DEEP CIRCULATION IN THE EXPANSE OF THE NORTH ATLANTIC OCEAN [1]

by

GEORG WÜST, Berlin.

(Reproduced from *Die Naturwissenschaften*, Berlin, 1936 - 24th Year, Part 9).

It has been the custom for some years to speak of a "troposphere" and also of a "stratosphere" in the ocean (2), i. e. of a layer of warm water having a large vertical temperature gradient, which is generally high in saline content and the locality of an active tropospherical circulation; and of a layer of fairly homogeneous cold water of low salinity in which only a slow circulation of the stratospherical mass occurs. The boundary between these two principal layers of the Ocean is not sharply defined. It is best characterized by the intermediary principal minimum of oxygen which may be traced from 45° S. to 55° N., and which for the most part coincides approximately with the isotherm of 8° C. The great expanse of the Ocean is thus composed of liquid stratospherical masses above which, between lat. 45° S. and lat. 55° N., lies a layer of warm water, namely a troposphere, having an average depth of about 500 metres only. The study of the stratosphere within the scope of the *Meteor* explorations is now complete (3). In accordance with the plan of MERZ (4), this study has not been confined to the exploration zone of the German Atlantic Expedition; but comprises, on the contrary, the entire expanse of the Atlantic Ocean, i. e. the series of measurements of temperature and salinity of some 70 exploring vessels taken between 1873 and 1933 — data which have been submitted to a standard system of analysis and classification. We shall not attempt here to give a synopsis of the particulars of the distribution of salinity and temperature disclosed by the numerous charts and sections which form the voluminous atlas (5). From this mass of material one special problem only will be selected for discussion — that of the diffusion and admixture of the stratosphere liquid masses throughout the entire expanse of the ocean.

Up to the present we have been compelled to deduce the principal characteristics of the deep circulation from longitudinal sections more or less arbitrarily drawn. It is evident that in this manner a three-dimensional image cannot be obtained and that there will result only an approximate representation of the north-south components. On the other hand, we might contrive to deduce the spatial diffusion of the different kinds of water from temperature and salinity charts plotted for various levels extending down to the ocean bottom. But that, again, is also impossible, since the control layers of these kinds of water rise and fall, and therefore are manifested only fragmentarily in the various horizontal planes. For these reasons we have adopted another method of deducing the circulation, rarely employed up to the present, which we shall call the "method of control layers" (*Kernschichtmethode*). We mean by this that we shall not proceed from longitudinal sections nor from charts of the various horizontal planes (at standard depths) which are based on plane surfaces; but rather from the charts of the control layers, which depict the regional distribution of the factors on curved surfaces, i. e. in space. The easily recognisable maxima and minima in the vertical distribution of

---

(1) *Lecture delivered on* 20th *May,* 1935, *at the Technical Session of the* Gesellschaft für Erdkunde *in Berlin.*

(2) A. DEFANT, Dynamische Ozeanographie, *Berlin. Jul. Springer,* 1929.

(3) G. WÜST : Die Stratosphäre des Atlantischen Ozeans. *Scientific results of the German Atlantic Expedition on the research and exploration vessel* Meteor, 1925-1927 : *Vol. VI, Part* 1, *Berlin,* 1935.

(4) A. MERZ : Die Deutsche Atlantische Expedition auf dem Vermessungs- und Forschungsschiff Meteor : 1st *Report. Sitzgsber. Preuss. Akad. Wiss. Physikmath/Kl* 31 (1925).

(5) *The Atlas accompanying Vol. VI comprising the* 92 *tables of the vertical and horizontal distribution of temperature, salinity and density in the stratosphere. Will appear shortly.*

salinity and oxygen are particularly suitable for determining the location in depth of these control layers. A glance at the vertical curves (Fig. 1, upper) representing the distribution of salinity between lat. 40° N. and lat. 41° S. shows that everywhere, in this immense space, the stratification of the stratospheric salinity follows the same basic law. Following the sudden drop in the troposphere, a pronounced salinity minimum is found everywhere at depths between 500 and 1000 metres, which we shall consider as the control layer of the intermediate subantarctic water Z_s. Below this stratum the salinity increases, reaching a maximum at depths between 1,200 and 2,800 m., forming the control layer of the upper deep water T_o. In the northeast Atlantic Ocean this is identical with the Mediterranean water M which is very rich in salt. The corresponding distribution of oxygen (Fig. 1, lower) shows, on the other hand, that in the highly saline depths two further layers of strongly renewed liquid masses exist, which are made manifest through the maxima of oxygen as the intermediate and lower deep waters, T_m and T_u. In the vertical distribution of temperature such retrogressions do not occur at all or at best they are but slightly intimated. The very low temperatures at the bottom are indicative of a fifth kind of water — the Antarctic bottom water, B_s.

If from this mass of data we ascertain the location in depth of the various control layers with their corresponding values of salinity, temperature and oxygenation, we shall obtain several sets of charts of the salinity, oxygenation and temperature giving a spatial representation of the diffusion and admixture.

Of these charts only a few have been selected for reproduction here.

First to be considered are the charts of the control masses of the *low salinity subantarctic intermediate water* (Fig. 2-5).

