maksimum kadar garam dalam tahun 1949 adalah 1,4° lebih tinggi dan kadar garamnja 0,11‰ lebih rendah daripada dalam tahun 1929. Topografi dari maksimum kadar garam jang berada diantara l.k. 100 dan 200 m. saling mempengaruhi erat sekali dengan arus dipermukaan.

In large areas of the tropical oceans a salinity maximum is situated shortly below the surface layer. At high temperatures it lies in the upper limit of the tropical discontinuity layer in a depth between 50 and 150 m. The area of origin of this watermass of high temperature and salinity is to be found in the region of high excess of evaporation over precipitation in about 20 °N and 20 °S. Here at its origin this watermass sinks and spreads towards the equator, accordingly to its density, at the upper limit of the discontinuity layer. As a result of its origin and spreading, this watermass is called the Subtropical Lower Water. In the Atlantic Ocean this phenomenon has been described by DEFANT (1936) when discussing the results of the Meteor-Expedition. In the Pacific Ocean a corresponding investigation is lacking, although this phenomenon seems to be more far-reaching there.

The position of the Subtropical Lower Water implies that it will be transported with the currents of the surface layer. It penetrates also with these currents into the smaller adjacent seas, so from the Pacific Ocean into Indonesian waters. A chart of the salinity distribution in 150 m depth in the Indonesian Archipelago, drawn by VAN RIEL (1938) from the observations of the Snellius-Expedition shows how far this process reaches.

In 1949 the Laboratorium Penyelidikan Laut in Djakarta has made serial observations in the Celebes Sea and in the adjoining parts of the

Pacific Ocean with the research ship "Siboela". These observations permit following the penetration of the Lower Water into the Indonesian waters between the Philippines and Irian (New Guinea). Also a comparison is possible between these observations and those of the Snellius and the Dana, which have made numerous oceanographical stations in this area in 1929 and 1930.

The observations. The area of this investigation includes the Celebes Sea and the western part of the Pacific Ocean south of 7°N and west of 140°E. In the Indonesian Archipelago the northern part of the Strait of Macassar and the region between Celebes and Irian are included (Fig. 1). In this area 96 stations of the Snellius (VAN RIEL, 1950) for the years 1929 and 1930 are available. Their positions are selected to be over the greatest depths, the trenches and the saddles, according to the character of this expedition as a deep sea expedition. Lesser regard has been taken to the conditions in the upper layers. Furthermore, the stations do not reach over the line Philippines -Irian into the Pacific Ocean.

The Dana has also taken oceanographic observations in this region at 26 stations in 1929 (THOMSEN, 1937). Some of these stations are situated in the western Pacific Ocean north of Irian and form a good supplement, to the Snellius observations. Both expeditions have determined temperature, salinity and oxygen with small intervalls in depth and the accuracy of the observations satisfies all requirements of modern oceanographic investigations.

In contrast to these deep sea expeditions, the "Siboela" made measurements only down to 250 m, and did not determine the oxygen-content. Because the investigations, were limited to the upper layers, the 57 stations could be uniformly distributed. The distance selected was 60 sm. The stations are situated in the southern part of the Celebes Sea, around the island Halmahera, and reach north of Irian up to 134 °E (Fig. 1). The observations have been made under the command of Mr. P. CH. VEEN, at this time oceanographer at the Laboratorium Penjelidikan Laut.

The observations taken at 57 stations have been worked up and are presented in the appendix. As far as obtainable from the protocols the temperatures were not corrected and therefore are reproduced only to 0.1° Centigrade. The accuracy of the salinity determination is about 0.04‰ which is insufficient for interpretation of deep sea observations.

However, for a treatment of the conditions in the upper 200 m with their relatively large fluctuations, this error might be permissible. Ac-

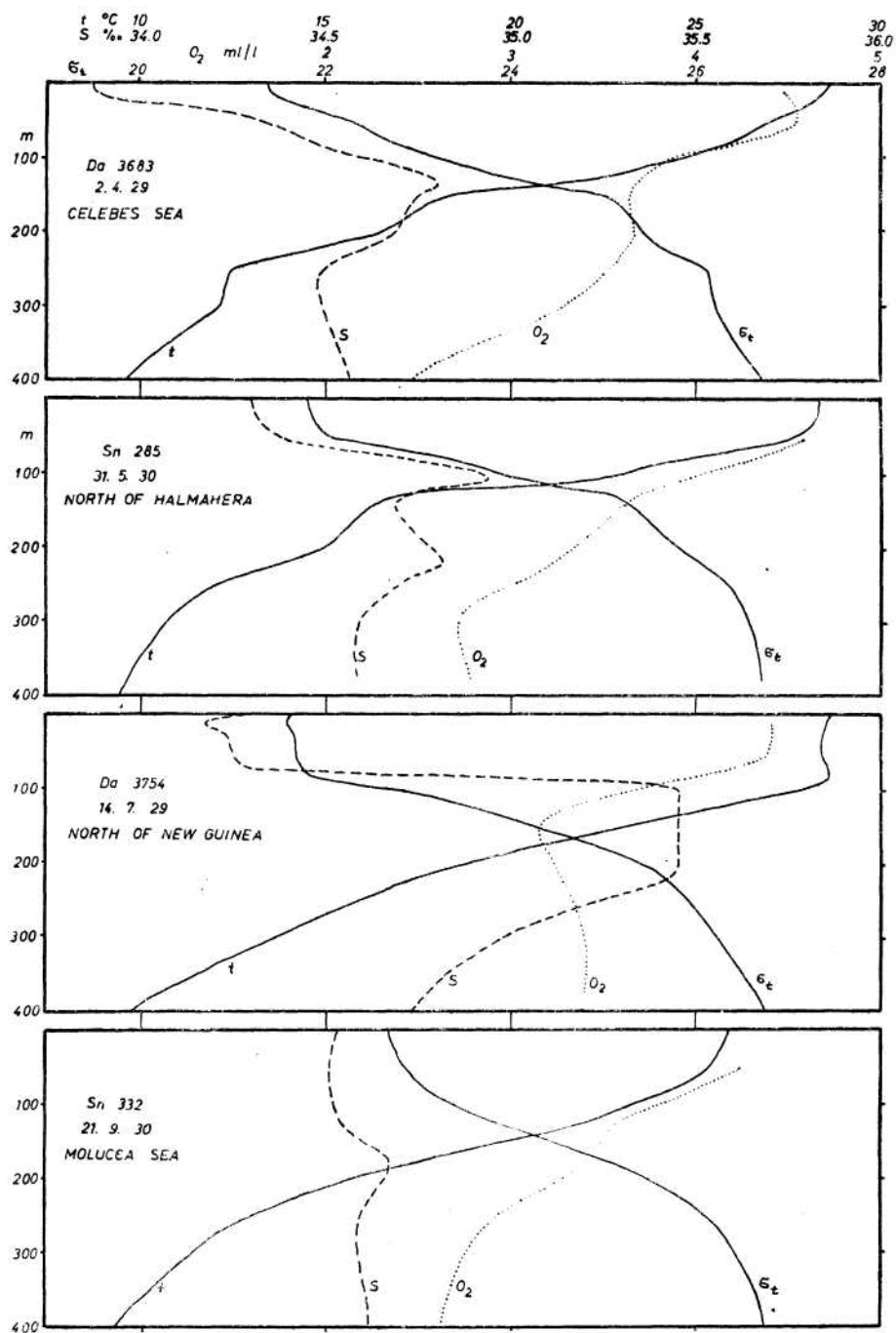


Fig. 2. Vertical distribution of temperature, salinity density and oxygen-content at four selected stations. The positions of the stations are given in Fig. 1.

is homogenous, while the temperature decreases from 27° to 19°. The distribution of density shows the Lower Water occupying the upper half of the discontinuity layer; in the lower half a gradual transition to the Intermediate Water takes place. That implies, that the Lower Water in fact follows the movement of the surface layer, because the boundary of movements lies in the lower parts of the discontinuity layer, as theoretical investigations of ROSSBY (1951) have shown. Within the Lower Water a small oxygen minimum is found.

About in the centre of the Celebes Sea the station Da 3683 is placed. Here a continuous transition from the waters of the surface to the Lower Water is noted produced by the mixing processes. The salinity in its maximum is 34,8‰, significantly less than the waters north of Irian with 35,5‰- Remarkable is the coincidence of the salinity maximum with the strongest density gradient in 135 m. An oxygen minimum is also indicated, although usually not found in the Celebes Sea. It might be more convenient to speak there from a layer of constant oxygen content, which lies shortly below the salinity maximum. The Intermediate Water is to be found at this station in about 270 m with salinities below 34,5‰ -

A completely new phenomenon of a double salinity maximum is shown at station Sn 285, situated at the entrance of the Celebes Sea north of Halmahera. This will later enable us to separate two water types in this region, which indicate two different regions of origin. But some conjectures may be made here. In the Celebes Sea (Da 3683) the salinity maximum has, with 3.65 cm³/l, a higher oxygen content than north of Irian (Da 3754), where it is only 3.30 cm³/l at a higher salinity.

That implies that the Lower Water in the Celebes Sea can not be derived by mixing from the water north of Irian because, in that case, salinity and oxygen would decrease simultaneously. Therefore two different water types with different regions of origin must exist, and the station Sn 285 must lie in the boundary zone of both water masses, which overlap here according to their density. Also, the difference in oxygen is clearly distinguished between both salinity maxima, which is 3.9 in the upper and 3.2 cm³/l in the lower maximum.

