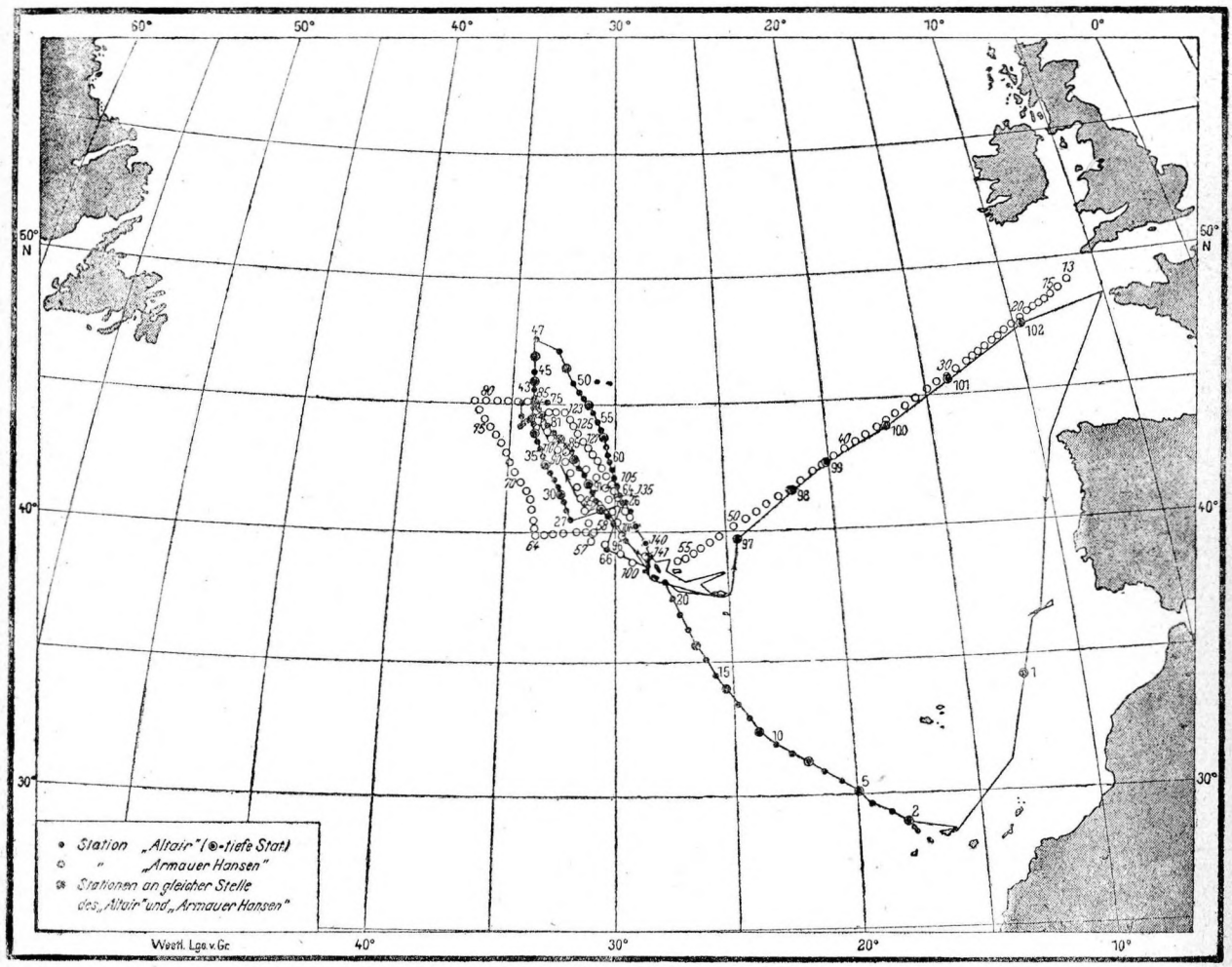
REPORT ON THE RESULTS OF THE WORK OF THE RESEARCH VESSEL "ALTAIR" TO THE NORTH AND WEST OF THE AZORES.

At the Meeting of the General Assembly of the International Union of Geodesy and and Geophysics at Edinburgh in September 1936 it was decided that an international exploration of the Gulf Stream should be undertaken by oceanographic research vessels. (1)

Some preliminary investigations were made for this purpose in May and June 1938 by the German vessel *"Altair"* of 4,000 tons, by the Norwegian vessel *"Armauer Hansen" of* 57 tons and by the french vessel *"Carimare"*.



Course and stations of the research vessels "Altair" *and* "Armauer Hansen" *in the North Atlantic* - May-June 1938.

(1) See *"Hydrographic Review"* Vol. XV, N° 2 of November 1938, page 86.

The results of the German investigations are given in a series of six fascicles appended to numbers VI, VIII, X, XI, III and IX of 15 March, 15 August, 15 October, 25 November 1940, 15 March 1941, and 15 September 1941 of the "*Annalen der Hydrographie und Maritimen Meteorologie*". The first fascicle contains, in addition, an introduction in which Professor A. DEFANT gives a general outline of the work accomplished by the vessels mentioned above. With regard to the "*Altair*" more complete details are given in the 5th fascicle by Georg Wüst. The 6th fascicle by D. Schröder, gives the details and the results of the meteorological observations and the measurements of wind velocities at high altitudes by the "*Altair*".

