# Hydrography, Climate and Fisheries in the Transition Area

by

**Otto Pettersson.**

The Transition Area comprises, according to the definition of the International Council of the 4th of Sept. 1925, the region between Hanstholmen and Lindesnæs in the West and Bornholm in the East, that is to say, Skagerak, Kattegat, the Danish straits, the Belt Sea and the Arcona basin. The most interesting part thereof, from the hydrographical point of view, is the Kattegat channel with the Great Belt, the connecting joint between the Ocean and the Baltic through which the surplus of the river-water from Scandinavia and from a part of North and Central Europe is brought to the Atlantic as a surface current, while the salt water from the ocean flows in as an under-current into the Baltic.

On both sides of the Kattegat channel there is a number of Danish and Swedish light-ships from which daily observations of salinity, temperature, direction and speed of currents are made. These observations, which have been going on for 40 years, have enabled one to calculate the magnitude of the exchange of water that takes place between the Baltic and the Ocean.

The water flowing out yearly from the Baltic is estimated to be about 480 cubic kilometers[1]) and is distributed among the different months of the year as follows:—

[1]) R. Witting: Hafsytan, Geoidytan och Landhöjningen. Fennia 39, No. 5, p. 123 (1918).

M. Knudsen: Beretning fra Kommissionen for Undersøgelser af Danske Farvande, Bd. 2, Hefte 2, p. 60 (1899), has calculated the yearly outflow of the Baltic to be 450 cubic kilometers.

J. P. Jacobsen: Die Wasserumsetzung durch den Öresund, den Grossen und den Kleinen Belt. Meddelelser fra Kommissionen for Havundersøgelser, Ser. Hydrografi, Bind II, No. 9 (1925).

| January | February | March | April | May | June |
|---|---|---|---|---|---|
| 20,5 km³. | 54,5 km³. | 75 km³. | 59,8 km³. | 779 km³. | 43,9 km³ |

| July | August | September | October | November | December |
|---|---|---|---|---|---|
| 11,7 km³. | 37,1 km³. | 55,6 km³. | 32,2 km³. | 5,2 km³. | 16,2 km³. |

The salt water entering the Baltic with the under-current has its origin partly from the North Sea and partly from the Norwegian Sea. The former follows the Jutland Bank, the latter flows in from the north through the Norwegian channel. The water from the Atlantic itself, with over 35 ‰ of salinity, penetrates also over the north part of the North Sea plateau into the Skagerak and fills up its deep basin, but comes out towards the bottom of the sea at the northern entrance of the Kattegat channel and enters therefore somewhat mixed into the Baltic.

The under-current in the Kattegat therefore is not formed of Atlantic water but either of North Sea water or of water from the Norwegian Sea. With the North Sea water enter the more southerly fish-species, as for instance mackerel, whiting, hake and autumn spawning herring from the North Sea banks and, as rarer guests, a few fish-species from the Bay of Biscay and the Mediterranean, that have come into the North Sea from the Atlantic. With the water from the Norwegian Sea come also boreal fish-species like leng, and spring-spawning hering.

It has already for 55 years been observed that these "north-fishes" arrived in winter and spring and the "south-fishes" in autumn[1]). There is consequently a yearly period of these fish migrations which was explained when it was discovered that there existed a yearly periodicity, corresponding with it, of the oceanic water circulation[2]), — a periodicity which is nowhere so clearly marked as in the Transition Area. It has been characterized by the Swedish scientists as the *Systole* and *Diastole* of the sea of which the pulse-beat makes itself most clearly felt in the variations of the under-current in the Kattegat channel[3]).

This periodicity depends on cosmic causes and is produced by the variations in gravitation caused by the position of the earth relatively

[1]) MÖBIUS und HEINCKE: Die Fische der Ostsee. Berichte der Commission zur Untersuchung der Deutschen Meere 1877—1881 (II) p. 278.

[2]) O. PETTERSSON och GUSTAF EKMAN: Grunddragen af Skageracks och Kattegats hydrografi, K. Svenska Vetenskapsakademiens Handlingar, Band 24, No. 11 (1891).

[3]) P. F. CLEVE, G. EKMAN och O. PETTERSSON: Les variations annuelles dans l'eau de surface de l'océan Atlantique, Göteborg 1899.

to the sun and the moon, that is to say by tidal forces. There have been found in the current-system of the Kattegat tidal periods of daily, half-daily, monthly, yearly and secular period — both in the surface-current and in the under-current.

The surface-current, the so-called Baltic current, is formed by the outflow from the Baltic which spreads itself as a thin surface layer over the Skagerak and the Norwegian channel. This layer of low salinity water checks the tide on the surface of the sea, so that in all the Transition Area, from Lindesnæs to the interior of the Baltic, the ebb and flood on the surface of the sea is insignificant. This is all the more extraordinary as the tidal waves in the south of the North Sea and on the west coast of Denmark attain a height of 2 to 3 metres, while opposite Jutland, near Lindesnæs on the Norwegian coast, the amplitude of the tidal wave is = 0.