In the Molucca Sea, southwest of Halmahera, where station Sn 332 is situated, the Lower Water is seen only in its last branch. The salinity in the maximum differs only 0.1‰ from those of the waters above and below the maximum, which lies below the middle of the discontinuity layer. A small deflection of the oxygen curve is noted near the salinity maximum.

The stations here presented show the variety of the hydro-graphic conditions and give a review over the situations in the region. They are selected from the whole material as representative of the respective regions. For further consideration the TS and TO₂ diagrams have been drawn for every station as well as the vertical curves of the properties. From these the temperature, the salinity, the oxygen content, the density and the depth of the salinity maximum could be obtained.

The horizontal distribution of properties in the salinity maximum. Charts of the distribution of the hydrographic factors have been drawn by means of the values obtained from the vertical curves. Here only three charts of the distribution of the salinity in its maximum and one chart of the distribution of oxygen in the salinity maximum are represented. Fig. 3 gives the chart of the salinity in its maximum for the period July/September 1929, drawn from Snellius and Dana stations. In the region north of Irian and east of Halmahera the salinity maximum has a relatively uniform salinity of 35.4‰. It extends to the west in a belt along the north coast of Irian, where salinities up to 35.6‰ are found and is deflected to the north off the east coast of Halmahera. To the north the salinity decreases slowly to 35.2‰. South of Mindanao a tongue with salinities above 34.9‰ extends to the center of the Celebes Sea. A discontinuity with a decrease of salinity from 35.4 to 34.9‰ reaches from Halmahera to the north. Between Halmahera and Irian the Lower Water also penetrates to the south with decreasing salinities.

The salinity in its maximum according to the results of the Siboeala in August/September 1949 is drawn in Fig. 4, and shows a similar distribution. The South Equatorial Current also extends along the north coast of Irian to the west and is deflected to the north* off Halmahera, where the salinity slowly decreases. Remarkable is the area of salinity below 35.0‰ northeast of Halmahera. Here a large eddy is situated, as later will be shown, in which the South Equatorial Current is turning to the Counter Current. The discontinuity north of Halmahera also is noted, but is not developed as sharply as in 1929. A tongue of higher salinity (34.7‰) this time does not reach to the center of the Celebes Sea, but to the north east corner of the island. In general the salinity is about 0.1 to 0.2 ‰ below that in 1929.

The third chart gives the distribution of the salinity in its maximum according to the results of the Snellius in May/June 1930, in the region between Halmahera and Mindanao, and in September/October 1930 in the region around Halmahera (Fig. 5). The higher density of stations in

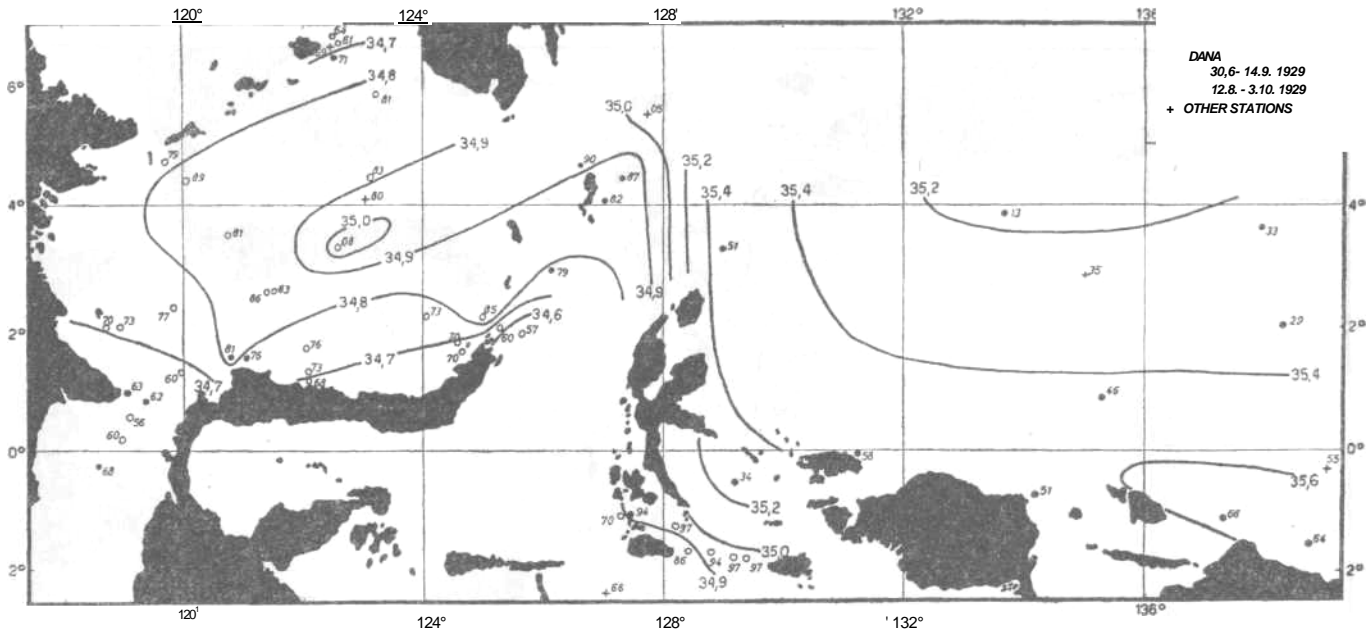


Fig. 3. Salinity in the salinity-maximum, July/September 1929.

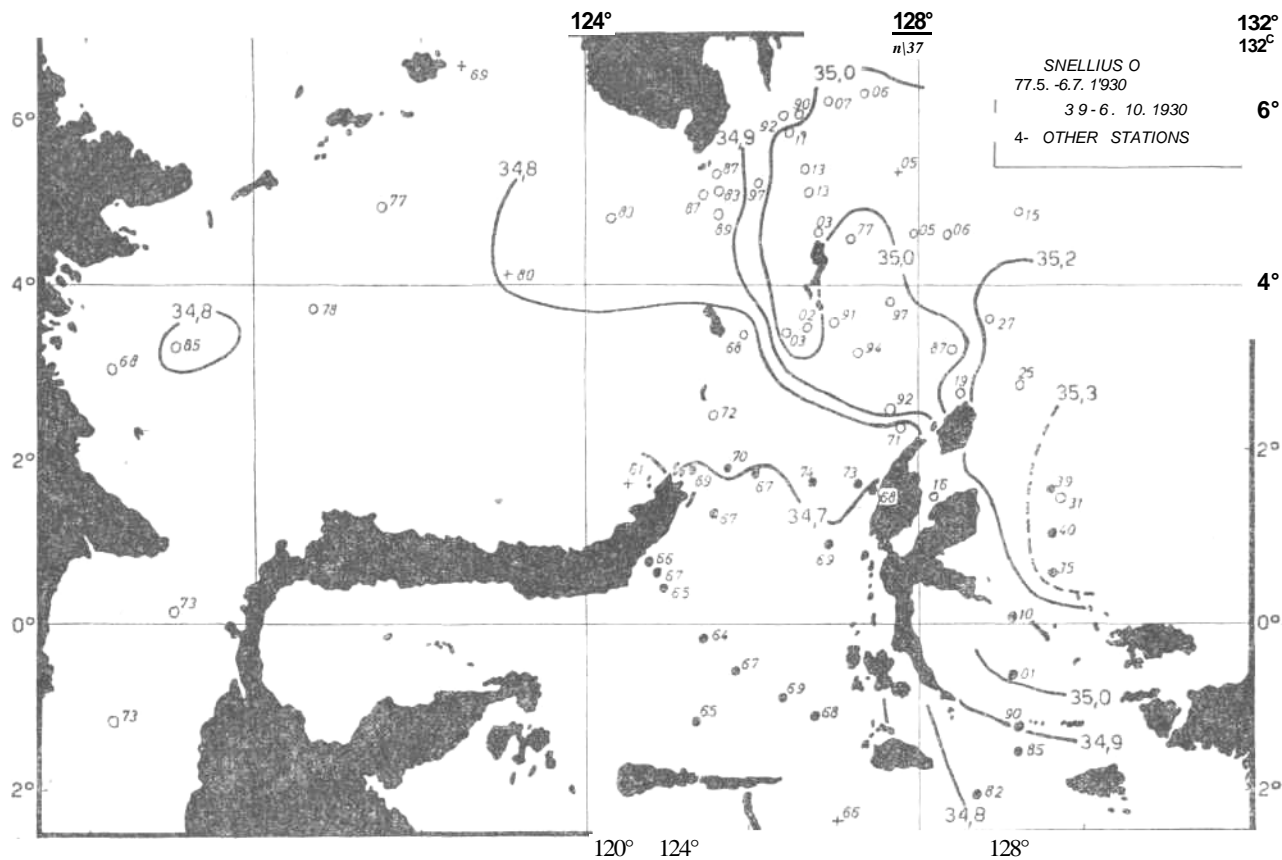


Fig. 5. Salinity in the salinity-maximum, May/July and September/October 1930.

this chart shows that the discontinuity north of Halmahera is split and is developed weakerly in this season. This is in accordance with the current conditions, as described by SCHOTT (1939), which shows the South Equatorial Current not developed in this region at this season. South of Mindanao relatively high saline waters (34.8‰) penetrate to the central parts of the Celebes Sea.