This vessel, on its voyage from Wilhelmshaven to Teneriffe (from 5 to 13 May 1938) occupied oceanographic stations for surface observations, took soundings on the Gettysburg and Dacia Banks and made one trial station at 4450 meters depth in three series in order to perfect the method and test the condition of the instruments.

On 19 May series observations were commenced along a track of 900 miles between the entrance to the Channel and the Azores. The twenty stations on this profile, spaced at intervals of 40 miles, were made in series at depths from 0 to 400 meters, then from 400 to 2000 meters, and finally, at every 3rd station from 2000 meters to the bottom.

The bad weather, especially at the beginning of the voyage, hindered the work considerably, caused great loss of time and sometimes endangered the instruments.

On the 5th of June the "*Altair Peak*" was discovered (Altairkuppe) (2).

The vessel remained at anchor on this peak from 16 to 20 June and there made observations of temperature and salinity every hour up to depths of 800 meters, in all 80 series. Four times, at noon, the series was prolonged to 1500 meters.

The measurements of current at depths of 5, 15, 30, 50, 100, 300, 500 and 800 meters were continued for 90 hours with the G. BÖHNECKE recording apparatus. (3).

Finally from 20 to 22 June lines of soundings were carried out radiating from the high point and there values of the temperatures and salinity were obtained in series from 13 to 1000 meters depth. At the same time a systematic survey was executed by means of 400 echo-soundings on twenty different courses.

On returning to Fayal, 16 stations had been occupied up to 1500 meters depths or to the bottom.

On 26 June Horta (Fayal) was passed, and as soon as the vessel was to the south of Pico, course was changed to E.S.E. to complete the closely spaced profiles by means of echo-soundings in the particularly interesting region of the insular shelf of the Azores.

A stay of two days at San Miguel was utilized on June 28th to visit the crater of Furnas, which is noted for its sulphurous activity. Several soundings and measurements of temperature made in the lake gave depths of from 50 to 100 meters which diminished to 12 to 13 meters in the center. The temperature at the surface was from 25.7° to 26° and at 12 meters was 16°.1; it does not appear that the water at the bottom is heated to any extent by volcanic action.

During the eight weeks (comprising the time taken occupied in going and returning) the "*Altair*" occupied 102 stations, made 299 series and 2149 observations, both for temperature and salinity, without counting the surface observations.

The "*Armauer Hansen*" completed the profile between Horta and the anchorage of the "*Altair*" between 16 and 19th June. She then anchored in the vicinity, but the weather became so bad that she was compelled to up anchor, and the "*Altair*" which had completed her work did the same. The two vessels each lost a portion of their hawsers.

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(2) See "*Hydrographic Review*" Vol. XVII, N° 1 of May 1940, page 167 and Vol. XVI N° 2 of November 1939 page 56.

The authors propose the German word "Kuppe" (peak, summit) to designate the abrupt formations of which the summit lies below the depth of 200 m.

(3) See "*Hydrographic Review*" Vol. XV N° 2, page 83.

The "*Armauer Hansen*" then executed a profile while en route towards Fayal a little more to the eastward of that of the "*Altair*". The total number of their oceanographic stations was 171.

In Fascicle N° 1 is given a list of the stations, both for the "*Altair*" and the "*Armauer Hansen*", with the positions, the echo-sounding depths obtained (uncorrected), the number of series and their depths.

The french vessel "*Carimare*" was also engaged in work from the 1st to the 20th of June in these regions and in particular made meteorological observations, 520 measurements of temperature of air and water every hour, and 260 samples of surface water every two hours. These samples, sent to the *Institut für Meereskunde* were analysed there at the same time as those collected by the "*Altair*".

In an appendix to the same fascicle Gerhard NEUMANN gives a detailed description of the results of the observations on temperature and salinity made by these three vessels.

INSTRUMENTS AND METHODS. — The instruments and the methods employed by the "*Meteor*" have been described in detail, as well as their accuracy in Volume IV of the "Work of the Meteor". These were in general the same as those used by the "*Altair*". In the 5th fascicle G. WÜST gives some information regarding them.

The large apparatus for the series observations, furnished by the *Institut für Meereskunde*, was mounted to port, nearly amidships in the vessel, just forward of the bridge, alongside the leadsman's platform and secured outside the rail. Its drum, previously used by the "*Meteor*" carried 6000 meters of galvanized steel wire of 4.5 mm. diameter. Two spare drums each carrying 4000 meters of similar wire had been furnished by the Falten and Guillaume-Carlswerk firm of Köln-Muhlheim, through the intermediary of the Deutsche Forschungsgemeinschaft. One strand of wire of 6000 meters having been broken it was necessary to cut out a section of 2000 meters and to splice in the new strand of wire of 4000 meters length.

For the collection of samples of water the expedition had available 44 bottles of the model D.A.E. (4) of which 20 had been loaned by the *Institut für Meereskunde* and recently constructed in the mechanical workshop of Marx and Berndt (Berlin) through the intermediary of the Deutsche Forschungsgemeinschaft; 14 were loaned by the Naval Observatory and 10 by the Deutsche Seewarte. These bottles were secured upright in a rack with shelves just abaft the apparatus for series observations; one bottle only was lost when it struck the bilge-keel on being hoisted aboard; it was rare that leakage occured near the spiggot and this was easily remedied.