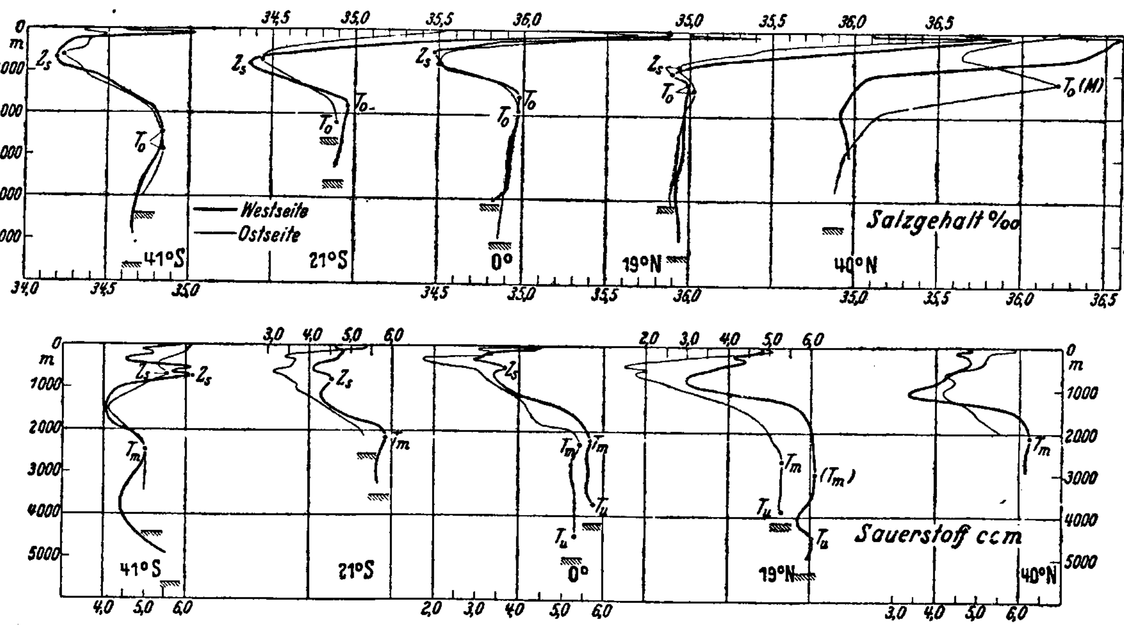


FIG. 1.

Vertical distribution of salinity and oxygen content in the North Atlantic between 41° S. and 40° N. (Z_s, T_o, T_m and T_u designate the control layers of intermedial subantarctic water or of deep North Atlantic water).

At the southern polar convergence this kind of water sinks to the lower levels and at about latitude 48° S. (at 58° S. in Drake Straits) its control layer is found at a depht of 100 m. From this point on it sinks rather rapidly to 800 metres, to reach its maximum depth of 900 to 1000 metres in the west, and 800 to 900 metres in the east, between latitudes 30° S. to 37° S. After a slight rise, which indicates the influence of morphological factors, the control layer is then found at dephts of 650 to 800 m. at lat. 10° N. One noteworthy feature is its slant, in which the deflective force due to the earth's rotation is made apparent. South of the equator it lies about 100 metres deeper in the west than in the east, while to the northward of the equator these relations are

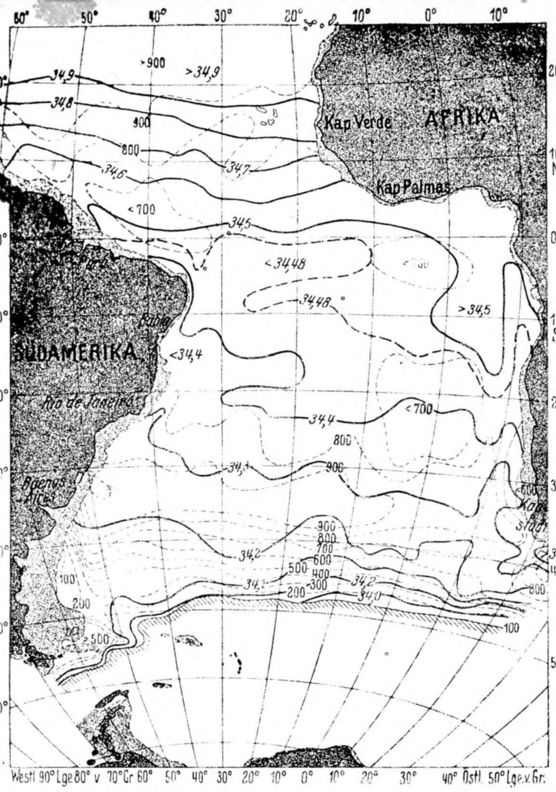


FIG. 2

Salinité en millièmes - Salinity in thousandths.