The chart of the oxygen distribution in the salinity maximum is drawn from all available observations, without regard to season. This presentation shows some remarkable characteristics having an essential meaning for the further investigations. The area north of Irian has a very uniform oxygen content with values between 3.2 to 3.4 cm³/l. Contrary to this, in the Celebes Sea an essentially higher oxygen content between 3.6 to 3.9 cm³/l is found. Clearly also, the discontinuity north of Halmahera is developed in the oxygen content, which increases from 3.3 to 4.0 cm³/l. The area of high oxygen south of Mindanao indicates that the Lower Water in the Celebes Sea is supplied from this source.

The distribution of temperature and density in the salinity maximum does not give such an uniform picture, because the maximum is met at higher or lower temperatures, according to the mixing processes with the waters above or below the maximum, depending on which is the stronger. The variation of the temperature is the controlling factor for the variation of the density, because the variations of salinity are comparable small. Therefore the charts of the distribution of these properties are not presented. The magnitude of those variations can be seen from the scattering of points in the TS diagram (Fig. 8). Temperatures vary between 25° and 17°, densities between 23.5 and 25.5 is the salinity maximum.

The origin of the water types. The envelopes, drawn from the TS diagrams of the three expeditions are given in Fig. 7. They show clearly that at least three water types take part in the mixing processes. These are the warm, low saline water with temperatures above 25° and salinities below 34‰, forming the surface layer. In the depths the Intermediate Water is spreading with low temperatures and salinities of about 34.5‰. Clearly two different Intermediate Waters are distinguished, the northern with 10° is warmer than the southern with 6°. These waters lie in the region north of Irian in about 300 and 800 m depth, respectively, and form there a salinity minimum. The Subtropical Lower Water with high temperature above 26° and high salinities above 36‰ forms the salinity maximum between 100 and 200 m. Later also this water type will be subdivided by means of its oxygen content. By the mixing processes the TS

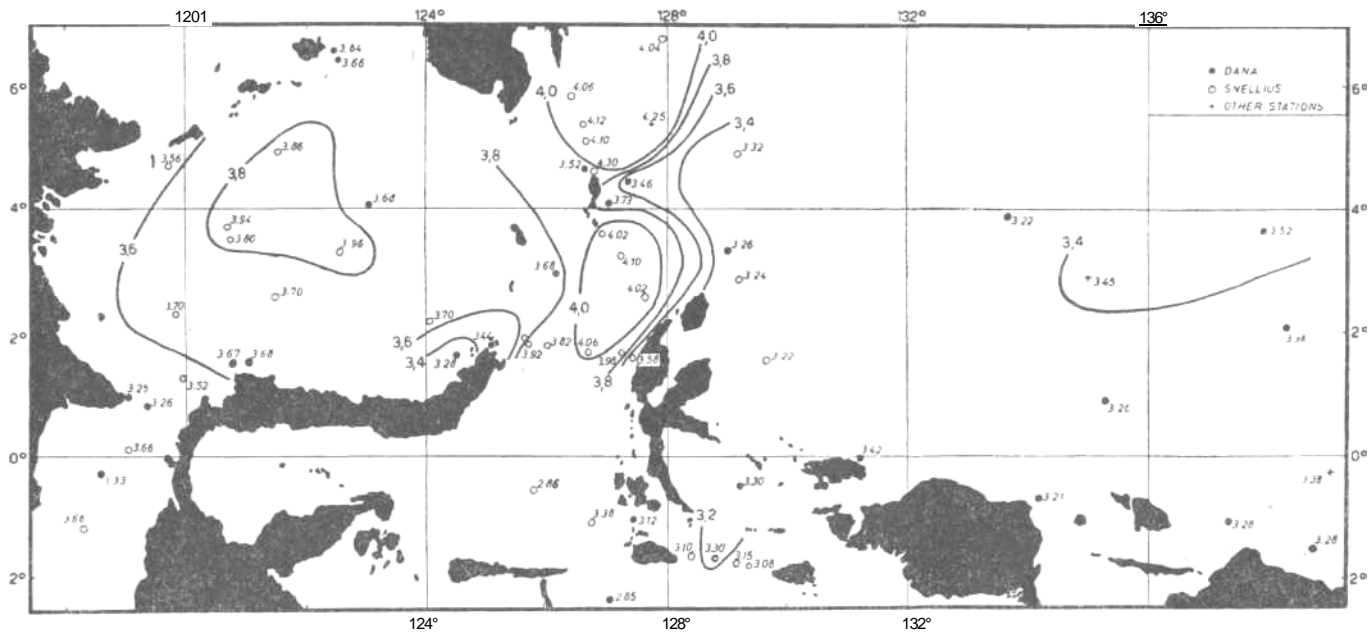


Fig. 6. Oxygen-content in the salinity-maximum.

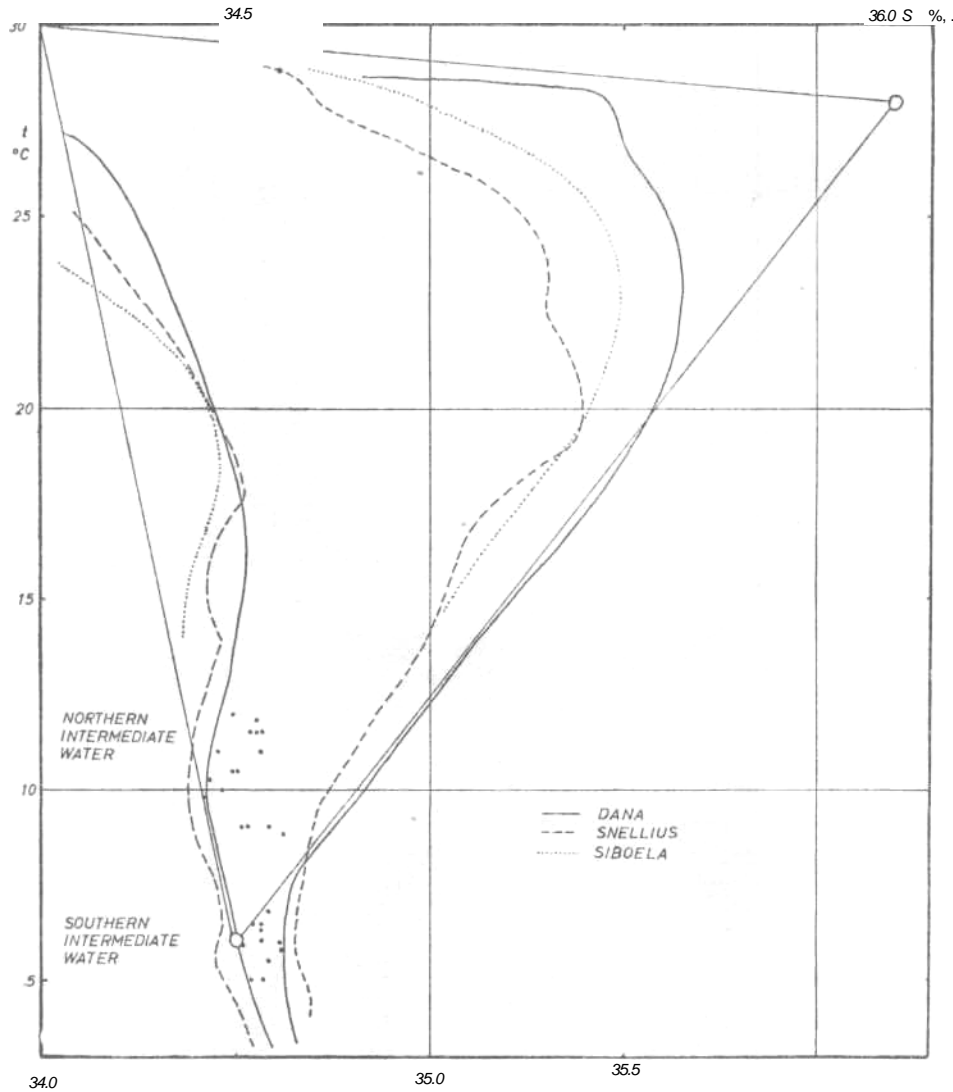


Fig. 7. Envelopes of the TS-curves of the stations of the three expeditions and TS-relation in the northern and southern Intermediate Water according to Dana stations.

values in the salinity maximum deviate more and more from these properties in the region of origin. This is demonstrated by the different recesses of the envelopes towards high salinities according to the extension of the station net of the three expeditions to the east. As mentioned

above, the oxygen content in the salinity maximum is higher in the Celebes Sea than in the region north of Irian. The Lower Water there cannot come from the region of the South Equatorial current. Furthermore, the discontinuity in the salinity and in the oxygen north of Halmahera indicates a boundary there. To come to an analysis of this pattern, the values of temperature, salinity and oxygen in the salinity maximum for all stations with oxygen observations were combined to a TS and a SO_2 diagram (Fig. 8). The $SO_{L>}$ diagram shows two different clouds of points, one with only a small increase of oxygen content with increasing salinity, representing the southern Lower Water, the other with a rapid increase in oxygen content with the salinity, the northern Lower Water, which reaches far higher values of oxygen. Transferring this subdivision to the TS diagram, one notes also there a subdivision, which is not distinguishable from the TS diagram alone. In general, the southern Lower Water has a higher salinity and a lower oxygen content. Also the stations Sn 83-86, situated southeast of Halmahera, can be identified very clearly by means of the SO_2 diagram as belonging to the southern Lower Water, although their TS values are falling into the range of the northern Lower Water.