Aboard the "*Altair*" were 67 reversible thermometers protected against pressure, most of them of the type D.A.E. (manufactured by the firm of Richter and Wiese of Berlin) of which 11 were graduated in divisions of 1/20th of a degree from — 2° to + 9°, and twelve from + 3° to + 13°, while the rest, designed for measurements in the upper layers were graduated in tenths of a degree from — 2° to + 20° or 28°. Twenty of these instruments were new, 17 came from the stock of the Institut für Meereskunde, 15 from the Naval Observatory and from the Deutsche Seewarte. The zero was verified before and after the expedition by Dr. NEUMANN at the "Institut für Meereskunde". Each thermometer has its record (aside from the results of the official calibrations carried out by the Physikalischen-Technischen Reichsanstalt) of all the tests and checks to which they have been subjected. In this manner it was easy to eliminate any defective thermometer.

Thanks to the excellent quality of the Richter reversing thermometers it was possible to abandon the method employed on the "*Meteor*" and save time by reading only one thermometer at each depth. The expedition had available 23 unprotected reversing thermometers of the type D.A.E. (Richter and Wiese), 14 of which were graduated in tenths of a degree between — 1° to + 30°, nine in 1/5th degree between 0° and 6o°. Thirteen of these thermometers had been recently constructed through the intermediary of the Deutsche Forschungsgemeinschaft, six came from the stock of the Deutsche Seewarte, four of them from the Institut für Meereskunde.

(4) *Deutsche Atlantische Expedition.*

These instruments, in which the small capillary tube and the mercury bulb withstand the full pressure of the column of water, functioned excellently. In 900 measurements of temperature only one was faulty as a result of failure of the detaching apparatus of the unprotected thermometer to function properly. The resistance of these thermometers to the pressure was still further augmented by a more suitable support for the mercury bulb and the curved capillary tube. Five of these instruments of the old type were broken, one was lost. The great angle of inclination of the wire, which sometimes reached as much as 45°, made the use of the unprotected thermometers (3 instruments for each series and 9 for stations at great depths) of great practical value.

The temperature of the surface was measured with the surface thermometers reading to 1/10th degree, plunged in the water drawn up in a zinc bucket, from which a sample was also taken for tests of salinity. This water was taken as far as possible near the bow of the vessel and carried immediately into the shade for protection during the measurements.

On this voyage successful use was made of the Sund apparatus for determining the temperature and the salinity of the surface water. This apparatus was improved by A. SCHUMACHER, and was attached to a spar about 5 meters long. A description of it is given in another article in this "Hydrographic Review".

Foreseeing that it would be necessary to collect a large number of samples of water, the expedition had taken 4000 green bottles, with a special sealing device, of 190 cc. capacity and 5000 bottles of 100 cc. capacity. The latter were destined for the titration of the surface water which had to be done only once and for the tests of the repetition series at the anchor station.

The vessel was well equipped with revolution counters, hand windlasses, (for the Sund apparatus for collecting surface water) with marline-spikes, spare parts as well as instruments of all sorts for the series apparatus and water samplers, complete apparatus for titration, test tubes, pipettes, chemical apparatus, laboratory supplies and special tables, etc.

Arrangements were made to permit a rapid execution of the series measurements, because they had to follow every 20 or 40 miles, i.e. with an interval of only one to two hours. Those stations which comprised 2 series (0-300-400-1500 meters) did not require on the average more than 1 h. 1/4; those with 3 series (to the bottom) required from 2 h. 1/2 to 3 h. depending upon the depth. A part of the titration and some of the chlorine tests were made on board; a comparison has been made between these results and those obtained in Germany in the laboratory. The latter are better, a fact which is certainly due to the difficulties of making the analysis arising from the rolling and the great changes in temperature.

The mean of the results of the titration in the laboratories shows an accuracy of 0.005 ‰ for the chlorinity or about 0.01 ‰ for the salinity. The salinity was calculated by means of the Knudsen formulae.

The bottom temperature was calculated from the readings of the thermometers (after applying the instrumental corrections) by means of the Schumacher formulae, in which account is taken of the coefficient of expansion of the glass used.

The density σ_t was calculated for the depths observed from the graphic tables of density in which the temperature and salinity are represented by rectangular coordinates, and the density by a group of curves. This procedure permits of an accuracy of 0.01 to 0.02. In case of necessity the second decimal can be exactly ascertained by using the large Sund slide-rule of the Geophysical Institute of Bergen.

The fascicle N° 5 shows the results of the observations in the form of two tables. Table 1 gives the values for the temperature, salinity and density for the depths actually observed, while those of Table 2 give these values for the standard depths which are interpolated by G. WÜST by means of the large scale vertical curves.

The Appendix to Fascicle N° 1, edited by Gerhard NEUMANN, gives in Tables I, II and III, the results of the observations on temperature and salinity of the samples of surface water collected by the three vessels :— "*Altair*", "*Armauer Hansen*" and "*Carimare*".