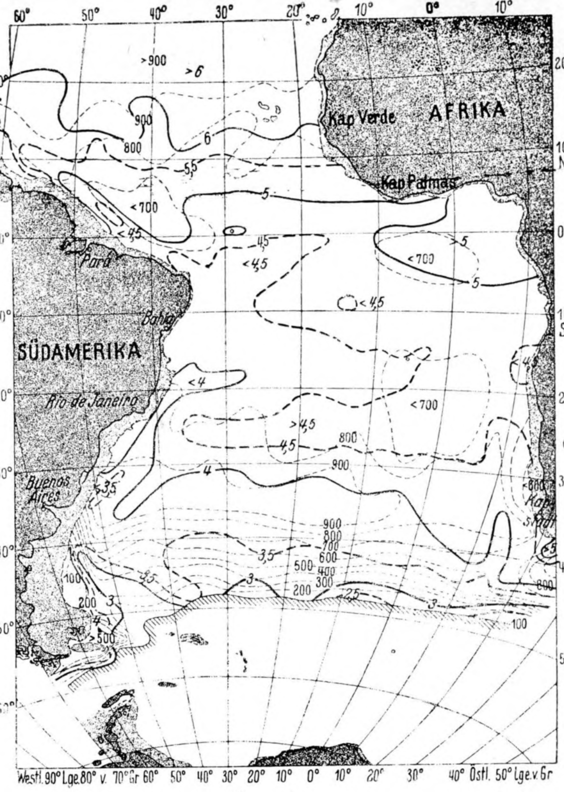
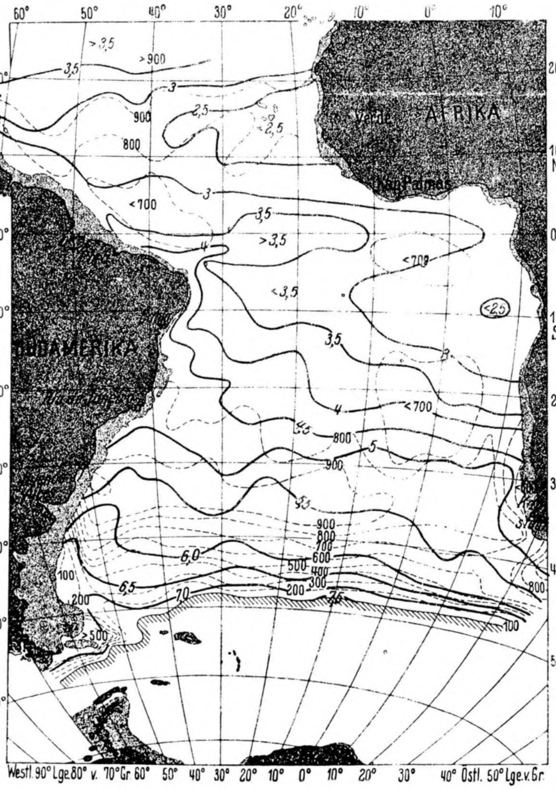
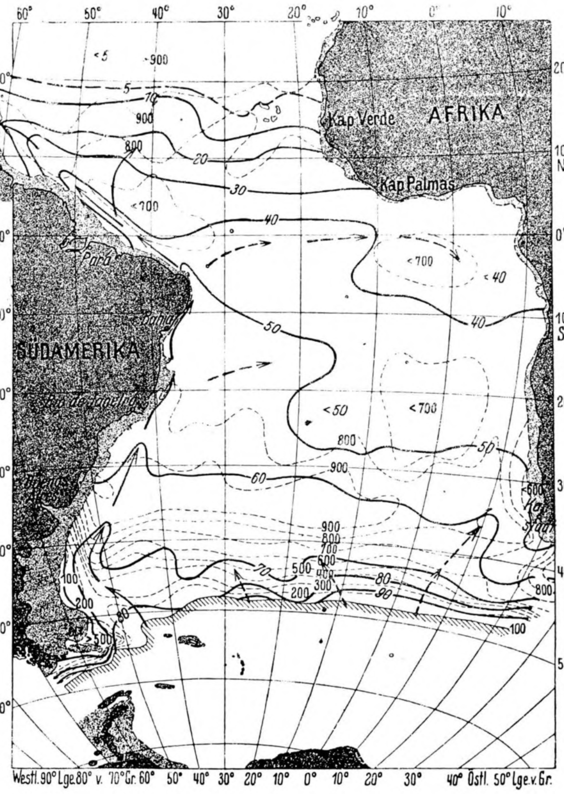


FIG. 3

Température en degrés C. - Temperatures in Centigrade.





Land

0–500 m.

FIG. 4

Oxygène en centimètres cubes par litre d'eau
Oxygen in cubic centimetres per litre of water.

FIG. 5

Pourcentage de la composante sub-antarctique
Percentage of the subantarctic component.

FIG. 2 à 5

Diffusion, mélange et situation en profondeur des masses caractéristiques de l'eau intermédiaire sub-antarctique (*minimum de salinité intermédiaire*). *Les lignes en tirets fins représentent en mètres la situation en profondeur de cette couche caractéristique. Les flèches en trait continu indiquent la diffusion principale, les flèches en trait discontinu, les dérivations.*

Diffusion, mixture and depth of control masses of intermediate subantarctic water (*minimum of intermedial salinity*). *The fine broken lines reoresent in metres the depth of this control layer. Arrows in one straight line indicate the principal diffusion ; arrows in broken line indicate the derivations.*

