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ON THE METHOD OF STUDYING THALASSOLOGY.*

By Prof. LUDOVICO MARINI.

THE scientific study of the sea, initiated by the genius of the Bolognese, Count Luigi Ferdinando Marsigli,† at the end of the seventeenth century, was not developed till the second half of the nineteenth century, after the American Maury had shown what important applications it was capable of. And this late development is readily explained, especially when we consider the great resources required by this study, owing to the vastness of the field to be explored, and the difficulty of reaching the greater part of it with available instruments of observation, and also have regard to the complex character of the science itself. And, in truth, the objects of thalassology are the phenomena which take place in the sea, and may be either of a physical or a chemical nature, so that recourse must be had to both of these sciences. And, moreover, for a complete knowledge of the conditions under which these phenomena occur, it is necessary to understand the nature, form, and constitution of the bodies by which the marine waters are limited—that is to say, the atmosphere above, the solid crust of our planet laterally and below; and, lastly, since it is important to be able to localize the facts according to their quality and intensity, meteorology, geology, and geography have also their share in these studies. Yet, despite its late origin, this science has already, in little over half a century of life, acquired such importance that even our Governments are making great outlays in organizing expeditions, in maintaining fixed establishments, and subventionizing associations engaged in furthering and encouraging such researches.

An indispensable condition for acquiring a really scientific knowledge in any department is the employment of a suitable method of study. Hence, if we wish to examine the data already acquired, in order to make them the starting-point for further research, it is above all necessary to inquire whether the method hitherto employed and to be employed in future is adequate for the purpose.

In determining the nature, form, and conditions of the bodies in contact with the marine water, as well as the values of the physical and chemical elements by which it is specialized, we may have two objects in view, whence it results that thalassology may be divided into two main sections. And, in fact, all those elements have different values, both in the same locality at different times and at the same time according to the locality. Hence we may undertake to determine the variations that they undergo from time to time in a given place, and calculate the mean values as may be required, and this constitutes a first part of thalassology analogous to that which in meteorology takes the name of climatology. Then from the difference in the values of the various elements in the different places, the conditions of equilibrium not being satisfied, there results a movement, a purely physical phenomenon, which constitutes the object of study of the second part—dynamic thalassology.

It is evident that the division made by me concerns the scope which may be given to thalassological investigations, not simply the division to be adopted in

* Memoir presented to the Fifth Italian Geographical Congress, held at Naples in April, 1904.

Touching the term "thalassology" I here employ, though generally little used, see Thoulet, 'Traité d'Océanographie,' vol. 1 (Statique), Introduction.

† See Prof. Cosimo Bertacchi, "Geografi italiani all' estero," *Memorie della Soc. Geogr. it.*, 1898, vol. 8, part i. *Id.*, "L'Italia e il suo Mare," *Bol. della Soc. Geogr. it*, 1900, 4th series, vol. 3, p. 762.

the compilation of a treatise on the subject. In this case it is necessary to consider the natural conditions in which the sea-water is found in contact with the other bodies by which it is limited, and their mutual relations; also to give a detailed explanation of the physical and chemical properties that characterize it, such as its chemical constitution, specific heat, melting temperature, dilatability, compressibility, thermic and electric conductibility, transparency under thermic, luminous, chemical radiations, etc. While these form the essential base of every such study, they are yet not so well known as they should be.*

It seems to me even important to note that the expression *marine statics* employed in many recent treatises, in order to distinguish this preliminary part, is not appropriate; for, although the tendency towards equilibrium is always operating, since the causes that disturb it also continue constantly to operate, actual equilibrium is never reached. It is well to avoid such an erroneous expression, since it might lead to serious errors were problems essentially dynamic to be regarded as purely static.

The biological section, which is often added to these two parts, does not, strictly speaking, come within the scope of thalassology as here understood. To wish to introduce it would be like wishing to regard the study of the distribution of the birds and insects that fly in the air as a part of meteorology, because the habitat of the various species and the migrations made by some of them depend on the changes of climate, and may serve to indicate them. In both cases the study of the distribution of organisms constitutes an important application of the respective sciences, and thalassology even owes to biological researches the chief impulse to its study.