The author has made a particular study in this fascicle of the oceanographic conditions of the surface water in the sector in which the observations were made. After a recapitulation of the observations and the work which was already available up to then and of which he furnishes a very complete bibliography at the end of the work, he has established, by making use of these, a chart of isothermal and isohaline curves of the mean temperature and salinity of the surface water in June, between the latitudes 36 and 49° N. and latitudes 25° to 40° W.

In the same region he has prepared from the records of the ships logs, a chart giving for each of the months of May, June and July, the mean vectors, the velocities and the stability of the surface currents, with a tracing representing the circulation of the waters for the month of June.

For this same month of June and in the same region he gives the curves representing the mean distribution of the temperature and the salinity; as well as the distribution according to observations made in June 1938. These same observations were used by him to establish a chart of the circulation of the surface water in June 1938 and two others showing the anomalies of temperature and salinity on the same date.

The observations of the " *Carimare* " also permitted him to study during this period daily temperatures of air and water, as well as the force of the wind. The latter reaches a maximum near noon and a minimum near 23 hours. During the entire time of the observations the water was warmer than the air, the difference varying between 0.99° and 1.29°.

The author gives the following summary of his article :—

" 1) On the surface of the sea to the N.W. and Northward of the Azores, are formed well-defined tongues of water as far as the salinity and temperature are concerned; these interwine like fingers and lead to the supposition of very complicated dynamic relations. The simple and regular delineation of the isolines, such as is found on the older charts showing the mean values of temperature and salinity, does not give even an indication of the characteristic features of the oceanographic state of the surface water in this region, because the results of the observations have, in most cases, been pushed to the point of over-simplification.

" It has also been realized that the mean movement of the water, based on the displacement of the ship's D.R. position, should, contrary to the former conception, be represented not by the single broad band of the Gulf Stream; but by three branches which appear to be separated by counter-currents. The schematic representation of the movement of the water may well be combined with the pattern of the isotherms and isohalines.

" During the international studies of the Gulf Stream in 1938, similar conditions were generally found, as well for the temperature and for the salinity as for the dynamic state of the ocean surface." '

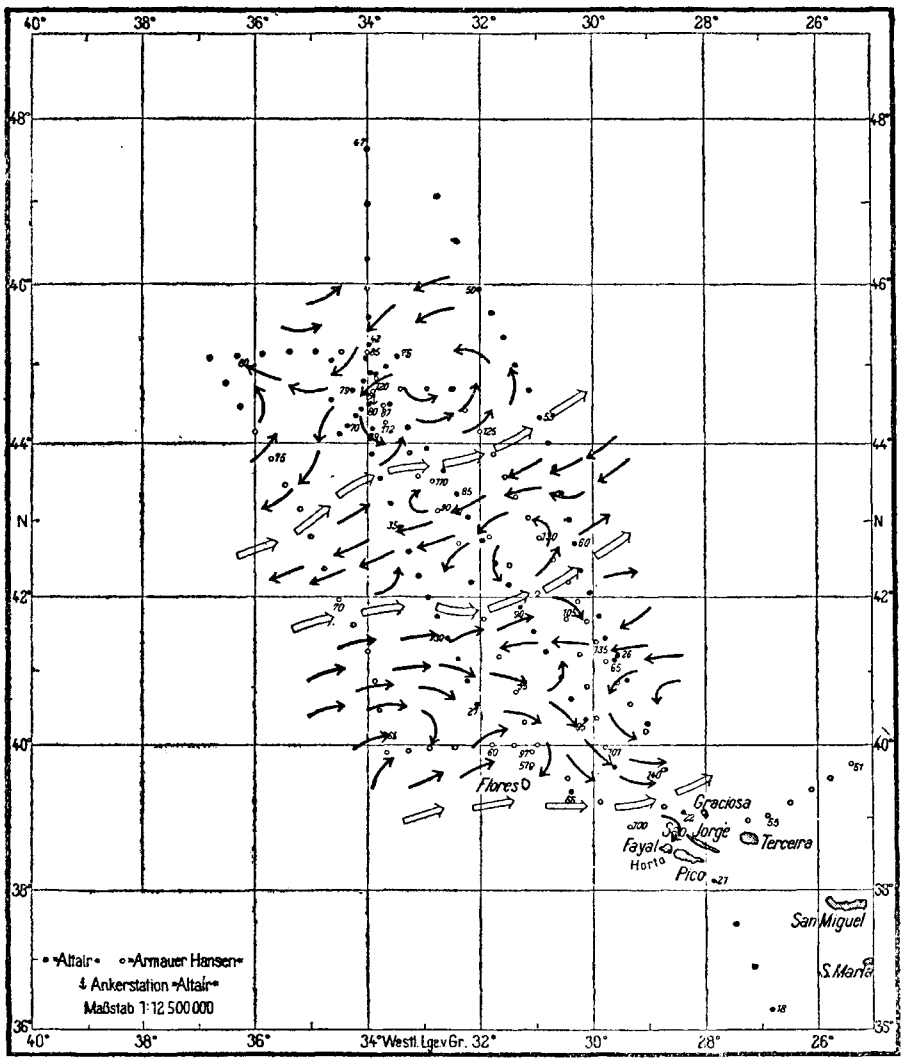
" The splitting up of the Gulf Stream into three branches appears to be a general phenomenon in this region. "

" The counter-currents are probably subjected to large variations both in position and intensity. With respect to the mean conditions the counter-current in June 1938 appears to have developed too strongly towards 43° N. and too weakly between 40° and 41° N. On the surface the aspect and the strength of these counter-currents depends mainly on the state of the prevailing winds. "

" 2) The annual variation in the temperature of the water in the region of the profiles executed by the " *Altair* " and the " *Armauer Hansen* " is entire normal; that is, it corresponds in general to the mean conditions which were predictable from the previous research carried out at sea in the corresponding latitudes. Only in the region of the Banks of Newfoundland is the annual variations very great, probably as a result of the continental character of these waters. The strong annual variation in temperature in the Gulf of St. Lawrence is certainly in close correlation with the heat transfer in the St. Lawrence current.