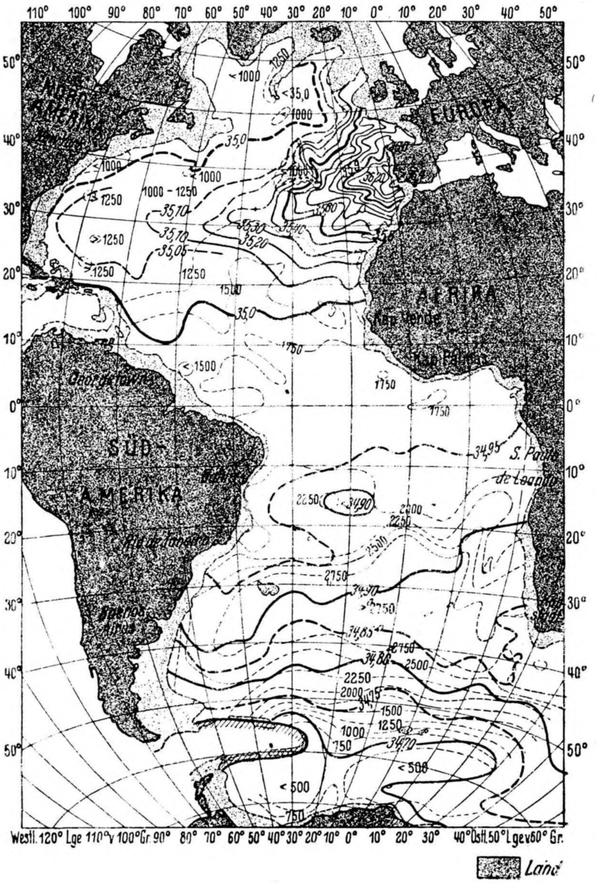


FIG. 7
Salinité en millièmes
Salinity in thousandths.

FIG. 8
Pourcentage de la composante méditerranéenne M
Percentage of the Mediterranean component M.

FIG. 7 et 8

Diffusion, mélange et situation en profondeur des masses caractéristiques de l'eau profonde nord-atlantique supérieure (*maximum de salinité intermédiaire*). *Les lignes en tirets fins représentent en mètres la situation en profondeur de cette couche caractéristique. Les flèches en trait continu indiquent la diffusion principale, les flèches en trait discontinu, les dérivations.*

Diffusion, mixture and depth of the characteristic masses of upper deep North Atlantic water (*intermedial salinity maximum*). *The fine broken lines indicate in metres the depth of this control layer. Arrows in one straight line indicate the principal diffusion, arrows in broken line indicate the derivations.*

reversed. Even in the diffusion of this kind of water the influence of the earth's rotation is made apparent, as shown by the salinity distribution within the control layer. (Fig. 2).

Thus to the northward of lat. 40° S., it shows a greater and greater preference for the western side. The overlapping of the isohalines indicates regional deviations from the "bed of the current" (Stromstrich), which inclines definitely to the westward, while in the Angola Bight, we even find indications of southerly components. In its final traces the intermediate water may be detected in the open sea between lat. 17° to 20° N ; while beyond the limits of our charts, traces of this water may still be found in the Florida Straits in lat. 26° N. This representation of the diffusion is beautifully confirmed by the oxygen distribution (Fig. 4), which reaches its highest values also in the west while in the east, and in particular in the Angola Bight, the renewal of the water masses must be quite imperfect corresponding to the very low values of oxygen content of less than 3 cub. cm.

If we plot all the salinity values of the intermediate water against corresponding values of the temperature, we arrive at the remarkable fact that to a great extent the points in both halves of the ocean group themselves very closely about the same straight line. On the basis of theoretical considerations it is permissible to deduce from the normal curve of these relations the percentage participation of the subantarctic component for the entire area, (Fig. 6), from its temperature and salinity. If the percentage ratios are plotted on a chart and the lines of equal salinity drawn (Fig. 5) we then obtain a picture of the diffusion of the subantarctic intermediate water which comprises the characteristic features of the salinity and temperature distribution and the ratio of admixture in numerical terms. Of special interest is the course of the 50 % curve which, in a narrow sense, also represents the boundary of the subantarctic intermediate water. In the east this line is found to the southward of Africa in lat. 38° S., while in the west it very nearly reaches the equator. The stream line arrows therefore hug the South-American continental shelf, showing plainly the influence of the deflective force due to the earth's rotation. It is surprising that in the northern hemisphere the

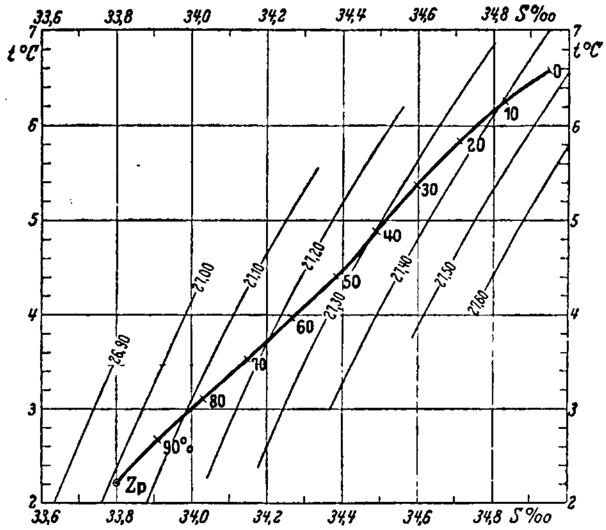


FIG. 6.

Normal curve showing the relation between temperature and salinity in the control layer of the subantarctic intermediate water.

axis of the main diffusion lies to the westward, instead of slanting towards the east, as should be expected under the influence of the deflective force due to the earth's rotation. In this locality there is evidently some other factor which is decisive with regard to the transport of the final traces of this water. These are the deep penetrating gradient forces (density) which, in the Guinea current and in the Caribbean Current exert their influence upon the liquid masses of the subantarctic intermediate layers and transport the final traces of this water on its detour through the American inland sea as far as the Florida Straits in lat. 26° N.