The difference between the two parts here distinguished by no means consists in the difference between the objects of study, because the elements in which the second is interested also form the subject of research for the first, which, however, is likewise occupied with some other matters with which dynamics are not concerned. The real difference consists mainly in the method employed in accordance with the objects aimed at, a method purely statistic in the one case, synchronous in the other. But in order that the data may be discussed, and thus lead to practical results, they must be collected in a way that may satisfy the requirements of both methods. Hence this is chiefly what should concern us, if we wish to arrive at right conclusions, that is, such as correspond to the facts.

It is certain and self-evident that the method of continuous registration carried out at most of the stations conveniently distributed over the whole space occupied by the whole oceans, satisfies all requirements. But in the present state of the science it is impossible to give it practical effect, especially at great depths and on the high seas. Hence, for researches to be made in those parts there have been organized great expeditions which, ranging over a vast oceanic region, collect thalassological data here and there, in different places, at different times (excepting the vertical series of temperature and density). From materials thus collected we may say at once and without hesitation that, speaking generally, no conclusions can be drawn. It is evident that they are in no way capable of being compared together, having nothing in common in respect of time or place. The truth of this principle was already fully recognised so far back as 1890, when, by means of the highly developed investigations in the northern seas, the variations that take place from season to season were determined

* Sandström und Helland-Hansen, "Ueber die Berechnung von Meeresströmungen," *Report on Norwegian Fishery and Marine Investigation*, vol. 2, 1902, No. 4, p. 25.

beyond all doubt.* Hence, in the impossibility of obtaining a continuous record, taking advantage of the slowness and sufficient regularity with which the variations of the oceanic elements occur, in order to facilitate the solution of the problem, it was thought advisable to limit to three months the interval of time in which it might be permitted, at least in a general way, to compare each successive series of observations one with another. On this principle was based the plan proposed by Profs. Pettersson and Ekman at the Sixth International Geographical Congress in London in 1895, for an international study of the northern waters.† But from the results of the first years of their investigations we arrive at the conclusion that variations of great range take place in the conditions of thalassological elements, even from month to month, variations which cause equivalent modifications in the type of circulation, which hence becomes distinctly different at the same period in different years, and of such variations no chart of mean conditions can give any information. In accordance with this very fact, in the bulletins issued by the International Committee for marine exploration,‡ the isothermal lines are scarcely traced at all, and on the few given isohalines doubts are even suggested regarding their real values, these being reduced from observations taken during a period of over one month. Hence it results that, for the purpose of perfect comparison of observations, at least in the upper strata, which, on the other hand, for many reasons are the most important, and particularly in places subject to great and rapid variations,§ in order to draw legitimate consequences, a more rigorous synchronism is needed. Therefore, in the present state of the science, and without excluding all efforts to achieve whatever may seem to be the best, the observations carried out in exploring ships under sail are by no means to be regretted. On the contrary, they should be multiplied to the utmost, always taking the greatest care that the records be obtained with absolutely identical methods, and so that complete confidence may be placed in their accuracy, and that they be determined on plans first thoroughly studied and laid down by means of preliminary observations. To complete the significance of these values, obtained thus independently and at intervals, the stations should be utilized where the records could be made continuous, that is to say, stations either established on *terra firma* along the seaboard, or else afloat on the light-ships, or on the model of the Scottish Ark. No valuable results can be expected until we possess a large number of values obtained in this way and then subjected to a rigorous criticism, such as that which in meteorology is applied to observations taken discontinuously. Then it will be possible, not only to know the average conditions of a region, but also to infer, which is the object of true science, what are the laws of phenomena having their bases in the sea and relations to the surrounding terrestrial surface and the atmosphere above; and to give in this way a scientific basis to the desired prognosis of the thalasso-meteorological phenomena. And meteorology, a science

* Without quoting numerous authorities, I may here refer to the monograph of H. N. Dickson, "The Circulation of the Surface Water of the North Atlantic Ocean," *Philosophical Transactions R. Soc.*, London, Series A, vol. **196** (1901), pp. 61, where is given a full bibliography of the subject.

† Pettersson, "Ueber die Beziehungen zwischen hydrographischen und meteorologischen Phänomenen," *Meteorologische Zeitschrift*, 1896.

‡ "Conseil permanent international pour l'exploration de la Mer.," *Bul. des Résultats acquis pendant les courses périodiques*, Nos. 1, 2 (1902), Nos. 3, 4 (1903).

