# ON THE EXISTENCE OF A SUB-SURFACE TIDE IN THE WESTERN MEDITERRANEAN.

by

F. MARTIN NAVARRO.

(*Bulletin de l'Institut Océanographique*, No. 656, Monaco, 20th August, 1934).

Experimental hydrodynamics readily make it clear that in a liquid mass formed of superimposed layers of different densities, an undulatory movement produced at the surface does not retain its characteristics when it is transmitted to the lower strata. If the density between the top layer and the lower is 0.03, the amplitude of an oscillation produced at the surface becomes thirty times larger when it is transmitted to the boundary surface of the lower layer. This theory provides a possible explanation of the phenomenon of "dead water" sometimes observed by navigators in polar seas, particularly by NANSEN on board the *Fram*. SANDSTRÖM has also shown experimentally that the action of wind on the surface water can result in internal waves of great height or in the formation of submarine seiches analogous to the well-known superficial seiches.

In the open sea, apart from these short-period undulatory movements (free waves, waves of "dead water" and sub-surface seiches), vertical displacements of the deep levels, of a more complicated type and longer period, have been recognised. Since 1908, PETTERSSON, while methodically studying the salinity of the water of the Gullmarfjord, on the west coast of Sweden, has shown the existence of internal waves whose period exactly follows the variation of lunar declination. In 1909, HELLAND-HANSEN and NANSEN showed the presence of vertical oscillations in various parts of the North-East Atlantic, attaining an amplitude of 200 metres and of a diurnal and semi-diurnal period. In 1927, after the *Meteor* Expedition, DEFANT confirmed the existence of internal tides in mid-ocean and found that the semi-diurnal tide wave is accompanied by free waves of very short period (about two hours only).

M. Martin NAVARRO, using the methodical observations made with a submarine thermograph by the Oceanographical Museum of Monaco and by the Oceanographic Laboratory of the Balearic Islands, has drawn up a comparative table of the thermal conditions existing in the Western Mediterranean at Palma and at Monaco, by plotting on graphs the temperature found at the surface and at depths of 25, 50, 75, and 100 metres during the various months of the year. The apparatus used was a light-weight compact IDRAC submarine recording thermograph, with a two-storied metal spiral system which is very sensitive and which very rapidly takes up a position of thermal equilibrium. This apparatus enables temperature records to be collected and to be compared on the graph with the phases of the moon and the astronomical coefficient of the tide. The graphs show a very distinct synchronism between the crests of the curves and the moon's meridian passages. On the graphs can be seen the principal half-daily wave accompanied by free waves of short duration. These phenomena would tend to prove by thermodynamics the existence of a tide wave in the western Mediterranean, where in certain cases, for example round about the equinox, the vertical displacement of the internal waters could be estimated to have an amplitude of some fifty metres. This new aspect of oceanography seems to impose a profound change on our method of working.

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# INTERNE GEZEITEN-WELLEN.

(INTERNAL TIDES).

by

O. PETTERSSON.

(*Rapports et Procès-verbaux des Réunions* of the *Conseil Permanent International pour l'Exploration de la Mer*, Vol. LXXXII, 26 pp. + 8-p. summary in English. Copenhagen, 1933 : Price, Kr. 1.75).

In a note presented to the ACADÉMIE DES SCIENCES of Paris on 30th January 1933, the distinguished Danish oceanographer O. PETTERSSON draws attention to a hiatus in the

classic theory of the tides. He shows that in using LAPLACE'S approximation, namely, to neglect the vertical acceleration in face of the horizontal acceleration in the problem of the tides, there is a risk of its proving insufficient in certain cases, notably in those regions where, on account of interference, the current remains roughly nil while the amplitude of the vertical oscillation may be relatively considerable.

Further, the Laplacean hypothesis of a displacement *en bloc* of the molecules of an individual vertical is only legitimate when the depth is small as compared with the wave-length; it may thus be invalid in certain restricted regions where the proper periods of oscillation may be short.

A more complete theory which takes the vertical acceleration into account (*) has shown that while the hypotheses of LAPLACE are sufficient for the study of the oceans as a whole, it is quite possible for certain isolated basins, deep and not very extensive, to have superposed nodal surfaces and turn out to be sites of vertical propagation.

As a result of numerous observations made in Scandinavian waters since 1907, it has been found in the region where stratification of the sea water is very distinct that internal tidal movements are shown by the soundings at the boundaries of the layers.

These new phenomena, which are found to have a semi-diurnal period, have been discussed by Prof. PETTERSSON in the work quoted above with a view to sketching out a possible solution of these anomalies.

Assuming in the high seas an upper layer of lesser density (the troposphere), and a lower layer (the stratosphere), the equipotential boundary surface of the two layers would be capable of extreme mobility under the action of the ascending and descending movements caused by the rhythmical variation of the vertical force of the tides. This vertical component, though powerless to affect the surface tide, would have the power to cause internal tidal movements in the open sea. The presence of this equipotential surface, which might be called the tropopause of the ocean, separating layers of different homogeneity, is especially in evidence at certain places. Observations place it at a depth of about 17 metres (9.3 fms.) in the Kattegat and 100 metres (54.7 fms.) in the equatorial Atlantic. It was in the Gullmarfjord that in 1909 an effect of internal tide was first observed, having an amplitude of about 15 to 20 metres and a period of twenty-seven days.

Prof. PETTERSSON insists upon the necessity, for this kind of observation, of using current meters of more advanced design, solidy moored on tripods and capable of taking photographic records.

## CURRENTS OF THE NORTH SEA.

(Extract from *Nature*, London, October 6, 1934, p. 543).

The measurement of horizontal currents in the sea presents numerous practical difficulties. In the northern North Sea these difficulties have been mainly overcome by the use of drift-bottles of suitable design. Recent analyses of elaborate drift-bottle experiments confirm the presence of extensive drift-currents in the northern North Sea. The drift-bottle and hydrographical records show that the main stream current affecting the northern North Sea is that which brings in Atlantic water around the north of Shetland through the Faroe-Shetland Channel.

In the southern North Sea, the hydrographcial conditions are governed largely by the flow of water through the Straits of Dover. By means of a current meter attached to the Varne Lightship, data concerning the strength and direction of this current have been collected continuously over the last eight years. The varying water movements observed, when balanced out over a term of years, have effected the same overall transport of water as would have been accomplished by a very slow river flowing at the rate of about 3.2 miles a day from the English Channel into the North Sea. In certain circumstances the current flows the other way. Following winds quicken it and head

(*) Marcel BRILLOUIN *and* Jean COULOMB : Oscillations d'un liquide pesant dans un bassin en rotation (*Oscillations of a heavy liquid in a basin in rotation*) : GAUTHIER-VILLARS, 1933.