One has tried to explain this on the assumption that there is to the south west of Lindesnæs a so-called amphidromic point where the wave penetrating into the North Sea through the Channel interferes with the wave entering round the north of Scotland.

POINCARÉ states:

"Le concours de ces deux ondes donne naissance dans la mer du Nord à une région amphidromique située à l'ouverture du Skagerak; un autre point amphidromique se trouve également formé plus au Sud entre la Hollande et l'Angleterre."[1])

The correct explanation seems to be that the tidal wave coming from the Atlantic dips under the water layer of the Baltic current at the entrance to the Skagerak and continues as an internal tidal wave towards the east through the Skagerak and the Kattegat channel in the boundary layer between the surface-current and the under-current. The trough of the tidal wave on its arrival at the border of the Baltic current is filled by the outflow of the light Baltic surface water. When afterwards the crest of the wave of the flood tide arrives, the layer of the surface water thins out and spreads over the surface of the sea. The vertical movement of the tide-water is thus changed into a horizontal contraction and expansion of the thin layer of the surface water.

Under this the tidal waves propagate themselves as under-current or internal waves with a reduced speed and an increased amplitude according to STOKES's theory.

In these internal wave-movements in the sea all periods appertaining to the original tide-water are found again, and it is worthy of remark,

[1]) H. POINCARÉ: Leçons de Mécanique Céleste, Tom. II, 2de Partie, p. 400 (1909).

that certain of these periods, belonging to the parallactic tide-water, which depends, not on the influence of the sun and the moon on the hydrosphere of the rotating earth, but on the position of the sun and the moon relatively to the earth, appear more clearly in the middle layers of the sea than on the surface, where the waves of the daily and half-daily periods (O. K., M. K.) dominate to such an extent that the parallactic waves become imperceptible (Mm. Mf. Ssa.) and can only be detected and measured by the calculation of long series of observations. Of these long-period parallactic tidal waves on the surface one has been able to detect in the North Sea region and in the Transition Area a yearly flood-wave from the ocean which culminates in October-December, when the water mark is at its highest, and has its yearly ebb-time in April-May when the water mark is at its lowest both on the coasts of the North Sea and of the Baltic (fig. 1).

In the middle layers of the sea these long-period wave-movements appear with the greatest clearness as internal waves of large amplitude, while the half-daily and the daily waves are damped and disappear through the influence of internal friction and usually only appear as under-water breakers against the coast-bank. Such internal flood-waves of half-daily period with an amplitude of about 3 metres have been observed at the entrance of the Great Belt[1]). Each time such a flood-wave in the boundary layer of the under-current (abt. 16 metres under the surface of the sea) penetrates into the Great Belt, the surface current is delayed or stopped until, 6 hours afterwards, the ebb appears in the boundary surface. Then the outflow of the Baltic water is accelerated up to 1 meter per second or even more.

While these powerful changes of level occur in the boundary layer of the under-current, and the surface-current in the strait alters its direction and speed, only a small ebb and flood is observed in the surface of the sea itself which reaches at the utmost ca. 30 cm. while the internal flood-wave in a depth of 16 metres raises and lowers its crest more than 3 metres. If there were not the protecting layer of surface-water checking, through its alternating retardation and acceleration in a horizontal direction, the influence on the sea-surface of the crests and troughs of the internal flood-waves, the flood-waves from the North Sea would twice a day inundate the lowlying coast of the Danish Isles and of Scania.

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[1]) O. Pettersson: Ström-studier vid Östersjöns portar. Svenska Hydrografisk Biologiska Kommissionens Skrifter, Häfte III.

G. Ridderstad, ibid.

J. P. Jacobsen: Beitrag zur Hydrographie der Dänischen Gewässer. Meddelelser fra Kommissionen for Havundersøgelser, Ser. Hydrografi Bd. II, No. 2, p. 83 o. 84.

The parallactic tidal waves of $^1/_2$ month's, one month's and one year's period in the middle layer of the Kattegat channel reach a much larger amplitude than 2—3 metres. Accordingly the under-current in the Kattegat does not flow continuously as a stream at the bottom of the sea but in cascades, in a series of large internal billows, the course of which can be followed through the channel of the Kattegat by means