On one side of the bed of the stream, or in the entire eastern half of the ocean, we have to deal with regional and in part with retrogressive movements. The participation of the original liquid masses generally falls here to less than 50 %, and even to 40 %, i.e. a mixture with layers immediately above and below constitutes the greater part of the control layer.

The next layer in the structure is taken from the upper North-Atlantic deep water, which is characterized by an intermediate maximum of salinity and can be traced throughout the entire expanse of the ocean. This deep layer of maximum salinity is most clearly defined in the eastern part of the North Atlantic Ocean, where it is identical with the "Mediterranean Water". Therefore this subsurface current of high salinity and temperature which penetrates into the Atlantic from the Mediterranean through the Straits of Gibraltar becomes the principal source of the upper deep water. To the northward of lat. 20° N. its control layer lies between 1000 and 1250 m. Sinking gradually in the south to a depth of 2750 m., in lat. 35° S., it finally rises rapidly in the Antarctic to about 500 m. The salinity distribution (Fig. 7) shows very strikingly the tremendous range of the Mediterranean influence exerted directly to the northward of 15° N. and its indirect effects to the north and south thereof through the meridional transport in the deep current. Although Jacobsen traced the Mediterranean water only as far as about long. 45° W., we realise that its regional diffusion is much more important and extends as far as the west side of the North American Basin (1). In this manner there is produced in the North Atlantic Ocean at a depth of from 1000 to 1250 metres a saline concentration of more than 35 °/°° which constitutes the principal source of the "upper deep current" the last traces of which may be followed far to the south. If we carry out the calculations for the percentage participation of the Mediterranean component, in a manner similar to the case of the "intermediate water" (Fig. 9), we again obtain a representation of the admixture (Fig. 8) which permits us to ascertain the path of principal diffusion and its deviations. We receive a clear impression of the powerful and far-reaching influence of the Mediterranean infiltration upon the mass structure of the Atlantic stratosphere, which gives numerical corroboration of the concept previously formulated by DEFANT (2). In the western part of the North Atlantic ocean the Mediterranean component *M* falls to 25-50 % while in the South Atlantic the values

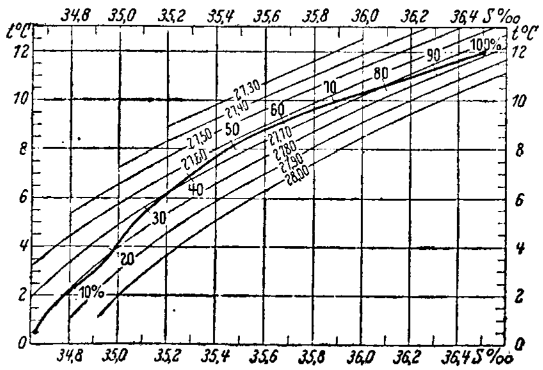


FIG. 9.

Normal curve of the correlation between temperature and salinity for the control layer of the upper North Atlantic *deep water.*

fall to about 20 %, dropping as low as 2 % in the Antarctic (3). The western part shows somewhat higher percentages than the eastern, which again points to the westerly

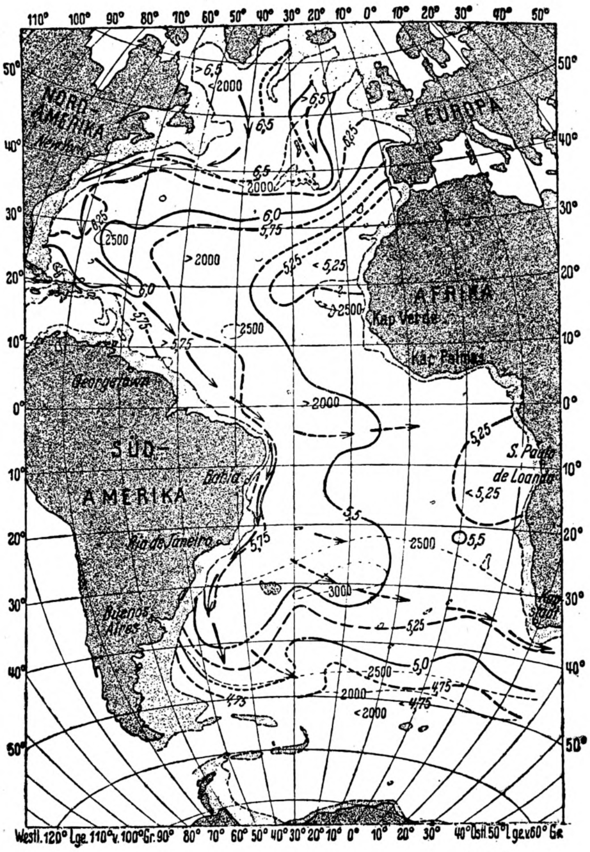
(1) J. P. JACOBSEN : Contribution to the hydrography of the North Atlantic. *The* Dana *Expedition* 1921 *to* 1922. *Copenhagen* 1929.

(2) A. DEFANT : Die ozeanische Zirkulation : *Congreso internacional de oceanografia etc. Seville* 1929 - *Madrid* 1930.