§ M. Knudsen ("L'Océanographie des détroits danois, La Géographie," *Bul. de la Soc. de Géographie de Paris*, vol. **5** (1902), pp. 21) states that observations in the Danish waters, subject to very sudden changes, have been taken, under the direction of Admiral C. F. Wandel by several vessels simultaneously, so as to complete the necessary records in twenty-four to forty-eight hours.

so closely related to thalassology, but more advanced, should serve as its model, if it too is to progress on strictly scientific lines. At the same time, meteorology also affords proof of the importance of continuous registration for determining averages, since it shows us how a true method of obtaining the mean temperature with non-continuous observations was not obtained until a way was found for determining the true mean from continuous records.

Assuredly the most important problem in thalassology is that of oceanic circulation, about which, however, diverse views are entertained by thalassologists. We have, first of all, carefully to distinguish the object aimed at, whether it be the mere verification of the facts, that is, of the course, duration, intensity of the circulating movements in view of the manifold and important effects produced by them, or else the purpose be to determine the laws of the phenomenon. The first case comes within the scope of the first part of thalassology, and in its study we have to employ both direct and indirect methods. The direct methods involve the use either of floating bodies left free to follow the movement of the waters in which they are placed, or of current-metres. The first floats may be freely cast adrift and left to themselves, the points of departure and arrival being alone recorded, in which case, apart from the doubts respecting the accuracy of the report on the spot where they have been picked up, they leave uncertainty regarding the course traversed by them; or else they may be followed by boats fixing their successive positions, and then they are available only for shallow currents, and, moreover, require much time and many hands even for the exploration of small regions. The current-metres, although requiring a great many observations to yield conclusive results, and in the state in which they actually are, must undergo further improvement in order to be perfectly and completely adapted to the purpose, still they are based on a principle which alone can afford the most complete and trustworthy indications. In the same category may be included the study of the plankton, which, especially when combined with other methods, appears to afford most valuable data on the existence of currents.

The indirect methods consist in following the variations of temperature, or of density, or of salinity, or of the volume of gases in solution. Temperature was at one time held to be the cause of marine currents;* but to it, as a sufficient element to indicate the presence of currents, no great value is now attached, owing to its extreme variability, especially under the influence of outward agencies. The density has been used by Bouquet de la Grye † and by Thoulet ‡ for tracing profiles of the surface of the ocean, on the assumption that above a given level the depths are in inverse ratio to the densities, and so for deducing from the slopes of the surface the direction of existing currents. But, besides the fact that in the particular instances where the principle has been applied by Thoulet, the density-values utilized are not comparable one with another for the reasons above stated,§ and that from the value of the surface density alone the weight or the pressure of a whole liquid column cannot be deduced, this fundamental principle on which the method is based is valid only where there is equilibrium, hence cannot be applied to the investigation of the conditions that produce lack of equilibrium.

Salinity and the tenure of gas have been preferred by the thalassologists of

* See 'Handbuch der Oceanographie, Boguslawski u. Krümmel,' vol. 2, chap. iii., with the numerous references on the subject.

† '*Annales de Chimie et de Physique*,' No. 5, vol. 25 (1882), p. 433.

‡ *Ibid.*, No. 6, vol. 14 (1888), p. 287.

§ Recently (*Comptes Rendus*, 1r semestre, 1904) Thoulet describes a modification to his method, avoiding only the errors arising from non-synchronism.

the International Association for marine exploration, as being suited for recognizing a portion of a body of marine water in its course across the ocean, hence useful for indicating the trend of currents generally. But neither these, nor the density, as Thoulet thinks,* nor any other element, is capable of identifying a body of marine water, as this, not being a chemically specialized body, changes with the shifting of position in space, both by diffusion and by the tendency to recover its equilibrium, the values of all its characteristic elements. Consequently, for the purpose of verifying the existence of currents, although the above-mentioned elements could often afford valuable indications, and especially be useful for a preliminary study, still they cannot be sufficient for a complete study, so that the preference undoubtedly lies with the direct methods, and especially with the records of the current-meter.