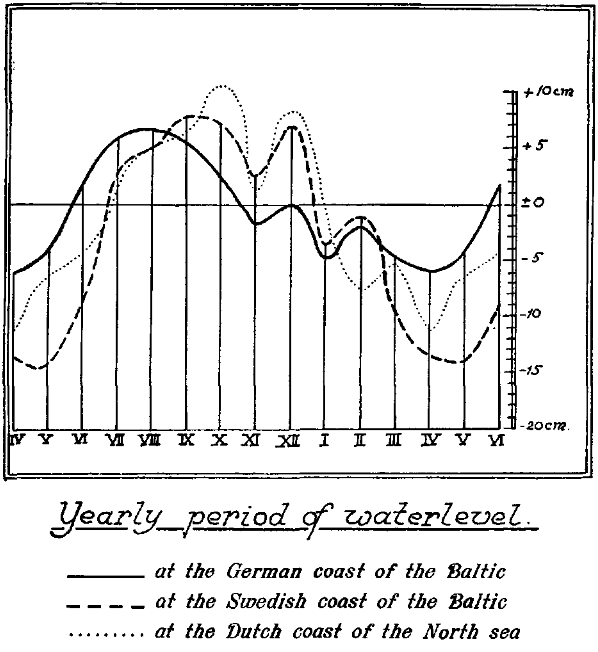


Fig. 1.

of hydrographical soundings from light-ships and by current-measurements with the registering apparatus prepared by G. Ekman and O. and H. Pettersson[1]). The following longitudinal sections through the Kattegat show certain characteristic variations of the under-current specially in the extreme northerly part of the Kattegat channel.

[1]) Svenska Hydrografisk Biologiska Kommissionens Skrifter, Häfte V.

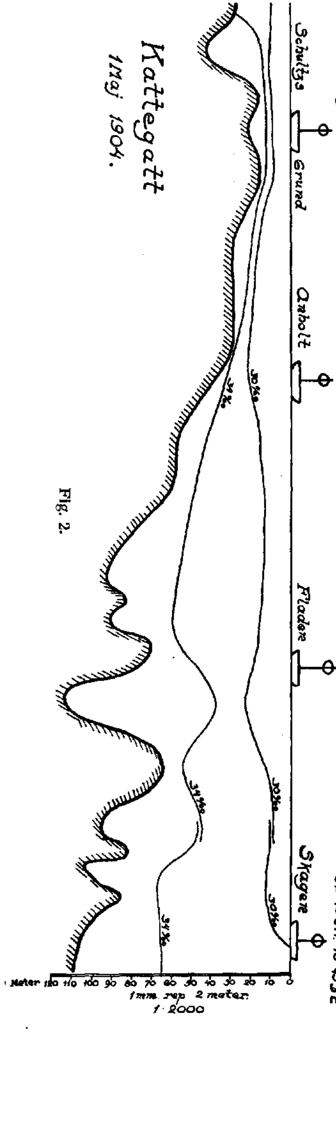
Kattegatt
1 Maj 1904.
Schultz Grund
Anholt
Fladen
Skagen
58°08'9 N. 11°11'2 E
56°46'0 N. 11°51'8 E.
57°13'0 N. 11°51'30 E
57°46'0 N. 10°43'3 E
30‰
34‰
Meter
1 mm rep 2 meter
1:2000

Fig. 2.

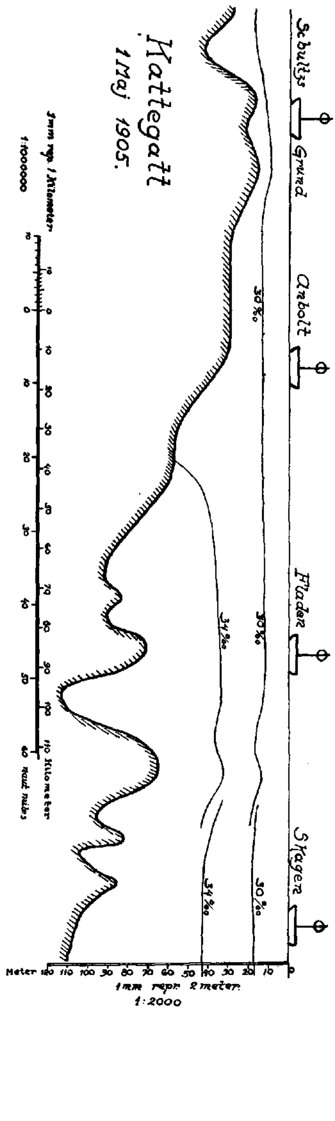
Kattegatt
1 Maj 1905.
Schultz Grund
Anholt
Fladen
Skagen
30‰
34‰
1 mm rep. 1 Kilometer
1:1000000
Kilometer
naut miles
Meter
1 mm repr. 2 meter.
1:2000

Fig. 3.

In every synoptic study of a large area such vertical changes in the shape of billows show themselves in the limiting surfaces of the different water-layers which mark the boundary of the waves of the under-water, — which in the present case are on their way south (see sections from May 1904 and 1905). The under-current in May is formed of North Sea water of 34 ‰, which isohaline can be considered as indicating its highest limiting surface. The 30 ‰ isohaline indicates approximately the lower limit of the surface-current. The water layers in between are formed of mixed water, a product of the intensive mixing process brought about by the friction between the entering and the outgoing current[1]).