" On the other hand the variation in the salinity is much more complicated; in the region of the Banks of Newfoundland it is the reverse of the annual course of the temperature. The principal cause of the annual periodic variation of the salinity, in the western part of the region investigated, is the variation in the chlorine transport by the

Labrador-Current which mixes and diffuses through the Gulf Stream, and which can be traced far to the eastward. The amplitude of the variation in the salinity decreases in full conformity with the known laws, and the dates on which the extreme values occur are distinctly retarded.



Probable circulation of the water on the surface in June 1938.
(The open arrows give the presumed position of the main current).

"If we grant that the horizontal mixing is the sole factor which is decisive in this periodic modification in the chlorine transport, we may then calculate the coefficient of lateral exchange. We find : $A = 4.9 \times 10^8$ cm. g. sec. On our hypothesis this value represents the maximum for the coefficient. The amplitude of the diurnal variation in the surface temperature from 1 to 19 June 1938 is low, as is the temperature of the air. It reaches 0.40° for the temperature of the water; 0.42° for that of the air. The water is always warmer than the air. The temperature difference, — water minus air, varies between 0°99 and 1°29. The observations of the "*Carimare*" give no evidence of any diurnal period in the surface salinity."

"3°) By means of observations taken from the drifting vessel ("*Carimare*") more detailed studies may be undertaken of several non-periodic variations in the temperature and salinity. It has been found that the precipitations may well considerably diminish the

surface salinity, but this diminution is only temporary and it is compensated to such an extent that at the end of 2 or 3 hours the previous conditions are approximately reestablished.

"It is certain also that the precipitation leads to a chilling of the air, but this effect is only transitory, since the temperature of the ocean surface is scarcely modified at all."

In the Fascicle N° 2, appended to Vol. VIII of 15 August 1940, Georg Wüst has prepared a chart showing the ocean relief of the insular shelf of the Azores and the region extending to the N.W.

"The "*Altair*" had been equipped by the Oberkommando of the Navy with the most recent type of echo-sounding apparatus developped by the "Atlas-Werke" of Bremen and "*Electrokustik*" of Kiel. Several magneto-striction apparatus with directional effects were employed. They might be called ultra-sonic sounders (of high frequency or period) because they make use of the inaudible high frequencies.

These apparatus always recorded the soundings with accuracy, up to the very greatest depths (nearly 5500 meters) under all conditions and even during storms. The second echo is generally recorded and often even the third.

For small or medium depths, the use of the magneto-striction apparatus eliminates the error due to slope, because the cone of dispersion of the ultra-sound is relatively small.

For the very great depths with the type of emission used the sound spreads out in all directions, but the error due to slope was generally of much less importance because the relief is not so accentuated. The author consequently omitted all slope corrections.

When there were only slight changes in the depths, soundings were taken every five to ten minutes, but where the bottom appeared to be rather uneven the intervals were spaced at 2 1/2 minutes or even one minute.

The "*Altair*" made in all 5800 soundings, of which 3800 were in the insular shelf of the Azores or to the N.W. of these islands.

By means of these soundings and of the previous soundings which were known to him, the author was able to prepare a representation of the insular shelf of the Azores and of the region extending to the N.W.

Although this representation is partly schematic and partly hypothetical, it is evident that the insular shelf is composed of crests and throughs running from W.N.W. to E.S.E., the crests being the submarine prolongations of the central elongated islands.

It would seem that one is confronted here with volcanic formations which are joined up to the directional tectonic lines. In order to establish the representation with greater certainty it would be necessary to execute still more numerous profiles more closely spaced and lying more normal to the principal depth contour lines.

The most remarkable depression is the one of 3509 meters which lies to the west of San Miguel and which Thoulet named the "Fosse de l'Hirondelle" (from the name of the vessel of the Prince of Monaco). W. Bremecke (1) made a series of temperature and salinity observations in this deep and also four soundings, with temperature and salinity observed near the bottom. He concluded that the principal mass of water therein is separated from that which surrounds it by ridges of approximately 1500 meters, but that these ridges are broken through in places to depths of about 2000 meters, and that the colder water penetrates within through these deeper openings. He suggested that it might be possible that the exceptionally high temperature and the low density encountered near the bottom of this deep are due to an access of heat from a volcanic bottom. However it is necessary to consider here not the temperature "in situ" but the potential temperatures and densities. From these considerations we reach the conclusion that the Hirondelle Deep is separated from the ocean on all sides by walls which reach a height of 1800 meters below the surface. The potential temperature of 4.2° and the salinity of 35.04 ‰ at 3261 meters in this isolated deep is representative of the state of water at about 1800 meters

(1) *The oceanographic work of the German Antarctic Expedition* 1911/12. *Archives of the Deutsche Seewarte XXXIX Hamburg* 1921, *page* 89.

depth outside the Deep. Outside, and at a depth of about 3300 meters, the potential temperature is about 1.7° degrees lower than within the deep. There is nothing to prove therefore that the volcanic bottom supplies any heat or causes an increase in the salinity.