But if the object be to determine the law of the phenomenon—that is, the relation between cause and effect, we must needs verify the effect, that is the movement, and discover and measure its causes. The inquiry concerning these causes may take a twofold course; in other words, we have to seek both the conditions of the marine elements by which the movement is produced, and the external causes that bring about the removal of the conditions of equilibrium. And these external causes may be either cosmic (solar radiation, rotation of the globe), or meteorological (atmospheric pressure, temperature of the air, humidity, winds), or geographical (presence of fresh-water streams or of particular materials constituting the terrestrial crust), or mechanical (movements of other bodies of marine waters, which by their trend, or owing to the special configuration of the basins, set up secondary currents), or biological (living organisms), which causes are all revealed by the variation of temperature, the salinity,† and local pressure. Hence, it is to the direct determinations of the values of these marine elements, and to their relations with the external conditions, that we must necessarily have recourse if we wish to successfully solve the problem. Nor are we to confine ourselves to one or other of these elements; but, as all may have their influence, they have all to be considered, since otherwise, looking at the question from a single point of view, we might come to wrong or at least partly defective conclusions.

In his exposition of the results of the Norwegian expedition in the North Atlantic, Mohn, by tracing what he calls wind-surface and density-surface, and by their means determining the current-surfaces, had already by their trend deduced the direction of the currents. Starting with the hydrodynamic equations under the simplified form given by Lord Kelvin, Bjerknes ‡ demonstrates a theorem by which may be calculated the increase of circulation of a closed curve, by means of the number of solenoids comprised within it and formed by the isobaric and isosteric surfaces. In Mohn's method the elements to be experimentally

* "Quelques Considérations sur l'étude des courants marins," *Annales de géographie*, vol. 4 (1894–95), p. 257.

† In his numerous essays, Thoulet rightly insists on the importance of not separating these two elements, temperature and salinity, but of considering them together in what he calls *density in situ*. Mohn had also introduced the idea in his dynamic studies ('The Norwegian North Atlantic Expedition,' 1876–78, No. xviii., *Circulation*); and Krümmel recognizes its importance in vol. 2 of the 'Handbuch der Oceanographie,' while Savy had already made use of it in 1868 ("Sur la Densité, la Salure et les Courants de l'Océan Atlantique," *Comptes Rendus*, vol. 67, p. 483).

‡ "Das dynamische Princip der Circulationsbewegungen in der Atmosphere," *Meteorologische Zeitschrift*, 1900, p. 97; and "Das Raumliche Gradient u. Circulation," *ibid.*, 1900, p. 481.

determined are the direction and velocity of the wind, or the distribution of atmospheric pressure for deducing these elements, and the density of marine water, from which is obtained the pressure. In the method of Bjerknes, from the density alone is calculated the specific volume, and the pressure is given from depth.* Mohn, besides leaving doubts regarding the validity of the relations between the velocity and direction of the marine currents and those of the wind, deduced empirically from an insufficient number of observations, overlooks the accelerating element, specific volume, which, as shown by Bjerknes, has much influence on the nature and velocity of the movements. To the Bjerknes method it is objected † that the effect of terrestrial rotation is neglected. But at the beginning of his essay the author expressly states that this is one of the generalizations to be introduced into Lord Kelvin's equations, but that he purposely overlooked all except the more important generalization—that is, about the limitating hypothesis respecting the density of the fluid. The deviations caused by the centrifugal force can always be brought under consideration, whenever it is desired, by means of the calculus. It is further urged that he takes no account of the direct action of the wind, which is now known to be the most important cause of marine currents. Now, the action of the wind may be shown either by the waters accumulating in the direction of its movement,‡ or by the friction causing on the surface of the sea a movement of the upper particles, which is then communicated to those below. In any case, the action of the wind is displayed in the change of pressure, caused either by changing the level, and consequently the height, of the liquid column, or by producing a movement which so acts that the pressure has to be regarded rather as dynamic than static. Hence it is absolutely necessary to be able to determine the pressure and the density with the greatest possible accuracy, especially in the upper strata, which, for the phenomena of circulation, are precisely the most important. For this purpose the pressure should be measured directly, and not merely by approximate methods, like those of Mohn or of Sandström, which are based on static considerations, and yield values that are affected by the experimental errors made in measuring the density and the depth employed in the calculus. For determining the density the best plan is to take the direct measurements on board as soon as possible by means of the hydrometers, since, besides all the objections to the preservation of the samples, the indirect methods tend to superadd the experimental errors due to two direct measurements subject, like all the others, to a source of error, namely, that of the salinity or chloridation or index of refraction, according to the method employed, and those occurring in the construction of the reduction tables (see Thoulet's numerous papers on this point). Moreover, all, or the greater part, of the sources of error which are attributed to the direct determinations are eliminated by using insulated bottles of the type devised by Pettersson and perfected by Nansen,§ slightly and easily modified so as to serve for the measurement of density by the hydrometers of total immersion, the records being made in the bottle itself at the moment the water is fished up, and without being transferred to another recipient. Collecting,