The amplitude of these internal tidal waves which are produced in the middle layer of the sea, as also their speed of propagation, depends upon the density and the depth of the higher and lower layer of water, in conformity with the formula given by Stokes. The speed of propagation being in the first place determined by the depth, the wave in the boundary layer proceeds slowly over the shallow parts of the Kattegat. Such a wave having penetrated on the 26th of Oct. 1898 into the Kattegat took 6 days to cover the distance of 34 nautical miles between the two Danish light-ships at Skagen and Læsö Rende on the Aalbæk plateau with a speed of 0.118 metres per second[2]). The calculated time by STOKES's formula was 6 days and 4 hours. Over the deepest parts of the Kattegat channel the wave proceeded with greater speed and was observed on *the 4th of November (after 9 days) at the Anholt light-ship, and on the* 7th of November at the Lappegrunden light-ship in Öresund after 12 days. It is however seldom that an under-water wave can be followed by means of light-ship observations all through the Kattegat channel. As a rule the motion of the internal wave is checked by friction already in the outermost part of the Kattegat (see sections page 310). The wave-front naturally advances considerably quicker than the water stream. According to M. KNUDSEN a water-particle of the under-current takes 2 to 3 months to come from Skagen to Schulz Grund, which lies at the mouth of the Great Belt.

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[1]) The effect is so powerful, that the greatest part of the salt water which enters into the Kattegat channel from the Skagerak as under-current is mixed up with the out-flowing water and moves with the Baltic current. According to M. KNUDSEN's calculation it is only a seventh part of the original flowing-in ocean water which finally reaches the Baltic. (MARTIN KNUDSEN: Ein Hydrographischer Lehrsatz. Ann. d. Hydrographie 1900).

[2]) O. PETTERSSON: Über die Wahrscheinlichkeit von periodischen und unperiodischen Schwankungen in dem atlantischen Strome etc. Svenska Hydrografisk Biologiska Kommissionens Skrifter Heft II, p. 23—24.

The wave-front passing through the Kattegat causes in the fjords off the Swedish coast oscillations, in the level of the bottom layer, of considerable amplitude. The level of the sea-surface being only little changed, the surface water in the fjord must stream out when the deep water outside the fjord rises to a higher level, and stream in again when the ebb begins in the deep water.

This effect in the fjords of the movements of the internal ocean tides in the Skagerak and Kattegat has been studied during a long run of years at the Swedish hydrographical station Bornö which is situated in the biggest and deepest fjord of Bohuslän, the Gullmar fjord. The position is particularly favourable because the tide on the surface is so unimportant that it does not conceal the powerful rhythmical movements which occur in the deep and can be automatically measured with registering apparatus, their character of a parallactic internal tidal phenomenon of monthly and yearly period having been thus determined. In the "Svenska Hydrografisk Biologiska Kommissionens Skrifter" there are series of such under-water waves represented. From a more recent work[1]) I extract a graphic representation of such waves, which appeared in Sept. 1922 at the constellation of the moon's nodapside, which happened at the autumnal equinox of that year, and brought about a variation in the tidal force which is represented in the following diagram. The relation between the variation of the force of the flood and the constellations of the moon and the internal changes of level in the deep water of the fjord is also shown in the diagram on p. 313.

The diagram contains also underneath a row of figures showing the quantity of herring taken during the autumn of the same year. There is in fact a connection between the yearly flood period of the ocean, which begins in September at the equinox with a series of big internal waves culminating in November, and the yearly period of herring-fishing in the Skagerak. Those waves have a $^1/_4$ yearly and a $^1/_2$ monthly period. The herring shoals following with the under-current seem to come in greatest quantities during the autumn and winter weeks when the internal movements in the sea are strongest. The herring-fishery is thus closely connected with the yearly hydrographical changes (the oceanic flood period during autumn and winter) like the mackerel-fishery which is related with the ebb period occurring in summer[2]).

The herring-fishery is also subjected to a longer secular periodicity

[1]) O. Pettersson: *Innere Bewegungen in den Zwischenschichten des Meeres und der Atmosphäre*, Acta Reg. Soc. Scientiarum Upsaliensis, Ser. IV, Vol. 6, No. 2 (1923).

[2]) See diagram of the change of the water mark, fig. 1 pag. 309.