Envelopes have been drawn for both Lower Waters from the TS diagrams of all stations, which could be identified by the SO_2 as belonging to the northern or southern Lower Water. These are shown in Fig. 9. It can be seen, that both planes partially overlap within which limits points from the southern, as well as from the northern Lower Water can lie. The subdivision according to this diagram is therefore not clear, but it is always possible to make such divisions, if oxygen values are available. Now all stations without oxygen observations were distributed by means of this diagram to one or the other Lower Water. The geographical position of the both Lower Waters in their boundary area is given in Fig. 10. The line of demarkation (full line) runs from Halmahera to the north and to the south and falls together with the discontinuity in salinity and oxygen, visible in Fig. 3-6. In parts of the area there is a double salinity maximum, as shown in Fig. 10. This second maximum in any case belongs to the southern Lower Water, as the TS values, drawn in Fig. 9 show. In the region of the double salinity maximum, northern Lower Water lies above the southern Lower Water. The extension of the southern Lower Water to the west is indicated by the broken line. The origin of this feature will be discussed later.

For an identification of the regions of origin of both water types, the TS correlation at the surface of the Pacific Ocean has been inves-

tigated. Therefore the charts of the average surface salinity and the seasonal charts of surface temperatures were used, as drawn by SCHOTT (1935). Presentations of the annual variation of surface salinity in the Pacific Ocean are not yet available. The investigation of the TS correlation shows that at the time of the temperature maximum in the regions of the salinity maxima can suitable TS values be found which explain the

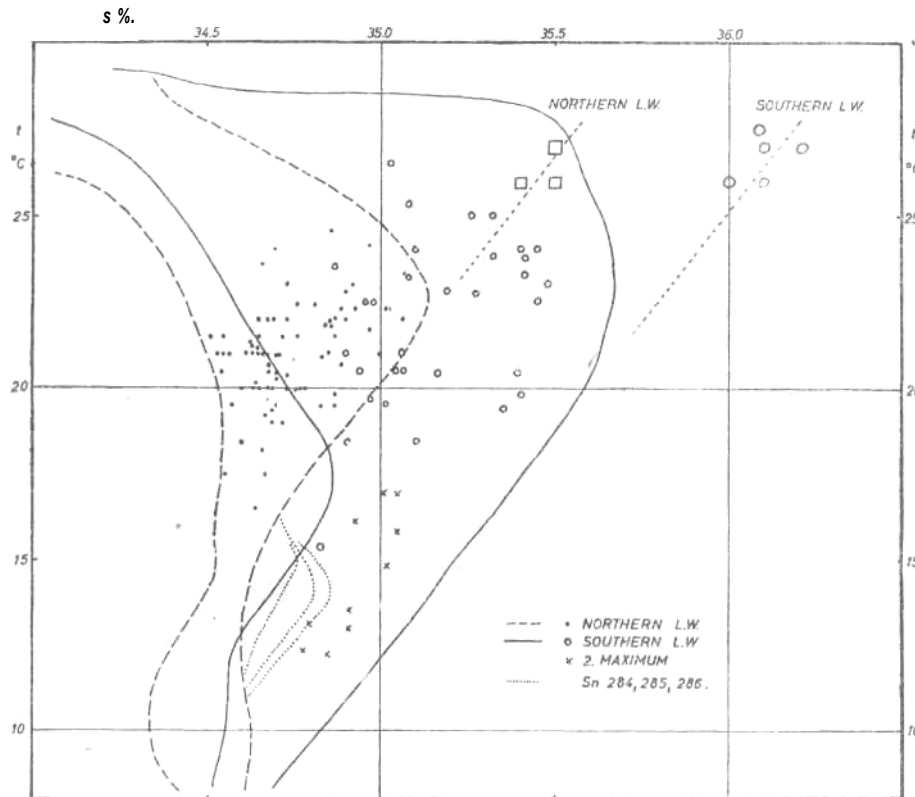


Fig. 9. Envelopes of the TS relations for the northern and southern Lower Water and TS values in the regions of origin of both water types.

origin of the Lower Waters. These values, which must lie at high temperature in the elongation of the branch of the envelopes running from the Intermediate to the Lower Water, are introduced in Fig. 9.

The salinity at the surface of the Pacific Ocean, according to SCHOTT (1935), is partly redrawn in Fig. 11. In this figure the regions are introduced with broken lines, in which suitable TS combinations occur, for the origin of the Lower Waters. These lie for the northern Lower Water in

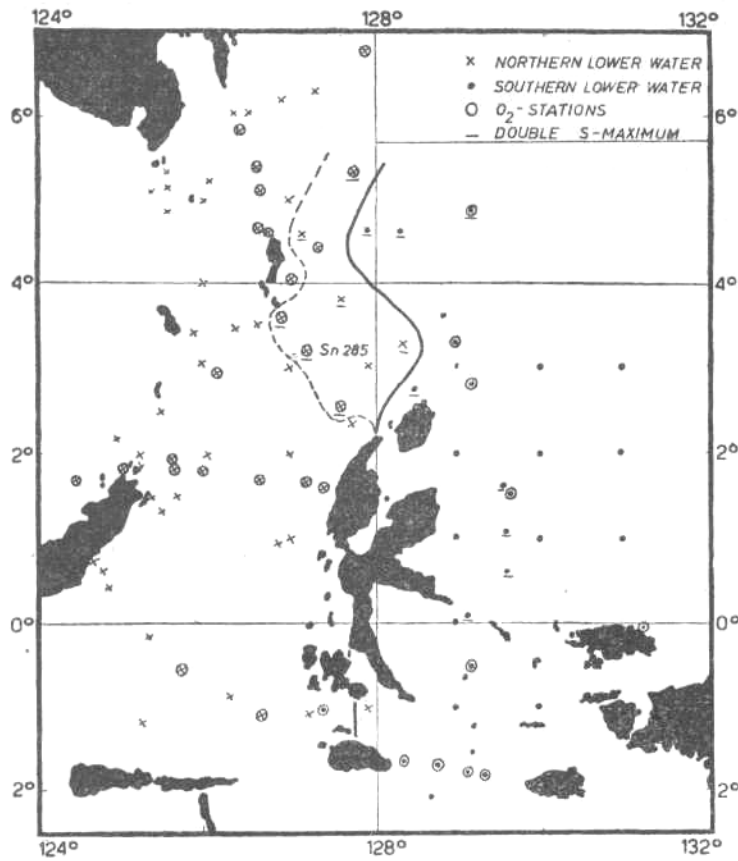


Fig. 10. Chart of the boundary of both Lower Waters and stations with a double salinity maximum.

about 25°N between 165°E and 165°W in August at a salinity of 35.5‰ and at temperatures up to 27°. The region of origin of the southern Lower Water lies in about 18°S between 120° and 150°W in February at a salinity of 36.2‰ and a temperature of 27°. The corresponding TS values are introduced into Fig. 9. Remarkable is the more eastern position of the southern region of origin and its higher salinity. Both regions fall together with a line of convergence (Fig. 11, dotted line), which can easily be seen in the current charts of the corresponding months. It is remarkable how far reaching is the extension of the Lower Waters formed at both these places which can be seen especially from Fig. 11. The properties

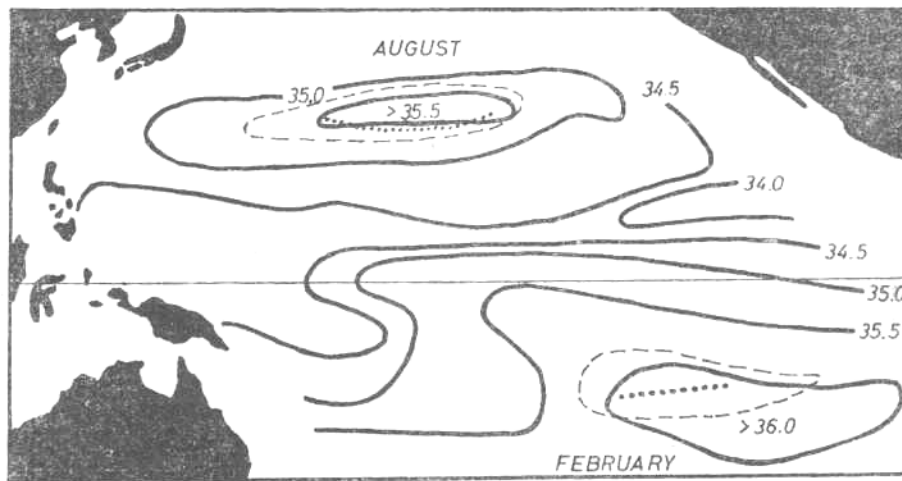


Fig. 11. Surface salinity in the Pacific Ocean after SCHOTT and regions of origin of both Lower Waters (broken line) and lines of convergence (dotted line).

of the water types which take part in the mixing processes in the region between the Philippines and Irian are summarized below:

Water type	temperature	salinity	remarks
Tropical surface water	> 27	< 34.5	low density
Northern Lower Water	26.5	35.5	100 - 150 m
Southern Lower Water	27	36.2	125 - 175 m
Northern Intermediate Water	10	34.5	300 m
Southern Intermediate Water	6	34.5	800 m

The double salinity maximum and the annual variation. In the region north and east of Halmahera at a number of stations a double salinity maximum is observed, but from Fig. 10 it can be seen that this feature has no uniform character, because between the stations with a double maximum one will always find stations with one maximum. Investigation leads to the conclusion that it must be the result of the annual variations. For such a comprehensive investigation of the annual variation not enough stations are available during the period November/April, as mentioned in the beginning.