In several other details the chart prepared by G. Wüst differs from that of Thoulet and Schott. Thus the iles of Pico and Sao Jorge are prolonged to the E.S.E. by crests showing peaks of from 800 to 1500 meters.

In order to better examine the shape of the Hirondelle Deep, the "*Altair*" executed two profiles of closely spaced soundings between San Miguel and Terceira, in directions taken as closely as possible normal to the submarine crests. The results are given on page 9, of Fascicle N° 2.

The insular shelf of the Azores; in strong relief, constitutes a dependency of the Great Atlantic Ridge in the shape of a tongue extending to the E.N.E. It is surrounded on the north and to the south by relatively uniform oceanic depths of from 3000 to 4000 meters.

The geologist, H. Cloos, analysing the tectonic of the Azores, offers the following comments :—

"The average distance of 24 kilometers which separates the folds is decidedly less than that which is generally encountered on the continents and leads to the assumption of a proportionately smaller thickness of the layer located between the Magma and the surface of the Lithosphere (the convex plateau). All of these results are in complete agreement with the lessons of vulcanology and geophysics. ....."

"There is no room for an opposition of principle between the bottom of the continents and that of the oceans".

G. Wüst (1) presents, on the Mercator projection, to the mean scale of 1 : 5,000,000 a sample chart of the bathymetry of the region which extends to the N.W. of the Azores between latitudes 36° and 49° North and longitudes 25° to 40° East.

A morphological hypothesis is necessary to establish this chart, on which the soundings are still too widely scattered in quite a few places. Although in the depths of from 3,000 to 4,000 meters the bottom is relatively slightly uneven, there are still isolated irregularities, such as the "*Altair-Kuppe*" in which certain parts seem to show slopes of 52 1/2° and whose peak contains a small indentation which might well be the crater of a volcano.

This chart also permits one to take into consideration the probable influence of the bottom relief on the course of the Gulf Stream. We have seen that in this region it splits into three branches. The most northernly branch is diverted to the eastward, by the "*Altair-Kuppe*" and the neighboring summit, then inclined to the N.E. by the great chain called the Atlantic Ridge. A cyclonic vortex is associated with these two summits, such as should be required by the theoretical works of Ekmann on the subject of the influence of the bottom on the currents. The central branch is directed towards the E.N.E. and then towards the N.E., adapting itself in a surprising manner to the deep trench which intervenes between the spur of at least 2500 meters and the principal crest of the Atlantic Ridge between latitudes 42° and 44° N.

The southern branch does not conform so clearly to the bottom relief although in its course towards the east it flows by the deepest trench which cuts through the Atlantic Ridge.

In the fascicles N° 3 and N° 4 appended to vol. X, of 15 October 1940 and XI of 15 November 1940 of the *Annalen der Hydrographie*, A. Defant has studied the positions

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(1) *The chart of the Azores is also on the Mercator projection to the mean scale of* 1 : 1,500,000.

That of the "Altair-Kuppe", on the same projection, is to the scale of 1 : 250,000. *The latter chart, established by* A. Defant *was reproduced on a somewhat larger scale in the Hydrographic Review Volumes XVI, N° 2 and XVII, N° 1 of November* 1939 *and May* 1940, *pages* 56 *and* 170.

The three charts of the Fascicle N° 2 are colored to bring out the relief.

of the "*Altair*" at her anchorage on the "*Altair-Kuppe*" from 16 to 20 June 1938 and the observations which were made there.

The "*Altair*" was anchored there at 17 hours on the 16th of June in a depth of 1100 meters with a scope of 3500 meters of cable, which she was forced to veer by another 4000 meters towards midnight. But on 17 June cable could be shortened between 15 h. and 16.50 h. by 1,500 meters; in this way from that time until 20 June at 15.30 h. the scope of the cable was not more than 5,000 meters. On 20 June the wind and sea having risen while getting underway, the hawser broke and the last 500 meters together with the anchor were lost.

The mean position of the ship, resulting from the noon positions each day, were :—

44° -'2.75' N. 33° -58' W.

The depth varied between 2390 and 1100 meters in view of the very uneven character of of the bottom.

Series oceanographic observations were taken every hour. These are given in the appendix of Fascicle N° 3. We find there also the direction and strength of the currents observed, as well as their North and East components. The current measurements were made by means of the G. Böhnecke apparatus.(1) One with a bifilar suspension and installed astern to starboard, was held at a distance of 1.9 meters from the side. It served for the measurements effected at depths of 5, 15, 30 and 50 meters. It was controlled by means of a hand-winch. The other, suspended by a single wire and somewhat further astern was kept at a distance of 3.98 meters from the side and moved by an electric winch. It served for the depths of 100, 300, 500 and 800 meters.

Every two hours a measurement was taken at each depth which lasted at least 15 minutes.