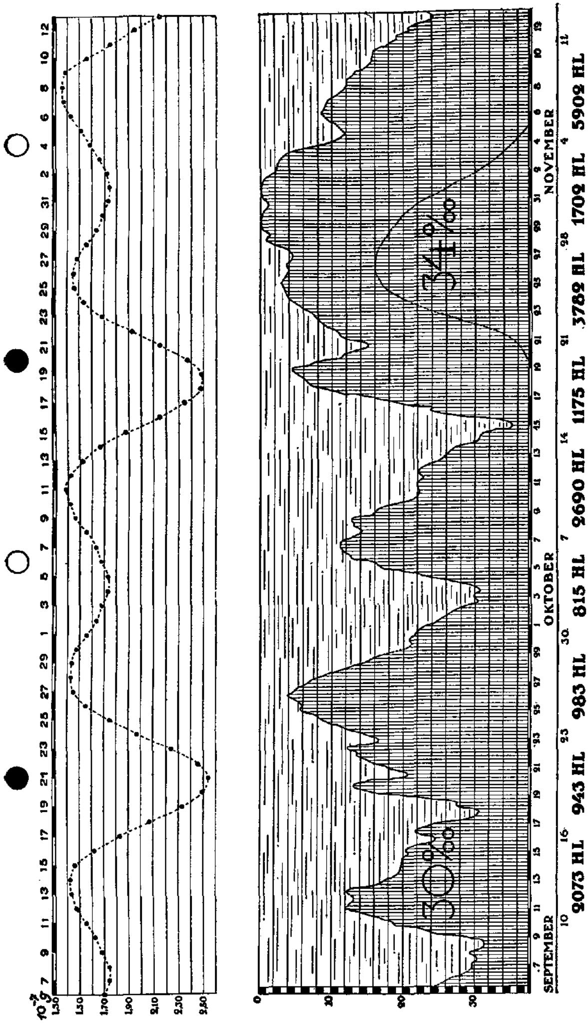
SEPTEMBER
OKTOBER
NOVEMBER
9073 HL
943 HL
983 HL
815 HL
9690 HL
1175 HL
3782 HL
1709 HL
5909 HL
30‰
34‰

Fig. 4.

known for a thousand years, which also depends on cosmic causes, i. e. the variation of the tidal force[1]) and has a period of 111 years. This periodicity shows itself as follows: during each century from 971 A. D. to the present time there has occurred a period of rich herring-fishing which lasted alternately abt. 20 to 30 and 50 to 70 years (big and small herring-fishing periods). These periods occurred thus[2]):

| Centuries | Periods |
|---|---|
| XIX | 1875—1896 |
| XVIII | 1752—1810 |
| XVII | 1660—1680 |
| XVI | 1556—1587 |
| XV | 1419—1474 |
| XIV | 1307—1362 |
| XIII | 1195—1250 |
| XII | 1083—1138 |
| XI | 971—1026 |

The longest of these herring-fishing periods were those which occurred in the XIIth, the XIVth and the XVth centuries when the constellation called nodapside of the orbit of the moon approached the time of the position of the winter-sun (Solstice) and the perihelium of the earth, which occurred in the beginning of the fifteenth century (perihelium-nodapside) when the strength of the flood (now and then) reached its absolute maximum[3]). This caused intensive movements in the middle layers of the sea, which led the herring-shoals farther towards the south than in our time, that is up to Öresund, where the big Hanseatic Herring-fishery occurred during the last centuries of the Middle Ages. This came to an end in the 17th century. In our times when the nodapside of the moon's orbit, which has a retrograde movement in the ecliptic, occurs earlier in the year (that is in September) the strength of the flood does not reach such high values and the influx of the herring in the Transition Area now stops at the outside part of the Kattegat channel, between Varberg and Skagen when it is at its best.

The last big herring-fishing period started in 1875 and closed in the winter of 1896. The hydrographical conditions that caused the cessa-

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[1]) O. Pettersson: Étude sur les mouvements internes dans la mer et dans l'air. Svenska Hydrografisk Biologiska Kommissionens Skrifter, Häfte VII.

[2]) A. W. Ljungman: Nordisk Tidsskrift for Fiskeri 1879. Köbenhavn.

[3]) O. Pettersson: Étude sur les mouvements internes dans la mer et dans l'air. Svenska Hydrografisk Biologiska Kommissionens Skrifter, Häfte VII.

tion of the herring-fishery are well known[1]). The reason was that the waters of the Atlantic current flowed with unusual strength over the north part of the North Sea in November 1896 and the following months and filled up the Norwegian channel, so that the inflow of water from the Norwegian Sea and partly also from the north part of the North Sea to the Skagerak was checked. During the preceding herring-fishing period the inflow of "sterile" Atlantic water had been small, consequently the entrance to the Skagerak had been open to the waters of the North Sea and of the Norwegian Sea and to the herring-shoals which jointly penetrated therefrom. This meant a considerable diminution of the winter herring-fishery on the west coast of Norway, during the Swedish herring-fishing period from 1875 to 1896. Afterwards the Norwegian herring-fishery soon increased to its former importance. During the secular herring-fishing periods in the Skagerak an alternation therefore takes place between the Norwegian and the Swedish herring-fishery. This alternation has been known for two centuries, but the cause of it has only been explained by the recent hydrographical researches.