To fill this lack it seems necessary to draw the attention to the general circulation in this region, as presented by SCHOTT (1939). He gives the surface currents in this region for summer and winter, that is

the times of the strongest and weakest development of the South Equatorial Current. During the period June/September, wherein nearly all our observations fall, the South Equatorial Current flows with high velocities to the west along the northern coast of Irian. Off the coast of Halmahera it is deflected to the north, where it joins with the waters, coming between Halmahera and Celebes from the Molucca Sea, and thence passes over into the Counter Current after being deflected further to the east. The Mindanao Current, resulting from the North Equatorial Current, is developed only weakly. It splits southeast of Mindanao, one branch going to the Celebes Sea, the other to the east into the Counter Current.

One finds a completely contrary development during the period December/March when the North Equatorial Current shows its strongest development. This leads also to a strong development of the Mindanao Current, which only partially enters the Celebes Sea. The greater part is deflected to the east into the Counter Current. In the region north of Irian only weak and irregular drift currents are found. Only east of 140°E can the South Equatorial Current be noted.

This description shows that the region north and east of Halmahera will be filled in the annual cycle alternately with watermasses of the North and of the South Equatorial Currents. To give a picture of the variation of the vertical distribution of temperature and salinity the TS curves of five stations in this region are drawn (Fig. 12), which positions are introduced into Fig. 1. It is clearly noted that in July the station Da 3745 belongs to the southern Lower Water, while in January the station A 162 belongs to the northern Lower Water. It is during the times between these that the exchange of watermasses must occur. The manner in which this occurs is shown by the stations Sn 269 and Sn 285 in May. The distribution existent in January is attacked from below, whereby the southern Lower Water moves underneath the northern. In this process the double maximum is formed, which is conditioned dynamically. This process of undersliding lasts as long as the whole water column is occupied by the southern Lower Water, and the conditions of the station Da 3745 are produced. The alternate process which occurs between September and January can be shown by means of the Japanese station 31/35 in December 1934. During this time the southern Lower Water is attacked from above by water masses of the northern Lower Water, so that its salinity maximum comes to lie always at lower temperatures, up to the time it is completely removed.

East of Halmahera a temporary double salinity maximum is found which seems also to be conditioned dynamically. Yet both maxima belong

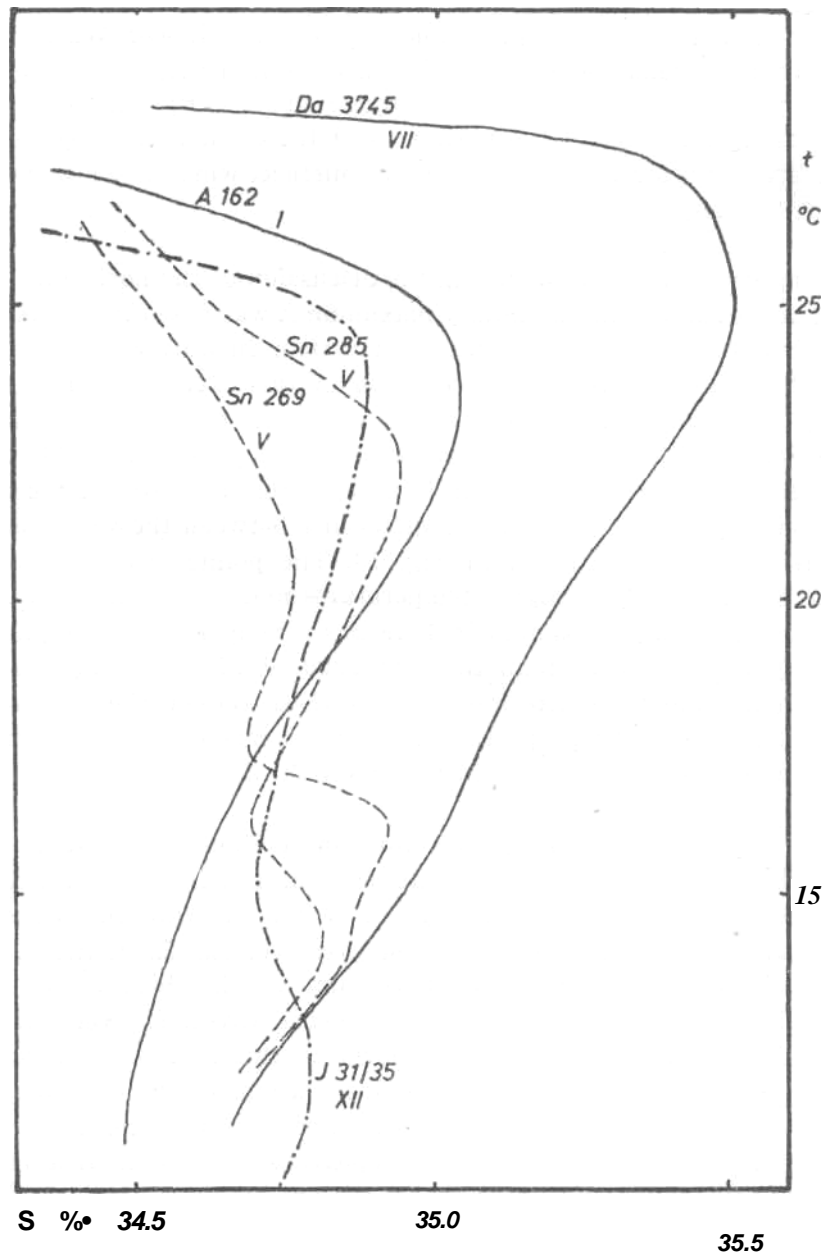


Fig. 12. TS relations of stations in the area of the double salinity maximum, demonstrating the annual change of water masses.

to the southern Lower Water. This second maximum seems to originate every year with the advancing of the South Equatorial Current if new Lower Water enters this region and replaces the Lower Water of the last year. Both double salinity maxima are reduced very simply to dynamical processes at the exchange of water masses. By this sample one notes the big influence of the variations of the circulation at the surface on the hydrographic conditions below the surface, which reaches deep into the discontinuity layer.

Longterm fluctuations. During the discussion of the horizontal distribution of the salinity in the salinity maximum it was noted that in August/September 1949 the salinity was higher than in July/September 1929 (Figs. 3, 4). For a further investigation of this fact the differences in salinity and temperature between TS values in the salinity maximum were calculated for neighbouring stations of both years. These 23 stations do not differ more than one month in time, so that an effect of the annual variation may be disregarded. The difference between the values of 1949 and these of 1929 are given in Fig. 13. The points show considerable scatter, but lie clearly at higher temperatures and lower salinities. On the average, the salinity maximum in 1949 has a temperature 2° higher and a salinity 0.1‰ lower than those of 1929. While the causes of these fluctuations cannot be determined from these observations it may be either variations in the properties of the water masses at their formation at the surface, or fluctuations in the strength of the circulation.

The depth of the salinity maximum in relation to the water movements. The depth of the salinity maximum, obtained from the vertical curves of salinity, is presented in Fig. 14. When drawing this chart, the values must be smoothed because of the great vertical fluctuations. These fluctuations of the depth of the maximum within short intervals are produced at first by internal tides and internal waves. The vertical movements of the discontinuity layer are large in this region and amount to 10-40 m, (LEK, 1938) according to the observations of the Snellius.

The depth of the salinity maximum and of the discontinuity layer must be in close connection with the topography of the surface and the currents in the surface layer. Because the observations originate mostly from the period June/September, one must compare them with the current charts of the same season. The charts of the surface currents given by SCHOTT (1939) for this region in northern summer are especially suit-