(3) *These values are relative only and should be reduced to about half in order to obtain the absolute percentages of the participation of the unadulterated Mediterranean,* (*i. e. east of Gibraltar*).

position of the current bed. However, the differences are not marked and it would appear here that we are dealing with a very gradual diffusion rather than with a "deep current". The last branches of this liquid mass finally reach the Atlantic South Polar Basin through the devious path of the south West-Indian Basin : a rather surprising result of the distant effect of the liquid masses formed in the North Atlantic Ocean.

Below this layer of maximum saline concentration lies a layer of maximum oxygenation at depths of 2000-3000 metres, which we shall designate as the *middle North Atlantic deep water.* The oxygenation chart (Fig. 10) shows that the principal source of this water, as WATTENBERG (1) surmised, lies in the northwestern part of the ocean in the waters of Greenland to the westward of the central ridge. North of the equator it is evidently the influence of the deflective force due to the earth's rotation which causes the current bed to be displaced so far towards the western rim ; to the southward of the equator it is bottom configuration and the compensation factors which are decisive for this unexpected westerly position. Noteworthy is the influence of the central ridge ;



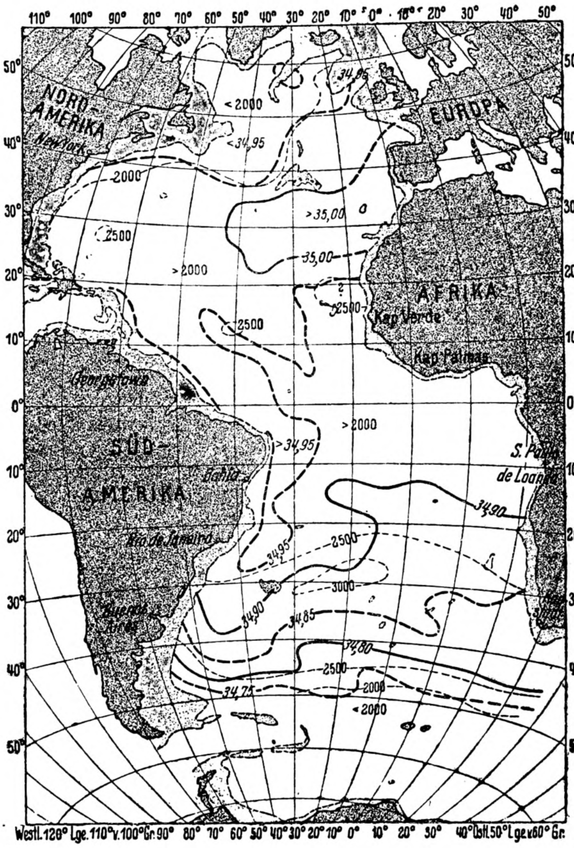


FIG. 10.
Oxygen in cubic centimetres.

FIG. 11.
Salinity in thousandths.

FIG. 10 & 11.
Diffusion, mixture and depth of the characteristic masses of middle deep North-Atlantic water (*intermedial maximum oxygen-content*). *The fine broken lines indicate in metres the depth of this control layer. Straight-line arrows indicate the principal diffusion ; broken-line arrows indicate the derivations.*

the 5.5 cub. cm. line practically coincides with it throughout between lat. 10° N. and 35° S. It is surprising also that in this stage of the structure there should still be an admixture of Mediterranean water as shown by the increase in salinity at about 35° N.

(1) H. WATTENBERG : Bericht über die chemischen Untersuchungen. *Z. d. Ges. f. Erdkunde, Berlin,* 1927.

lat. (Fig. 11). Therefore in the curve of correlations of temperature and salinity we have a point of inversion which characterises the properties of the deep water in lat. 35° N. (Fig. 12).

The entire current phenomenon which can be followed through 110° of latitude forms the complement to the *Antarctic bottom current* which, as was shown previously, is also propagated primarily in the western trough, although in the opposite direction. (1)

Owing to a deficiency in observational data, it was formerly the practice to deduce the deep circulation from longitudinal sections and the opinion was held that the tongue-shaped isohaline curves indicated in every case the meridional component of the current along the axis of the section. MERZ, in order to outline more clearly his working hypothesis for the vertical circulation in the Atlantic, went a step further and in the longitudinal section, at long. 30° W. showed current arrows differing in accordance with the assumed velocities of the current. The correctness of this procedure was even more convincingly evidenced when all the north-south sections throughout the Atlantic Ocean produced the same qualitative picture, a fact which was corroborated over the entire breadth of the ocean by the analytical elaboration in question. Thus, in the diffusion of the liquid masses within the sectional planes there was apparent proof of the existence of meridionally directed currents within these planes. In the subsequent extension of this method the conclusion was necessarily reached that throughout the entire width of the ocean there existed north-south components — and therefore there developed the concept of an intermediate current with a predominating northerly component and a deep current with a predominating southerly component. *Our spatial analytical elaboration shows, however, that with all five kinds of water with predominating north and south components, a stream-like character of diffusion can only be spoken of on the far western side of the ocean. In the eastern part of the ocean the liquid masses are transported by regional diffusion and in places even by contrary movements or rather slow gyrations.* In other words : the inter-hemisphere exchange of waters is so active on the western side of the ocean that it leaves its mark upon the thermohaline stratification over the entire breadth of the ocean. The meridional components deduced from the eastern longitudinal sections do not relate therefore to the plane of the section, but are valid for the west side only.