The light-ships stationed in the Kattegat have to be with-drawn during certain cold winters for a few weeks or months on account of the drift-ice which is formed in the southern and central Kattegat and is driven out with the surface current into the Skagerak where it melts in the salter and warmer sea-water. The ice in the Kattegat is formed partly in the fjords and near the shore, and partly it appears as the so-called "pancake-ice", that is to say in the form of discs shaped like plates, suddenly rising from the deep. It then fills up the sea for miles around with a layer of loose but dense closely packed ice-lumps which hinder all sea-traffic and fishing. During the severe winter in 1879 Gustaf Ekman[2]) was able to ascertain the conditions of the formation of pancake-ice in the Kattegat. During cold and quiet weather, the surface layer in the Kattegat of 26 ‰ to 29 ‰ salinity can be cooled down to —1° C. without ice being formed. If afterwards a fresh water-layer of 16 ‰ to 22 ‰ salinity from the current glides over the salt and cold water, the formation of ice can be suddenly produced in the boundary surface, while the lower cold water-layer, which on account of its high salinity cannot freeze, absorbs the latent heat developed during ice formation in the boundary surface under the upper layer. In February 1879 such an ice-formation occurred at abt. 8 metres deep

[1]) G. Ekman, J. Hjort, P. T. Cleve, O. Pettersson, Skageraks tillstånd under den nuvaranda sillfiskeperioden. Göteborg 1897.

[2]) Grunddragen af Skageraks och Kattegats Hydrografi, p. 122.

under the surface. In the night of the 26th February the sea was in the morning, as far as one could see from the position of the farthest light-house[1]), covered with a thick layer of ice-lumps.

The formation of ice in the Kattegat has after-effects[2]) on the temperature of the under-current during the spring following a severe ice-winter. A severe atmospheric period of cold has some influence on the North Sea surface-water that afterwards enters into the Skagerak and forms the under-current in the Kattegat, which there during spring after an ice-winter brings colder water than usual into the Baltic. Superimposed on this comes also the influence of the ice-melting itself. The ice is formed in the Kattegat and melts at the expense of the heat of the surrounding water when it is carried out with the Baltic current into the Skagerak. The water around the ice gets cooler and sinks to the level of the under-current which thus becomes colder. The hydrographical statistics show that after a severe ice-winter a cold wave propagates itself towards the south with the under-current, through the Kattegat channel, from Skagen to the Great Belt. About four months after the disappearance of the ice, its after-effect is shown in the bottom water in the Great Belt and at the light-ship of Schulz Grund by a negative temperature-anomaly of abt. $1^1/_4$ degrees centigrade. That this after-effect comes as late as four months after the close of the ice-season must depend upon the fact that a double transport has here to be considered, that is: in the first place, of the melting ice with the surface-current out into the Skagerak and then of the cooled-off sinking water with the under-current southward through the Kattegat channel, this last mentioned transport taking about 2 to 3 months.

It is remarkable that ice-winters in the Transition Area occur periodically and that the period coincides with the secular herring-fishing periods, so that the most severe winters causing ice formation in the sea occur during these herring-fishing periods. For the same reason, at the present time, Sweden has, as a rule, milder winters with ice-free water in the Skagerak and the Kattegat. The last herring-fishing period ended in 1896. From 1896 to 1918 only 2 hard winters have occurred, that is, in 1909 and in 1917, while during the herring-fishing period that lasted from 1875 to 1897 there were 10 ice-winters, viz: 1875, 1876, 1879, 1881, 1886, 1888, 1889, 1891, 1893, 1895. Some of those winters were so severe that sea traffic entirely stopped for 1 to 2 months. The change came in the winter 1896—1897

[1]) Väderöbod light-house, situated 15 miles off the coast.

[2]) J. GEHRKE: On the after-effect of ice-winters upon the deep-sea temperatures of the Kattegat. Publications de Circonstance N:o 75 (1922).

and was caused as already mentioned by a strong inflow of Atlantic water, which cut off the immigration of herring with the boreal water from the Norwegian Sea and brought about warmer water and milder climatic conditions within the Transition Area.

During the preceding secular herring-fishing period which lasted from 1750 to 1810 two groups of excessively cold ice-winters occurred just during the culmination of the winter herring-fishery. Such hard winters were thus experienced during 13 years[1]) that is: 1780, 1781, 1782, 1784, 1785, 1786, and 1790, 1800, 1802, 1803, 1804, 1805, 1809.

If one goes back still further into time, that is, back to the secular herring-fishing periods in the 16th, 15th, and 14th centuries, severe winters in the years 1660—1680; 1556—1587; 1419—1474, during which the Baltic itself froze to a great extent, are mentioned in contemporary chronicles.

In general the picture obtained about those climatic changes is as follows:—

Each secular herring-fishing period in the Transition Area has been accompanied by disturbances in our winter climate, which, judging from the investigations made during the last period 1876—1897, depend upon the checking of the Atlantic current and upon the prevailing inflow of boreal water from the Norwegian Sea through the Norwegian Channel.

This shows how important it is for future prognostications of the fishery and the winter-climate to carry out hydrographical researches into the conditions prevailing in the Norwegian Channel at various seasons and particularly in autumn and winter[2]).