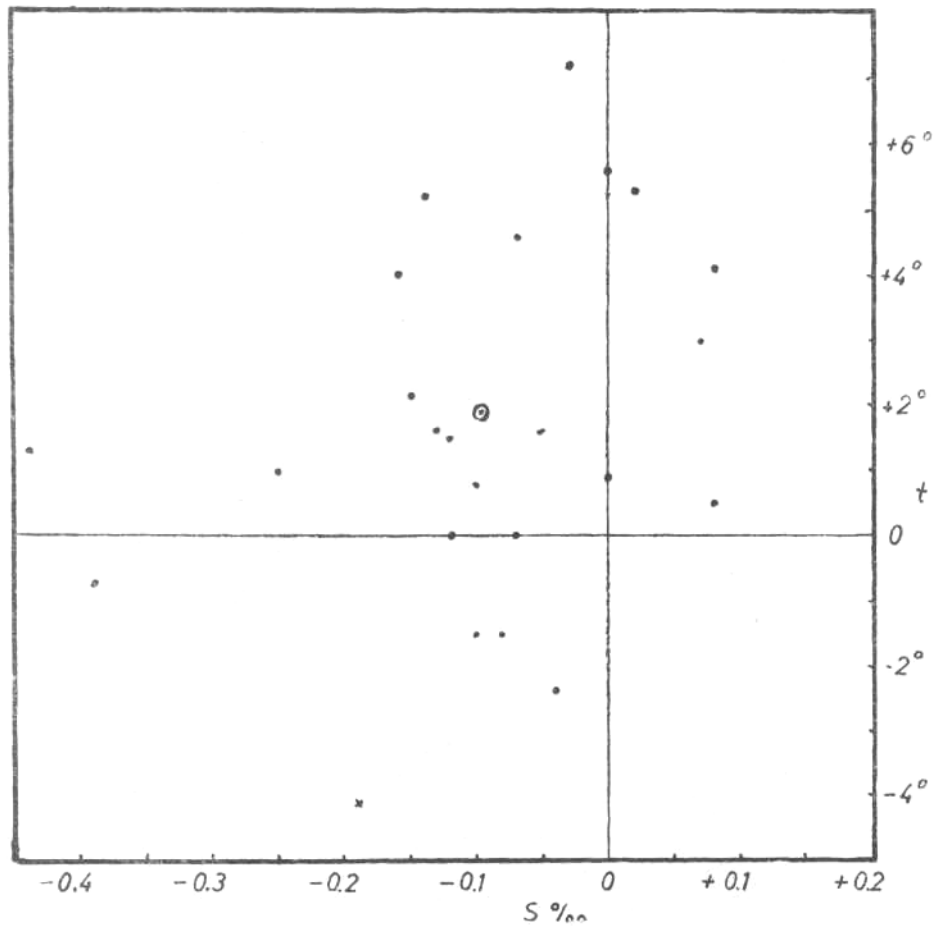


Fig. 13. Difference of the TS values in the salinity maximum of neighbouring stations between 1929 and 1949.

able. The current boundaries, convergences and divergences given by him are introduced into Fig. 14.

The most remarkable feature in the circulation of this region is the large eddy northeast of Halmahera, in which the South Equatorial Current turns into the Counter Current. The end of the line of convergence between both currents given by SCHOTT falls nearly into the centre of this eddy. Furthermore, this presentation shows the South Equatorial Current following the slope when crossing the equator north of Irian, because the deflecting force of the earth's rotation vanishes at the equator. Contrary to this in the region of the Counter Current a considerable cross slope exists.

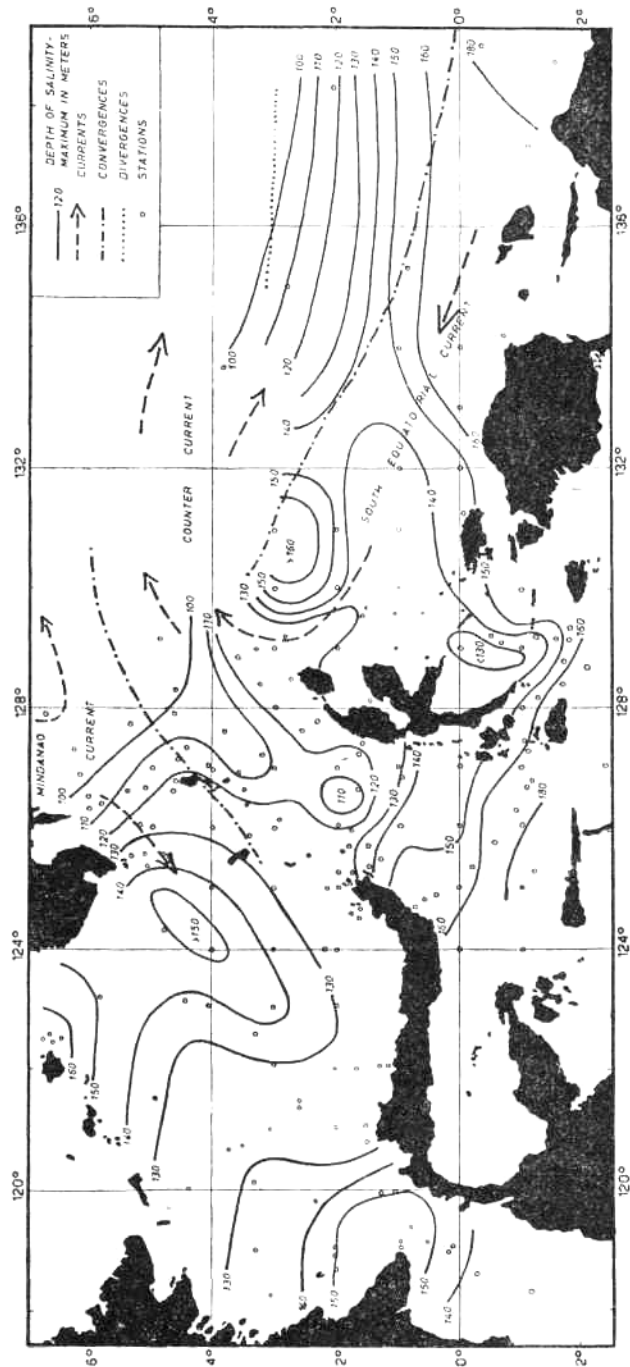


Fig. 14. Topography of the salinity maximum.

According to the chart of SCHOTT, water masses flow to the north between the northeast corner of Celebes and the island Halmahera, joining with the Counter Current. These water masses also follow the slope when * crossing the equator, but a cross slope is noted in the course of this flow just at about 4°N.

The Mindanao Current comes from the north and splits southeast of Mindanao into two branches, one of these joining with the Counter Current, the other flowing into the Celebes Sea. Here no clear correlation to the topography of the salinity maximum can be noted. Indeed, the observations of the Snellius in this region are for May only, and in this month the splitting of the Mindanao Current might take place further south, a conclusion drawn from the charts of SCHOTT for the northern winter. One could identify the branch of the Mindanao Current, forming the Counter Current with the 100 m depth line, while one had to associate the branch flowing to the Celebes sea with the 130 m depth line.

In the Celebes Sea Fig. 14 shows a large anticyclonic eddy in its center in about 4°N and 124°E. Contrary to this, the charts of the surface currents (US Hydrographic Office, 1945) show a cyclonic eddy not only in August, but during the whole year in the Celebes Sea. A conclusion in this question can be made only with a knowledge of the current observations used in drawing these charts, or with more extensive observations.

Appendix.

List of oceanographic stations obtained by MS SIBOELA in 1949 in the region north of Irian and in the Celebes Sea.

(m depth of observation; t temperature C°; S salinity ‰; * interpolated values).

Station Si. 1. 13. 8. 1949 01 ^h			Station Si. 2. 13. 8. 1949 11 ^h			Station Si. 3. 13. 8. 1949 20 ^h		
1° 00' N, 120° 00' E			1° 00' N, 119° 00' E.			2° 00' N, 119° 00' E.		
m	t	s	m	t	s	m	t	s
0	28,8	33,89	0	28,4	34,02	0	28,4	34,11
10	28,8	33,85	10	28,5	34,01	10	28,4	34,04
20	28,7	33,87	20	28,5	34,03	20	28,3	34,01
30	28,8	33,85	30	28,4	34,06	30	28,3	33,94
50	27,5	34,43	50	28,2	33,97	50	27,6	34,19
75	24,7	34,58	75	27,3	34,22	75	27,4	34,28
100	24,0	34,64*	100	25,7	34,41	82	26,3	34,42*
150	22,2	34,73	150	21,1	34,66	123	26,0	34,47
200	21,3	34,70*	200	19,2	34,60*	164	25,9	34,51
250	17,8	34,54	250	12,7	34,40	205	22,5	34,68

Station Si. 5.
14. 8. 1949 16^h
3° OO' N, 120° OO' E.

m	t	s
0	29,2	34,04
9	29,0	33,65
18	28,9	33,76
27	28,8	33,69
46	28,6	33,87
68	27,8	34,27
90	23,6	34,66
136	19,2	34,54
152	15,3	34,45
227	12,2	34,40

Station Si. 6.
15. 8. 1949 02^h
2° OO' N, 120° OO' E.

m	t	s
0	28,5	33,57
10	28,8	33,68
20	28,9	33,81
30	28,9	33,79
50	28,6	33,84
65	28,6	34,19
87	24,8	34,56
130	19,8	34,61
173	17,4	34,53
217	15,0	34,36

Station Si. 7.
15. 8. 1949 13^h
2° OO' N, 121° OO' E.

m	t	s
0	31,5	33,73
10	29,0	33,85
20	29,0	33,86
30	28,6	34,00
50	28,2	34,21
71	24,3	34,58
94	20,8	34,57
141	17,6	34,58
188	15,9	34,44
235	14,4	34,38

Station Si. 8.
15. 8. 1949 22^h
3° OO' N, 121° OO' E.

m	t	s
0	28,8	33,83
10	28,8	33,77
20	28,8	33,90
30	28,5	33,90
50	27,7	34,25
76	27,4	34,15
115	26,5	34,52
153	22,4	34,73
192	18,0	34,53

Station Si. 9.
16. 8. 1949 08^h
3° OO' N, 122° OO' E.

m	t	s
0	28,2	33,95
10	28,7	33,98
20	28,6	33,96
30	28,6	33,94
50	27,1	34,38
71	25,1	34,70
94	23,7	34,74
141	18,6	34,76
188	18,1	34,68
235	14,1	34,39

Station Si. 10
16. 8. 1949 17^h
2° OO' N, 122° OO' E.

m	t	s
0	29,0	33,88
10	28,9	33,82
20	28,7	34,07
30	28,5	34,10
50	27,8	34,18
73	27,3	34,20
97	24,0	34,65
145	22,4	34,76
193	17,1	34,59
242	14,9	34,52

Station Si. 11.
17. 8. 1949 03^h
2° OO' N, 123° OO' E.