But from still another point of view, the concepts which have been formed regarding the nature of the deep circulation engendered by the longitudinal sections must be somewhat revised. *As contrasted with horizontal movements, the vertical exchange movements have been greatly neglected* and it has generally been assumed that in the control layers the factor of admixture played a relatively subordinate rôle, because at the boundaries of these liquid masses, vertical exchanges were supposedly much restricted. In this connection it should be stated that in the ocean, with the exception of the well-defined tropical discontinuity layers in the troposphere, there are no limiting layers in the sense of barriers. As a result of the confused movements in the horizontal stream lines all of the layers in the stratosphere are subjected to various exchange processes which necessitate an equalization of the properties in a vertical direction. As early as 1929, DEFANT (2), proceeding from theoretical considerations had shown convincingly that vertical temperature and salinity distribution in the ocean was a product of "horizontal advection" — (by this DEFANT meant the slow horizontal circulation movements) — and of vertical mixing processes. In two subsequent investigations DEFANT (3) succeeded in formulating the mathematical correlation between the advection and mixing and in deducing from this the exchange relations between the Antarctic bottom current and the Sub-Antarctic intermediate current. Starting with the DEFANT equations, THORADE (4) expounded five theoretical cases in which diffusion phenomena may be accompanied by

---

(1) *Compare* Naturwiss. 22, 430 (1934) : H. THORADE : Das sudpolare Bodenwasser und seine Ausbreitung nach WÜST.

(2) A. DEFANT : Die vertikale Verteilung von Temperatur und Salzgehalt im Weltmeere. *Z. d. Ges. f. Erdkunde, Berlin* 1929.

(3) A. DEFANT : Die Turbulenz der Meeresströmungen. *Rapports et Procès-verbaux. Cons. perm. international* 67 (1930).— A. DEFANT : Zur Dynamik des antarktischen Bodenstroms im Atlantischen Ozean. *Z. Geophysik II Braunschweig* 1935.

(4) H. THORADE: Strömung und zungenförmigs Ausbreitung. *Gerlands Beitr. Geophysik* 34, *Leipzig* 1931.

deep currents where one kind of water infiltrates with another. Our elaboration confirms this hypothesis from another point of view and shows *that even in the control layers, the factor of vertical admixture possesses very great importance.* As our charts of admixture

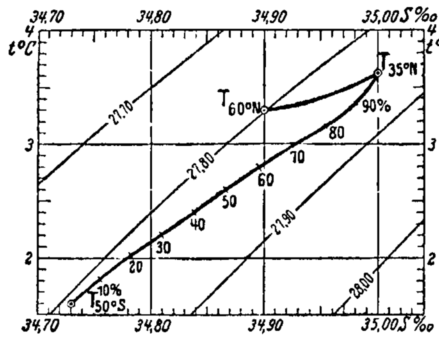


FIG. 12.

Normal curve of relation between temperature and salinity in the control layer of middle *North-Atlantic deep water.*

show, even in these layers the participation of the original water sinks to less than 50 %, except in the bed of the current. Since, however, the conditions in the stratosphere from such standpoint may be considered stationary, in the control layers as much of the original kind of water must be added as a result of the horizontal circulation as is lost to it by vertical exchange with the layers above and below. In this manner the water particles from the control layers of the intermediate water mix with the deep water and even the bottom water and vice versa. In the case of such vertical transport of liquid particles by admixture it is a question of such complicated and confused movements that they cannot be represented by stream lines and must be strictly differentiated from the processes of horizontal advection, which, in the bed of the current certainly possess more the character of currents and which can here — and here only — be indicated by current arrows. These considerations are therefore incompatible with the generally accepted idea of the lack of mutual influence of the control layers on each other and stand in direct opposition to the concept recently expounded by the Frenchman LE DANOIS (1) as a basis for his theory of oceanic transgression. LE DANOIS considers it an established fact that the liquid masses of different temperature and salinity do not intermix when they are present in large volumes. He sees proof of his theory in the layers which are very poor in oxygen (of less than 1 to 1.5 c. cm.) below the tropospherical discontinuity layer, which he considers a kind of "fossilized" water and which is considered to have retained its same quality, if not the quantity, from eocene ages. In accordance with our ideas it is a case of approximately quiet bounding layers lying between oppositely directed currents, in which advection and exchange naturally fall to very low values. But even these layers are very gradually renewed as a result of turbulence in the layers above and below, which is apparent from the fact that the oxygen content never — in spite of the additional consumption — sinks to a value of zero.

In all five kinds of water, to which are still to be added two unimportant subarctic components, the bed of the current lies entirely on the western side of the ocean. This is a rather remarkable phenomenon for which we can present no satisfactory explanation so long as reliable values for the current velocities are not available.

A comprehensive *survey of the entire stratospherical circulation* is afforded by the following illustration (Fig. 13) which is a diagrammatic representation of the conditions in so far as not only the western side of the ocean is shown but also, by the dotted arrows the diffusion of the Mediterranean waters on the eastern side. It gives a general idea of the depths of the control layers and their limits, these being deduced from the intermediate minima of oxygenation and the temperature discontinuities respectively.

(1) LE DANOIS, Les transgressions océaniques. *Rev. des travaux de l'office des pêches maritimes. Paris* 1934.