The chief duty of hydrography is to study the water circulation in the Ocean and to account for the forces and the sources of energy that drive the current-system of the sea. The opinion now prevailing is that that energy is produced by outside mechanical causes: winds, changes in the pressure of the air, in the atmosphere, and hydrostatic over-pressure in the sea itself, by level-differences produced on account of differential warming of the surface-layer and of the dilution of the surface-water through rain and outflowing river-water from the continents etc. All these factors act upon the oceanic circulation but in most cases this effect is occasional and momentary. An outside mechanical cause

[1]) reckoned from 1780.

[2]) O. Pettersson: Kosmiska orsaker till rörelserna i havets och atmosfärens mellanskikt. Svenska Hydrografisk Biologiska Kommissionens Skrifter, Häfte VII.

can only be effective so long as it is continuous. In the Transition Area there is such a continuous effective cause, namely: the hydrostatic over-pressure from the Baltic which receives yearly more water from the rivers than can be evaporated[1]). The surplus is discharged through the current that passes through the Kattegat ("Baltic current").

It was believed that this surplus of river-water should cause a much higher water-level in the Baltic and slipshod calculations have given the difference in the height of the water between the Finnish Bay and the centre of the Norwegian Sea to be up to 2—3 metres and so on. Accurate levellings show that this is incorrect. In the average the difference of level between Gjedser (Baltic) and the Kattegat is only abt. 10 cm. and between Bottenviken and Westfjorden on the Norwegian coast, may be, double as much, therefore the hydrostatic over-pressure from the Baltic cannot be the primus movens of the water exchange occurring between the Ocean and the Baltic. That exchange is produced by a hydrodynamic pressure brought about by water of greater density than that in the Baltic, flowing through the Belt and sinking into the deep basin of the Baltic, driving up and replacing the lighter bottom-water. The inner circulation of water-layers in the form of wedges, which I have described in several preceding works and given again in the diagram, Figure 5, is thus produced in the whole Baltic. The little "water-fall" on the surface of the ocean of 10 cm. on the average, has an unimportant effect compared with the bigger submarine water-fall of 25 to 30 metres, which the under-current in the Kattegat performs at the southern end of the Great Belt and between the Arcona basin and the depths of Gotland, and so on. The internal energies acting here can be estimated by means of V. Bjerknes' solenoid theory, and the following diagram, showing a hydrodynamic section along the whole of the Baltic, from the Great Belt to Bottenviken, gives us an idea of its effect, see pag. 319. The illustration shows how the internal field of energy of the Baltic is concentrated in the Great Belt and in the Belt-Sea where the number of C. G. S. Solenoids is the largest. That internal field of energy acts like a stretched spring accelarating the water. When there is a strong air-pressure over the Baltic and an easterly wind, the surface-water is driven against the mouth of the Baltic and the height of the water rises. This works on the Solenoid field so that the isotherms become more vertical, — "the spring is stretched". At the

[1]) contrary to the Mediterranean.

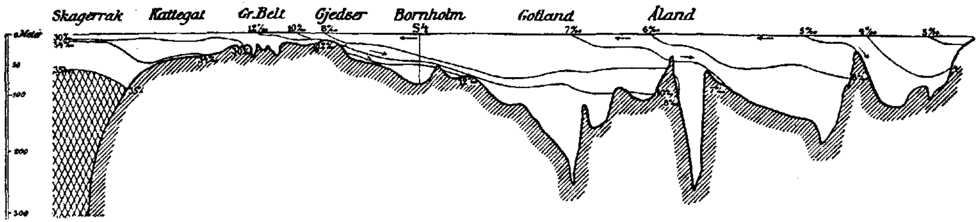


Fig. 5.

Dynamic Section of the Great Belt and the Baltic with C.G.S.-Solenoids.
F. W. Sandström.

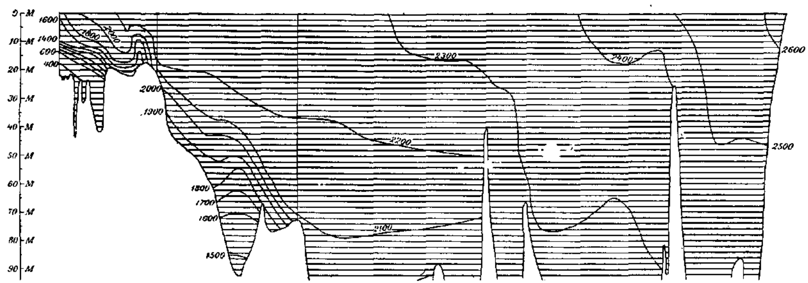


Fig. 6.

end of the driving up the isotherms become more horizontal, — "the spring becomes lax" and its potential energy is transformed into work, that is, by the acceleration of the out-going current until the stationary condition is restored.