m	t	s
0	28,7	33,88
10	28,9	33,77
20	28,8	33,87
30	28,7	33,95
50	26,9	34,33
58	24,4	34,49
77	23,1	34,55
115	19,5	34,76
153	15,8	34,56
192	14,5	34,49

Station Si. 12.
17. 8. 1949 12^h
3° OO' N, 123° OO' E.

m	t	s
0	28,8	33,93
10	28,7	33,85
20	28,7	33,90
30	28,8	33,89
50	28,2	33,99
75	27,1	34,20
100	25,5	34,59
150	16,5	34,51
200	12,3	34,32
250	10,2	34,23

Station Si. 13
18. 8. 1949 00^h
2° OO' N, 124° OO' E.

m	t	s
0	28,0	39,93
10	28,5	33,86
20	28,6	33,90
30	28,2	33,82
50	28,0	33,87
75	25,1	34,53
100	23,3	34,54
150	19,2	34,63
200	14,9	34,42
250	13,7	34,35

Station Si. 14.
18. 8. 1949 06^h
2° 00' N, 125° 00' E.

m	t	s
0	27,8	33,88
10	28,5	33,96
20	28,3	33,87
30	28,1	33,87
50	27,2	33,99
75	24,0	34,70
100	22,0	34,66
150	18,5	34,59
200	15,2	34,41
250	12,2	34,37

Station Si. 17.
22. 8. 1949 23^h
3° 00' N, 124° 00' E.

m	t	s
0	28,7	34,07
10	29,1	34,04
20	29,0	33,91
30	28,7	—
50	28,5	—
71	28,1	—
94	25,0	34,64
141	21,8	34,65
188	16,5	34,59
135	13,8	34,36

Station Si. 20.
24. 8. 1949 15^h
4° 00' N, 126° 00' E.

m	t	s
0	28,6	33,82
10	28,6	33,79
20	28,6	33,79
30	28,6	33,79
44	28,6	33,80
65	28,4	33,94
87	27,6	34,33
130	23,9	34,74
173	20,4	34,80
217	16,8	34,54

Station Si. 15.
22. 8. 1949 04^h
4° 00' N, 125° 00' E.

m	t	s
0	28,1	33,84
10	28,6	33,85
20	28,6	33,85
30	28,6	33,90
48	28,5	33,95
73	27,4	34,36
97	24,4	34,44
145	18,7	34,52
193	15,5	34,51
242	11,8	34,27

Station Si. 18.
23. 8. 1949 08^h
3° 00' N, 125° 00' E.

m	t	s
0	28,7	34,05
10	28,8	34,04
20	28,7	34,05
30	28,7	34,28
44	27,6	34,26
65	25,3	34,43
87	23,7	34,62
130	19,0	34,64
173	16,3	34,57
297	13,3	34,37

Station Si. 21.
25. 8. 1949 00^h
5° 00' N, 126° 00' E.

m	t	s
0	28,5	33,83
10	28,9	33,76
20	28,7	33,79
30	28,5	33,94
44	28,4	34,13
65	27,0	34,50
87	25,1	34,63
130	20,4	34,77
173	18,2	34,76
217	14,4	24,53

Station Si. 16.
22. 8. 1949 14^h
4° 00' N, 124° 00' E.

m	t	s
0	28,7	33,91
10	29,1	33,90
20	28,8	33,99
30	28,7	33,84
48	28,6	33,93
73	27,1	34,39
97	24,7	34,53
145	19,1	34,56
193	17,0	34,57
242	14,7	34,44

Station Si. 19.
24. 8. 1949 06^h
3° 00' N, 126° 00' E.

m	t	s
0	28,0	34,05
10	28,2	33,93
20	28,4	34,18
30	28,2	34,03
50	27,4	34,31
58	26,3	34,38
77	24,8	34,61
115	23,9	34,63
153	18,3	34,57
192	15,2	—

Station Si. 22.
25. 8. 1949 09^h
5° 00' N, 127° 00' E.

m	t	s
0	28,5	33,77
10	28,8	33,77
20	28,7	33,82
30	28,7	33,82
50	28,6	33,79
73	28,3	34,00
97	26,5	34,41
145	21,0	34,82
193	14,3	34,50
242	11,9	34,37

Station Si. 23.
25. 8. 1949 22^h
4° 00' N, 127° 00' E.

m	t	s
0	27,9	33,69
10	28,3	33,79
20	28,5	33,73
30	28,3	33,83
50	28,2	34,01
72	25,9	34,50
97	24,1	34,76
145	20,5	34,85
193	17,1	34,67
242	12,3	34,48

Station Si. 26.
27. 8. 1949 04^h
1° 00' N, 127° 00' E.

m	t	s
0	27,4	33,66
10	27,7	33,70
20	27,7	33,74
30	27,7	33,62
50	27,7	33,70
73	27,3	33,86
97	24,2	34,02
145	19,4	34,54
193	16,4	34,48
242	14,3	34,40

Station Si. 29.
28. 8. 1949 12^h
1° 00' S, 126° 00' E.

m	t	s
0	26,7	34,02
10	26,7	34,09
20	26,6	34,01
30	26,6	34,03
50	26,6	34,01
54	26,5	34,02
71	26,4	34,02
106	24,8	34,09
142	23,0	34,32
177	20,7	34,45

Station Si. 24.
26. 8. 1949 08^h
3° 00' N, 127° 00' E.

m	t	s
0	27,0	33,54
10	27,2	33,39
20	27,0	33,48
30	27,0	33,52
44	27,0	33,47
65	26,8	33,63
87	26,0	33,94
130	18,8	34,65
173	17,7	34,62
217	16,5	34,55

Station Si. 27.
27. 8. 1949 17^b
0° 00' N, 127° 00' E.

m	t	s
0	27,3	33,58
10	27,0	33,59
20	26,8	33,60
30	26,6	33,55
50	25,7	33,78
75	23,9	34,04
100	21,3	34,36
150	17,6	34,45
200	14,7	34,37
250	12,9	34,38

Station Si. 30.
28. 8. 1949 21^h
1° 00' S, 125° 00' E.

m	t	s
0	27,6	33,79
10	27,6	33,78
20	27,3	33,79
30	26,9	33,70
50	26,7	34,05
75	25,1	34,01
100	22,9	34,37
150	17,6	34,51
200	15,3	34,55
250	12,7	34,48

Station Si. 25.
26. 8. 1949 18^h
2° 00' N, 127° 00' E.

m	t	s
0	27,7	33,63
10	27,9	33,67
20	27,8	33,70
30	27,7	33,61
50	27,0	33,59
73	26,9	33,82
97	24,0	34,40 ^o
145	19,1	34,59
193	16,6	34,51
242	14,0	34,42

Station Si. 28.
28. 9. 1949 02^h
1° 00' S, 127° 00' E.

m	t	s
0	26,7	33,66
10	26,7	33,59
20	26,7	33,58
30	26,7	33,66
50	27,0	34,95
75	26,1	34,12
100	23,8	24,20
150	21,9	34,43
200	16,8	34,50
250	13,7	34,44

Station Si. 31.
29. 8. 1949 06^h
1° 00' S, 124° 00' E.

m	t	s
0	26,2	32,74
10	26,2	33,37
20	26,5	33,59
30	26,0	33,82
50	24,7	34,11
58	23,4	34,37
77	22,8	34,40
115	19,5	34,57
153	16,6	34,45
192	14,0	34,41

Station Si. 32.
29. 8. 1949 15^h
0° 00' , 124° 00' E.

m	t	s
0	26,5	28,26
10	27,2	32,09
20	27,4	33,23
30	27,3	33,34
50	26,6	33,72
75	25,7	33,71
100	23,7	34,18
150	20,6	34,54
200	15,5	34,51
250	12,7	34,48

Station Si. 35.
30. 8. 1949 17^h
1° 00' N, 126° 00' E.

m	t	s
0	27,1	33,56
10	27,3	33,55
20	27,2	33,55
30	27,1	33,59
50	26,9	33,63
54	26,8	33,59
71	26,2	33,68
106	24,4	34,34
142	22,6	34,43
177	19,8	34,54

Station Si. 38.
3. 9. 1949 13^h
1° 35' N, 125° 30' E.

m	t	s
0	26,1	33,74
10	26,3	33,78
20	26,1	33,81
30	26,0	33,93
50	25,3	34,14
65	25,1	34,13
87	24,2	34,35
130	21,6	34,55
173	18,7	34,49
217	15,6	34,42

Station Si. 33.
30. 8. 1949 00^h
0° 00' , 125° 00' E.

m	t	s
0	27,3	33,54
10	27,1	33,56
20	27,3	33,57
30	27,3	33,62
50	26,8	33,59
73	25,3	33,93
97	23,7	34,21
145	21,9	34,50
193	15,2	34,47
242	13,0	34,46

Station Si. 36.
31. 8. 1949 02^h
2° 00' N, 126° 00' E.

m	t	s
0	26,9	33,52
10	27,1	33,52
20	26,8	33,60
28	26,5	33,83
46	26,3	33,83
50	26,0	33,90
65	24,4	34,36
98	22,3	34,61
130	19,5	34,60
164	16,8	34,48

Station Si. 39.
6. 9. 1949 22^h
3° 00' N, 128° 00' E.