The heading of the vessel was read every minute. The mean value of the ship's heading each half hour is given in the appendix to Fascicle N° 3. At the same time were recorded the direction and velocity of the wind and state of sea, the clouds and precipitations as well as the depth under the vessel and the trend of the cable with respect to the heading.

These headings were extremely variable; each period of rest was followed by a certain number of oscillations of more or less constant period and with generally decreasing amplitude. This amplitude was sometimes very great and the variations in the heading exceeded one quadrant; the period varied between 30 and 45 minutes, but it was not possible to ascertain what were the external circumstances on which the duration depended.

These current measurements were naturally influenced by the veering of the vessel. This however did not render them unserviceable because the causes of the error could be eliminated, thanks to a knowledge of the headings. Even the semi-hourly mean of these values was sufficient for the elimination of the larger movements; there appear thereupon the long period oscillations which are related to the variations in the wind and current.

A diagram shows graphically the relation between the ship's heading and the direction of the wind. Almost all of the points plotted thereon are comprised between two rectilinear parallels, one of which corresponds to the case in which the two directions coincide and the other to those in which the wind strikes the vessel at an angle of 45° to port, such that the vessel is deviated on the average by 35° from the direction of the wind. This angle does not appear to depend upon the wind-force.

Another curve shows the relationship between the depths measured beneath the vessel and the heading, while the cable was at 5,000 meters.

On the basis of these two curves and the chart of the "*Atlair-Kuppe*" the author has constructed a diagram of the various positions of the ship for the different wind directions, and then the possible position of the ship with respect to a point where the cable leaves the bottom.

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(1) *See description of this apparatus in the Hydrographic Review Vol. XV, N° 2, November* 1938, *page* 83.

In the first case he assumes that the vessel was always oriented exactly in the wind on a circle whose radius was 0.6 miles. He deduced from this that the "*Altair*", as a result of the variable direction of the wind, moved on a circle of 4 to 5 kilometers radius. An examination of the soundings permitted the position of the anchor to be fixed on the chart of the "*Altair-Kuppe*", the trend of the cable after the engines were stopped was deduced as being S.W. according to the directions of current and wind. The length of cable lying on the bottom was assumed as 1.2 miles and the point is noted on the chart where it leaves the bottom; a point which was almost exactly the highest point of the "*Altair-Kuppe*".

Plotting the positions of the vessel in accordance with the observed soundings, one is lead to the conclusion that the vessel occupied positions which were 1 mile to the S.W., then to the South, then to the East and finally to the N.E. of this point.

The mean of these headings during the 1/2 hour bring out oscillations of very long period, of which certain periods frequently recurr. Their cause appears to be the periodic oscillations of the current and the wind. Subjected to a harmonic analysis these observations give periods of which the maximum amplitudes correspond to the durations of 22.3; 14.5; 11.3 and 6 h. The periods of 22.3 and 11.3 hours may well be due to the action of the tidal currents, of which the diurnal component has a duration of 23.9 hours and the semi-diurnal component one of 13.3 hours. It may be also that these components combine with the diurnal component of the direction and force of the wind.

The period corresponding to the greatest amplitude is that of 14.5 hours. This has recurred in the measurements of the current and even in the two components of its velocity, where it is doubtless superposed on the semi-diurnal tidal period and that of the inertia. For this latitude the period of the inertial movement is 17.1 hours. The author concludes from this that the principal oscillations of the "*Altair*", having a period of 14.5 hours, are caused by the tidal currents and the inertia.

The curves in Fascicle N° 4 give the values of the N. and E. components of the currents at depths of 5, 15, 30, 100, 300, 500 and 800 meters. The very complicated results of these observations are represented thereon by a heavy line; the superposition of the semi-diurnal tidal-wave and that having a period of 17 h. is shown by a fine line; the fundamental current by a broken line. After a very close study of these results, then those of the series observations on the temperature, salinity and density, the author reaches a conclusion regarding the constitution of the ocean and its stratification in this region, which deductions are confirmed by a theoretical analysis of the problem. He summarizes his examination as follows :—

(1) The anchor station was made outside the principal bed of the Gulf Stream, in the region of the counter-current which delimits it to the northward. At all depths the fundamental current tends to the West with a small component towards the south. Up to about 25 m. depth, there is a constant velocity of 15.2 cm/sec., this increases gradually up to 20.5 cm/sec. at 150 meters depth; then it is diminished, at first slowly and then rapidly down to 6 cm/sec. at 800 m. The variations in this fundamental current were slight during the time at anchor.

(2) On this current are superposed :

a) The perturbations of the semi-diurnal period. The amplitude and the phase of these oscillations are almost constant for the entire layer between 0 and 800 meters. The principal elements of the current ellipse are: Direction of the major axis 40° E; maximum strength 8.3 cm/sec. Principal phase 0.4^8 h after the transit of the moon at the Greenwich meridian. Ratio of minor axis to major axis 0.43. Rotation of the current: *cum sole*.