The internal field of energy of the sea forms a conservative element in the water-circulation, which counteracts each occasional change and tends to bring back the condition of stationary balance which has etablished itself in the ocean in the course of thousands of years.

It was thought further, that the water-level of the Baltic would be governed by the rain-period and the ice-melting on the Continent. This hypothesis is, however, refuted by the diagram in Fig. 1, which shows that the highest and lowest water-mark occur (with a few weeks advance) simultaneously in the Baltic and on the coasts of Sweden and Holland, namely, in November and May. The maxima and minima of the water-level are not determined by the river-water from the Continent and by atmospheric conditions, but form the epochs of the yearly tidal wave of the ocean.

## Übersicht.

Der Wasserüberfluss der Ostsee entleert sich als Oberstrom durch das Kattegat, während ein Unterstrom von Meereswasser aus dem Norwegischen Meer und aus der Nordsee eindringt. Atlantisches Wasser von mehr als 35 $^0/_{00}$ Salzgehalt dringt wohl in das tiefe Skagerak-Bassin hinein, aber nicht weiter. Die erste Anzeige davon, dass dieser Einfluss von periodischer Natur ist, war die bekannte Beobachtung von Möbius und Heincke 1877 über die Erscheinung der s. g. "Südfische" in der letzten Hälfte des Jahres und der "Nordfische" in den ersten Monaten im Kattegat. Nach den späteren Untersuchungen von Gustaf Ekman, P. Cleve und O. Pettersson sind diese Fischwanderungen eng verknüpft mit einer hydrographischen Periodizität: nämlich einer jährlichen Tide des Ozeans, deren Flutzeit in den Herbst und deren Ebbezeit in den Frühling fällt. Pettersson, welcher diese Periodizität eingehend studiert hat, macht darauf aufmerksam, dass diese jährliche Tide sich kund gibt durch den jährlichen Wechsel des Wasserniveaus in der Nordsee und Ostsee, welches im November seinen höchsten und im Mai seinen niedrigsten Stand hat. Die Amplitude ist gering, 10—20 Zentimeter (Fig. 1). Auch die tägliche und halbtägliche Tidebewegung an der Oberfläche ist sehr klein in der Transition Area und ganz besonders auffallend ist es, dass diese grade vor der Südspitze Norwegens verschwindet, während 30 Meilen südlich davon an der jütischen Küste der Tidenhub etwa 2 Meter beträgt. Der Verf. erklärt dies so, dass die Tidenwelle von der Nordsee vor dem Rande des Baltischen Stromes untertaucht und als interne Welle in der Zwischenschicht im Skagerak und Kattegat auftritt. Das Wellental wird ausgefüllt von dem leichteren baltischen Oberwasser, das sich wiederum über die Oberfläche ausbreitet, wenn der Wellenberg naht. Die vertikale Tide-Bewegung wird in eine horizontale verwandelt. Diese Dämpfung des Tidenhubs verschont die skandinavischen Länder mit den gewaltsamen Verheerungen von Sturmfluten. Die interne Tide in diesen Meeren zeigt sich in gewaltigen Wellenbewegungen an der Oberfläche des Unterstromes, welcher dadurch einen kaskadenhaften Verlauf erhält, worin langperiodische parallaktische Bewegungen auftreten, welche an der Oberfläche unmerklich sind, ihren Einfluss jedoch auf die Fischwanderungen ausüben.

Der quantitative Austausch von Wasser zwischen der Ostsee und dem Ozean ist eingehend studiert von den dänischen Hydrographen Knudsen, Jacobsen und Gehrke und theoretisch verifiziert durch R. Wittings Arbeiten. Über die sekulären Variationen in dem Wasseraustausch und in den Fischwanderungen in der Transition Area hat man Arbeiten von A. W. Ljungman und O. Pettersson. Der Übergang von der letzten grossen Heringsfischerei-Periode Skageraks im Winter 1896 wurde von Cleve, G. Ekman, J. Hjort und Pettersson studiert. Die grossen Heringsfischerei-Perioden von ungefähr 111 Jahren, über die seit dem 10. Jahrhundert historische Urkunden vorliegen, beruhen auf kosmischen Ursachen, nämlich auf dem Einfluss des Umlaufs der Knotenapside der Mondbahn auf die Flutkraft. Diese sekulären Perioden markieren zugleich den Wechsel unseres Winterklimas, welches durch Wechsel zwischen dem Einfluss des Atlantischen Wassers und dem borealen Wasser des Norwegischen Meeres im Skagerak im Herbst und Winter bestimmt wird. Der Wasseraustausch zwischen der Ostsee und dem Meere beruht nicht so sehr auf dem wechselndem hydrostatischen Überdruck von Seiten der Ostsee, sondern auf dem inneren Kraftfeld in den verschiedenen Wasserschichten, welches durch die Isostären und das Solenoiden-Netz nach Bjerknes' Theorie von J. W. Sandström ausgerechnet und durch das Diagramm Seite 319 repräsentiert ist.