The three sources of the stratospherical liquid masses are indicated by S (Antarctic), M (Mediterranean infiltration) and N (higher N. Atlantic latitudes), the polar convergence being indicated by the letter P. The rather asymmetrical arrangement of this

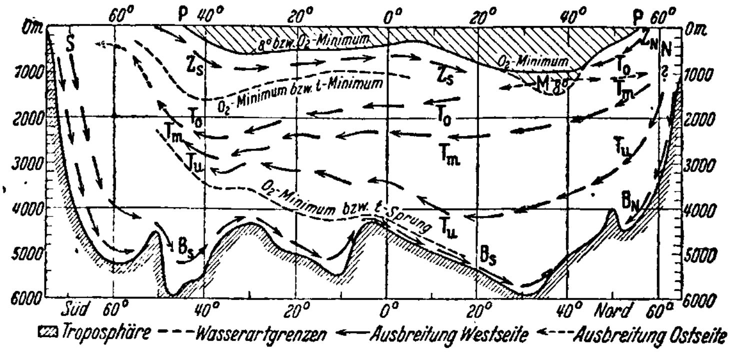


FIG. 13.

Diagram of the meridional diffusion of the stratospheric control masses in the Atlantic Ocean.

Z_s = Intermediate subantarctic water; Z_N = Intermediate North-Atlantic water; T_o = North Atlantic upper deep water; T_m = North Atlantic middle deep water; T_u = North Atlantic lower deep water; B_s = Antarctic bottom water; B_N = Subarctic bottom water; M = Mediterranean water.

circulation is very clearly indicated in this diagram. It is essentially a question of a circulation of Antarctic and North Atlantic components, which predominate chiefly on the western side of the ocean. Arctic and subarctic components, which are indicated in the diagram by the letters Z_N and B_N, play a very subordinate rôle. The causes of this asymmetry lie in the orographical and morphological conditions in the Atlantic Ocean, i. e. in the small area of access for the polar deep current N, in the closing off of the Arctic Basin by the high rises, and further by the lateral in-thrust of the Mediterranean waters and finally in the deep-seated influence of the Gulf Stream which constantly transports considerable quantities of salt and heat to the higher northern latitudes. The lateral infiltration of the Mediterranean water through the Straits of Gibraltar is the primary cause of the concentration of warm water of high salinity at the 1500 metre level between lat. 30° and 45° N. The principal minimum of oxygenation, which in these areas lies about 600 metres higher than the 8° C isotherm, shows that the accumulation of these tropospherical liquid masses cannot be attributed to the sinking of the liquid masses of higher salinity and temperature coming from the subtropical convergence zone. This concept is confirmed by the investigations of the stability relations, conducted by v. SCHUBERT (1), which show that the northern subtropical convergence zone is bounded below by a limiting layer at about 900 metres' depth which coincides exactly with the minimum of oxygenation. In the relatively deep position of the minimum of oxygen in the North Atlantic Ocean, i. e. in the great vertical mass of the troposphere, we see the effect of the Gulf Stream system whose high velocities in the depths give rise to strong lateral forces as a result of which the warm and highly saline liquid masses are forced down to greater depths.

Up to now we have tacitly assumed that the conditions in the stratosphere were constant. That this assumption is very closely approximated is proved by the fact that — aside from the sources of origin in the polar regions — the observations in quite different months and over a period of about 60 years are in fairly close agreement. Owing to this circumstance, which very materially facilitates the qualitative elaboration of the circulation problem, oceanography has a decided advantage over meteorology, in which the variation in the factors must always be taken into consideration. However, with the increase and perfection of the observations, second order differences in the case of the oceanographic stratosphere also increase, and these can only be explained on the basis of temporary variations (either periodical or irregular). Several authors, following an idea of WATTENBERG (2), have sought to calculate the velocity of the intermediate

(1) O. v. SCHUBERT : Die Stabilitätsverhältnisse des Atlantischen Ozeans. *Scientific Results of the German-Atlantic Expedition on the* Meteor : 1925-27, *Vol. VI, Part II, Berlin,* 1935.

(2) *Z. d. Ges. Erdkunde, Berlin,* 1927, 140.

and deep currents from the spatial differences between the maxima and minima in the control layers, which they regard as varying with the seasons. From a critical examination of the data I am convinced that the values of current velocity of 3-4 cm. per sec. have only a mathematical importance, since these attempts do not apply to the "bed of the current" (Stromstrich) and since the distance between stations in the exploring expedition was maintained at 200 nautical miles, smaller values than 3 cm/sec. could not be obtained (1). Further, the dynamic analysis of the temperature and salinity observations in accordance with the well-known method of BJERKNES, SANDSTRÖM and HELLAND-HANSEN which, in the case of the strong gradient currents in the stratified troposphere yields plausible values for the current velocities, encounters considerable difficulties in the stratosphere. The friction and mixing influences, which in the troposphere can be neglected in comparison with the horizontal movements are, as shown by our admixture charts, of comparable magnitude with the horizontal circulation when similarly applied in the homogeneous stratosphere. Therefore by neglecting the factor R we cannot expect to deduce the current velocity in the depths of the stratosphere from the well-known circulation equation, as derived from the pressure and density distribution, particularly as the above-mentioned small temporary variations enter as a further source of error. Therefore, dynamic methods must first be developed which will eliminate these sources of disturbance and take into consideration the exchange magnitudes. Before that it would be premature to give any numerical values for the circulation velocities in the stratosphere.

(1) *The proof is given by the author on page* 182-201 *in his extensive work on the "Stratosphere", etc.*