This determination of the elements of the semi-diurnal tidal current is in agreement with the previous ideas held regarding tides in the North Atlantic."

b)" The perturbations of 17 hour period. This period corresponds almost exactly to that of the oscillatory inertial movements for this latitude (44° 32'). The amplitudes and phases of the two components of the current oscillations show, at each depth, certain properties which are peculiar to the movements due to pure inertia. Their amplitudes are the same, their phases displaced by one quarter period with respect to each other; this, in such a manner that the current diagram closely approaches a circle with right-hand rotation. For the rest, the current oscillations show the *character of the internal waves on the discontinuity surface*, while above and below this discontinuity layer (maximum vertical gradient of density),

between 15 and 25 meters depth, there is a complete reversal of the oscillatory movements. It appears that at about 400 meters depth, there occurs a further reversal of phase in a second discontinuity layer which is much less pronounced.

The analysis of 88 series measurements, made each hour at the station, shows, in the first place, a mean oceanic structure which is characterized by four layers :

1) An upper layer, of about 25 meters thickness with a discontinuity layer clearly defined near 25 meters.

2) A middle layer of about 100 to 150 meters with a normal increase in density.

3) A second discontinuity layer, less clearly defined, between 350 and 450 meters.

4) A lower layer from 500 meters down, with a normal density gradient.

" The variations in the temperature and the salinity during the stay at anchor were very great and irregular from hour to hour. In this one could distinguish however the influence of the 17 hour perturbation as well as that of the semi-diurnal tidal period. The analysis yielded very small values for the amplitudes of these waves and they could only be brought into evidence by grouping together the layers which showed similar types of curves.

" As might have been foreseen from the equation $S = f(t)$, the temperature and the salinity follow with the same rhythm. It follows therefore, that both for the 17 hourly perturbation as well as that of the semi-diurnal tidal period, the phases are about the same in the upper and middle layers, while they appear to differ from these by about one half period in the lower layer, in so far as their small amplitude permits of an exact determination.

" A detailed study of the relations between the perturbations of the currents and those of the ocean structure leads to the surprising conclusion that in the entire region about the Altair-kuppe, one can represent the ocean in a schematic manner as composed of two superposed systems :—

" 1) An upper system which extends to about 150 or 200 meters and which comprises the upper layer and the upper half of the middle layer of the ocean. In this system there is included at about 25 meters depth the maximum density gradient (first discontinuity layer). This upper system forms on the average a cyclonic vortex, strongly stratified, of which the velocity of rotation increases with the depth. To this there corresponds a concentration of light upper water masses about the axis of rotation.

" 2) A lower system, from 200 meters downwards; this comprises the lower half of the middle layer and the masses of deeper water. Towards 400 meters depths there is a slight augmentation in the normal increase in the density (second discontinuity layer). This lower system forms on the average a cyclonic vortex, slightly stratified, in which the velocity of rotation diminishes as the depth increases. To this corresponds an accumulation of heavy waters of the lower layers about the axis of rotation.

" On this general scheme are superposed the periodic current variations of 17 hour period and the semi-diurnal periods. The current variations of 17 hour period with their strong amplitude produce, especially in the upper system, a complete reversal of the relations. The modifications which they produce in the lower system, as well as those which result from the semi-diurnal tidal period are not so pronounced. In the upper system, on the contrary, the type of vertical current structure is completely reversed at regular intervals, and at the same time the thermo-haline structure.

" Between 0 h. and 7 h., and especially at 2 h there is produced in this system a strong increase in the velocity of rotation with the depth.

The indentation of the curves of equal pressure which is produced on the average in the center of the vortex soon transmits an augmenation to the edges.

Between 9 h. and 14 h., and particularly at 10 1/2 h. there is produced, on the contrary, a diminution in the velocity of rotation when the depth increases, which corresponds to a swelling in the curves of equal density in the center of the vortex and to their weakening at the edges. The curves of equal density, as well as the isotherms and isohalines therefore oscillate in liaison with the oscillations of the current forces on each side of a line of nodes.

The relations between the current perturbations and those of the constitution of the thermo-halines are therefore necessitated by hydrodynamic considerations, and should always be expected when a disturbance occurs in the static stratification of the masses of water which causes them to be displaced from their position of equilibrium. The oscillations about the stationary position should conform to the natural period of oscillation of the entire oscillatory system. We have therefore attempted to deduce from theoretical considerations the the natural zonal period of oscillations of an oceanic mass doubly stratified, as well as the interior limiting surfaces. The theory furnished the remarkable result that the period of free oscillations of the limiting surfaces and the fundamental current approach each other more and more on a globe of rotation of the period of the inertial oscillations, the greater the horizontal dimensions of the oscillating system. In the cases which are encountered in practice in the ocean, the period of free oscillations of the system approach so closely the period of inertia that they can scarcely be distinguished.

"The application of the results of the theory to the actual case, which may well be schematically characterized in the upper system as an oceanic volume doubly stratified, gives a natural period of free oscillation of about 16.8 hours, while the period of inertial oscillations is 17.1 hours. There is therefore no doubt that all of the concordant oscillatory phenomena for the currents and the thermo-haline structure, observed at the anchor station of the *Altair,* simply represent oscillations natural to this region of the ocean in which the static equilibrium has been disturbed. This disturbance to the equilibrium arose from a storm which prevailed in that region before the anchor station was made; the return to the previous static condition, which is accomplished by oscillations about the condition of equilibrium occurs with a natural period of 17 hours.

It must be attributed to a happy chance that for once on an anchor station these closely spaced current and series observations made it possible for these relations to be clearly brought out.

P. V.