m	t	s
0	28,4	33,70
10	28,6	33,78
20	28,4	33,88
30	28,2	33,76
50	27,5	33,76
75	27,4	33,77
100	26,8	34,25
150	24,8	34,84
200	17,7	34,69
250	14,6	34,58

Station Si. 34.
30. 8. 1949 09^h
0° 00' , 126° 00' E.

m	t	s
0	26,8	33,56
10	27,1	33,68
20	27,0	33,59
30	26,4	33,83
50	26,0	33,88
75	24,2	34,04
100	21,8	34,48
150	19,5	34,46
200	16,6	34,50
250	14,5	—

Station Si. 37.
3. 9. 1949. 11^h
1° 35' N, 125° 05' E.

m	t	s
0	27,7	34,10
10	27,3	33,99
20	27,2	34,03
30	27,0	34,05
50	26,2	34,02
75	24,9	34,14
100	24,2	34,33
150	20,4	34,50
200	17,6	34,48
250	13,4	34,36

Station Si. 40.
7. 9. 1949 07^h
3° 00' N, 129° 00' E.

m	t	s
0	28,5	33,39
10	29,1	33,87
20	29,0	33,97
30	29,0	33,90
50	28,8	34,06
75	28,8	34,19
97	26,6	34,80
145	23,6	35,39
193	18,9	34,98
242	16,4	34,82

Station Si. 41
7. 9. 1949 17^h
3° 00' N, 130° 00' E.

m	t	s
0	30,9	33,78
10	29,5	33,77
20	29,4	33,91
30	29,3	33,91
50	29,3	34,05
75	29,0	34,13
100	28,8	34,31
150	26,6	34,82
200	25,7	34,87
250	21,4	34,95

Station Si. 44.
8. 9. 1949 21^h
2° 00' N, 130° 00' E.

m	t	s
0	29,2	33,77
10	29,3	33,82
20	29,2	33,90
30	29,1	33,85
50	29,0	34,00
73	28,8	34,45
97	27,2	35,02
145	22,8	34,92
192	20,6	34,92
242	17,7	34,92

Station Si. 47.
10. 9. 1949 04^h
0° 00' 129° 00' E.

m	t	s
0	28,6	33,95
10	28,7	33,97
20	28,7	33,95
30	28,5	33,94
47	28,4	34,08
70	27,5	34,30
94	23,8	35,10
141	20,4	34,87
188	18,9	34,84
235	15,5	34,77

Station Si. 42.
8. 9. 1949 03^h
3° 00' N, 131° 00' E.

m	t	s
0	28,7	33,61
10	29,3	33,72
20	29,2	33,76
30	29,2	33,74
50	29,0	33,71
75	28,9	34,06
100	27,3	34,84
150	22,9	34,92
200	19,9	34,94
250	15,4	34,47

Station Si. 45.
9. 9. 1949 07^h
2° 00' N, 129° 00' E.

m	t	s
0	28,7	33,92
10	28,9	33,85
20	28,9	33,86
30	28,9	33,83
50	28,8	34,18
75	28,7	34,50
100	26,6	35,22
150	21,7	35,17
200	17,5	34,96
250	15,5	34,72

Station Si. 48
10. 9. 1949 15^h
0° 00' , 130° 00' E.

m	t	s
0	28,9	33,94
10	28,8	34,17
20	28,6	34,16
30	28,6	34,19
50	28,5	34,45
75	26,6	34,67
100	26,2	34,67

Station Si. 43.
8. 9. 1949 11^h
2° 00' N, 131° 00' E.

m	t	s
0	29,4	33,48
10	29,2	33,64
20	29,2	33,79
30	29,1	33,88
50	29,1	33,87
68	29,1	33,95
91	28,9	34,51
136	24,7	34,94
182	21,9	35,05
227	17,5	35,01

Station Si. 46.
9. 9. 1949 18^h
1° 00' N, 129° 00' E.

m	t	s
0	28,6	33,68
10	28,8	33,83
20	28,9	34,09
30	28,9	34,14
50	28,7	34,24
73	28,3	24,54
97	26,7	35,15
145	23,1	35,44
193	17,0	34,65
242	15,0	34,57

Station Si. 49.
11. 9. 1949 01^h
1° 00' N, 130° 00' E.

m	t	s
0	29,2	33,73
10	29,3	33,68
20	29,2	33,75
30	29,1	33,93
50	29,0	34,29
70	28,6	34,81
94	26,5	34,20
141	23,1	35,17
188	20,5	34,96
235	17,2	34,84

Station Si. 50
11. 9. 1949 11h
1° 00' N, 131° 00' E.

m	t	s
0	29,6	33,92
10	29,2	33,82
20	29,3	33,91
25	29,2	33,83
30	29,1	33,92
50	29,0	34,02
68	28,9	34,55
91	27,3	34,98
136	23,2	35,08
182	20,4	35,04
227	15,7	34,62

Station Si. 53.
12. 9. 1949 18h
1° 00' N, 134° 00' E.

m	t	s
0	29,7	33,85
10	29,3	33,89
20	29,3	33,87
30	29,1	34,10
50	29,1	34,15
71	28,7	34,36
94	28,0	34,90
141	23,9	35,47
188	19,8	35,40
235	15,6	35,01

Station Si. 56.
13. 9. 1949 23h
0° 00' , 132° 00' E.

m	t	s
0	29,0	33,59
10	29,3	33,67
20	29,3	33,73
30	29,2	33,83
50	29,0	34,06
75	28,8	34,23
100	26,5	35,06
150	23,2	35,31
200	19,4	35,01
250	15,2	34,78

Station Si. 51.
11. 9. 1949 21h
1° 00' N, 132° 00' E.

m	t	s
0	29,3	33,67
10	29,4	33,64
20	29,4	33,69
30	29,3	33,88
50	29,2	34,02
75	28,5	34,66
100	26,8	35,03
150	21,7	35,02
200	17,7	34,79
250	15,1	—

Station Si. 54.
13. 9. 1949 04h
0° 00' , 134° 00' E.

m	t	s
0	29,1	32,84
10	29,2	33,72
20	29,1	33,86
30	29,1	34,06
50	29,0	34,07
75	28,9	34,31
100	27,4	34,80
150	22,6	35,40
200	19,2	35,25
250	16,9	35,15

Station Si. 57.
15. 9. 1949 04h
1° 00' S, 130° 00' E.

m	t	s
0	28,4	33,76
10	28,7	34,06
20	28,4	34,07
30	28,3	33,99
50	28,3	34,08
75	26,9	34,22
100	24,2	34,57
150	20,9	34,90
200	17,2	34,78
250	15,2	34,70

Station Si. 52.
12. 9. 1949 07h
1° 00' N, 133° 00' E.

m	t	s
0	29,2	33,65
10	29,3	33,52
20	29,3	33,63
30	29,3	33,81
50	29,4	33,93
75	28,9	34,37
100	26,4	35,16
150	22,9	35,45
200	20,2	35,38
250	14,4	35,01

Station Si. 55.
13. 9. 1949 13h
0° 00' , 133° 00' E.

m	t	s
0	29,6	33,42
10	29,3	33,86
20	29,2	33,91
30	29,1	33,96
50	28,9	34,18
71	28,4	34,50
94	27,6	34,52
141	25,1	35,35
188	22,7	35,40
235	17,1	34,76

Station Si. 58.
15. 9. 1949 13h
1° 00' S, 129° 00' E.

m	t	s
0	28,7	34,06
10	28,7	34,06
20	28,5	34,11
30	27,4	34,46
50	26,8	34,48
75	25,1	34,88
100	23,0	34,98
150	21,6	34,96
200	18,4	34,89
250	15,9	34,76

Station Si. 59.
15. 9. 1949 22^h
1° 00' S, 128° 00' E.

m	t	s
0	27,8	34,03
10	27,7	—
20	27,7	—
30	27,7	—
50	27,8	—
75	27,4	34,09
100	26,2	34,26
150	21,0	34,53
200	16,2	34,48
250	14,5	34,53

REFERENCES:

- BRENNECKE, W. 1909. Forschungsreise S.M.S. Planet 1906/7, Band 3. BRUNEAU, L., N. JERLOV and F. KOCZY 1953. Reports of the Swedish Deep-Sea Expedition, Vol. 3, No. 4. DEFANT, A. 1936. Die Troposphäre, Deutsche Atlantische Exped. METEOR Band 6, Teil 1, Lief. 3.
- LEK, L., 1938. The Snellius Expedition, Vol 2, Part 3. Leiden 1938. VAN RIEL, P. M., 1938. The Snellius Expedition, Vol. 1, Part 3. Leiden 1938. VAN RIEL, P. M. a.o., 1950. Oceanographic results, The Snellius Expedition, Vol. 2, Part 6, Leiden 1950. ROSSBY, C. G., 1951. On the vertical and horizontal concentration of momentum in air and ocean currents. Tellus, Vol. 3, No. 1.
- SCHOTT, G., 1935. Geographie des Indischen und Stillen Ozeans, Hamburg 1935.
- SCHOTT, G., 1939. Die aquatorialen Stromungen des westlichen Stillen Ozeans. Ann Hydr. 1939, 5.
- THOMSEN, H., 1937. Dana Report, No. 12, Copenhagen 1937. The Hydrographic Bulletin. The results of oceanographic observations in the north western Pacific Ocean, No. 3, 1931-35, Tokyo 1950. US Hydrographic Office, Currents in the South China, Java, Celebes and Sulu Seas. H. O. Publ. No. 236, Washington 1945.