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* Sandström und Helland-Hansen, "Ueber die Berechnung von Meeresströmungen," 'Report on Norwegian Fishery and Marine Investigation,' vol. 2, 1902, No. 4.

† Krümmel in a note to "Geographische Studien über das Barents Meer," by Dr. Breitfuss, *Petermanns Mitteilungen*, 1904, No. 2.

‡ A. W. Cronander, 'On the Laws of Movement of Sea-Currents and Rivers.' Norrköping: 1898.

§ Nansen, 'Some Oceanographical Results of the Expedition with the *Michael Sars*. Preliminary Report.

therefore, with such precautions, a great number of values of these fundamental elements, together with the others—temperature, salinity, gas, etc.—which can be useful for the purpose, provided they are strictly comparable, taking into account, also, the conditions of the limiting surfaces, and placing all in relation with the observed currents, it will be possible to detect the general laws of circulation.

Lastly, for marine dynamics, pursuing the study of the tides, which has been most ably treated and well advanced towards its complete scientific acquisition, precisely because for its study we possess a method of continuous observation, it is of the utmost importance to still further investigate wave motion, which lends itself to so many most interesting thalassological and meteorological problems.*

In conclusion, if we want to promote thalassology on thoroughly scientific lines, and thus raise them to the high level of the other kindred sciences, we must, above all, bring to perfection the methods of measurement of the various marine elements which accompany and correspond with the progress made in those sciences of which thalassology makes use.† Hence, in accordance with those methods, our observations have to be made synchronously and with the greatest possible continuity on the well-matured plans adapted to the special conditions of the basins to be studied and of the investigations to be carried out.

THE INDIAN CENSUS REPORT.‡

THE results of the third general census of India occupy a goodly row of over sixty volumes, varying in bulk from the slim publications of Ajmer and Coorg to the veritable "John Trundley" of tomes laid on the statistical altar by Baroda and Mysore. The cream of this mass of literature and figures has been deftly skimmed off by Messrs. Risley, Gait, and Grierson into a couple of moderate-sized volumes full of an interest as varied and comprehensive as is to be found anywhere in this particular field of demography. Those, indeed, who have been steeped in the almost colourless analysis of numbers which is all that convention prescribes for a census in the prosaic West, may be a little perturbed by the oriental profusion which here greets them. It may even be that they will rise from the perusal of this report with a sense that the modicum of solid statistics provided for them has been diluted with a Falstaffian proportion of the sack of ethnological speculation. It is as well, therefore, to bear in mind the oft-repeated warning that India is a geographical expression except in regard to politics, and that the extraordinary diversity of the racial and social elements contained within it renders it impracticable to explain adequately the significance of even the numerical results of a census without recourse to more or less ethnographical detail. Between each enumeration new facts are brought to light or old ones fitted into new places, and in the lower ranks of Indian society, beliefs, customs, and even languages are fading out of existence with astonishing celerity. The Indian census reporter,

* During the revision of proofs I have seen in the *Geographical Journal*, May, 1904, the paper "On the Dimension of Deep-sea Waves, and their Relation to Meteorological and Geographical Conditions," by Vaughan Cornish.

† F. Nansen, 'The Norwegian North Polar Expedition,' 1893–96, Scientific Results, vol. 3, No. ix.; 'The Oceanography of the North Polar Basin,' preface.

‡ 'Census of India, 1901.' Vols. 1, 1a and Appendices. Part i. report; part ii. tables. By H. H. Risley and E. A. Gait. Ethnographic Appendices. By H. H. Risley. Folio. *Maps.* Calcutta: 1903. Cf. also 'General Report of the Census of India, 1901' [Parl. Paper, Cd 2047]. Eyre & Spottiswoode. 1904.