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On Bathy-hypsographical Maps ; with special reference to a combination of the Ordnance and Admiralty Surveys.

By E. G. RAVENSTEIN.

Maps, p. 64.

THE bathy-hypsographical map, which aims at exhibiting by means of contours or otherwise the configuration of the solid surface of the earth, is a product of modern times. This is only natural, when we consider that instruments capable of measuring heights and depths with some approach to accuracy, and yet expeditiously, have only within a comparatively recent period been placed at the service of geographical explorers and surveyors.

It was Pascal who showed in 1658 how the barometer might be utilised as a hypsometer, but that instrument only became in reality available when De Luc published his formula in 1722. On the other hand, although mariners have heaved the lead from immemorial times, it is only since the invention of deep-sea sounding apparatus, like that of Brooke (1852), that we are in a position to delineate the configuration of the ocean bed with some confidence in the general correctness of our results.

Charts indicating the depth of the sea are of more ancient date than maps giving the heights of mountains. It was Gerard Mercator who first introduced soundings in a map of Holland, in 1585, and his contemporary, Lucas Janszon Waghenae, the famous "Waggoner" of the British seamen of the sixteenth century, popularised this method in his numerous charts, since 1586. It is another Dutchman, Cruquius, to whom we owe the introduction of bathymetrical contours or fathom-lines, which first made their appearance in a chart of the Merwede, which he published in 1728. The meritorious French geographer Philip Buache adopted this method in his well-known chart of the English Channel, placed before the French Academy in 1737, although only published in 1757.

It was this same Buache who first suggested that elevations above the sea-level might be indicated according to the same method of contouring. Marcellin Ducarla of Vabres (b. 1738, d. 1816), revived this idea, and his friend Dupain-Triel of Paris (b. 1722, d. 1805), first acted upon it in 1791, when he published a map of France—"La France considérée dans les différents hauteurs de ses plaines"—which delineates the vertical configuration of the land by means of horizontal contours drawn at intervals of 60 feet. When Horsell, in 1835, tinted his contoured map of Norway and Sweden, according to height, all the features which distinguish the hypsographical maps of the present day had been introduced.

The next step in advance was taken by combining contoured hypso-

graphical maps with similar bathygraphical maps. This was done, as far as I am aware, by E. von Sydow, whose popular school-maps show the elevation of the land as also the depth of the sea by means of tints. Ziegler of Zurich, as early as 1856, published a "Hypsometric Atlas," which indicates ocean-depths, though still very crudely. Numerous maps of the same type have since been published by Dr. Berghaus, Keith Johnston, Kiepert, Petermann, and others, and at the present time not even an elementary atlas of physical geography is deemed complete unless it contains one or more maps of this class.

Cartographers, in effecting this combination of the "map" with the "chart," appear hitherto to have ignored the fact, that the heights on the one and the depths shown on the other, are not referred to the same datum level. The maps, consequently, with which they have presented us, give heights above an assumed mean level of the sea, whilst the depths, as taken from Admiralty charts, are referred to low water at ordinary spring-tides at the particular spot at which the soundings were taken. The foreshore, or at all events that portion of it which lies between low water and the mean water-level, is thus altogether ignored, and instead of a *combination* of Ordnance and Admiralty surveys, we are presented with a *juxtaposition* of Ordnance maps and Admiralty charts.

That this rough method is scientifically inadmissible is obvious. True, where the land borders upon a sea exhibiting no tidal oscillations, or where the scale of a map is small and the vertical interval between the horizontal contours proportionately considerable, this does not seriously, if at all, affect the correctness of the delineation. But when the maps are drawn on a large scale, we must not lose sight of the fact that the difference between the low and mean water-levels is frequently of considerable amount. Around the British Islands, for instance, the spring rise of the tides varies between four and 40 feet, the average being about 12 feet.*

It is obvious that in any delineation of the surface configuration of the solid surface of our earth by means of horizontal contours, these contours ought to be referred to the same datum-level. In other words, we must represent the sculptured surface of the earth's crust as if the sea had retired and the whole of its bed had become exposed to view. The principal contour would then encompass a datum-plane which might conveniently be taken to be identical with the mean water-level at some particular spot, whilst all other contours would be laid down on planes parallel with it.

The preparation of a map on this principle would appear to be simple enough, and only when we approach our task with a view of practically carrying out the method here suggested do we begin to realise the difficulties which it presents.

* See the accompanying sketch-map, based upon Commander H. Harris's 'Tide Tables,' 1884.

Our first task should be the selection of a datum-level. We are no longer able to accept as such what is called the mean level of the sea; for this mean level is by no means conformable to the surface of an ellipsoid of rotation. Theoretical considerations no less than actual measurements prove this. We may still speak of the mean level of the sea with reference to any particular locality, and can determine this level by means of tidal observations carried on during a sufficient period, but it is no longer permissible to speak of the mean level of the sea at large as an available datum-plane to which elevations or depressions may be reduced.

This is not an occasion for discussing the causes which affect the mean level of the sea, but I may be permitted to place before you the results of several of the more carefully conducted spirit-levellings in support of the assertion that there exist differences in the mean level of neighbouring seas.

The Mediterranean, as might have been expected from its greater salinity and the increased density resulting therefrom, is found by eight independent lines of spirit-levelling to be at a lower level than the Atlantic. Some of the results are as follows * :—

Lines of Spirit-levelling.						Mediterranean below the Atlantic or North Sea.
Amsterdam and Trieste	..	..	..	..	..	1·94 feet.
Amsterdam and Marseille	..	..	..	..	..	2·69 „
Brest and Marseille	..	..	..	..	..	5·315 „
Bayonne and Bouc (Rhône mouth)	..	..	..	..	..	2·709 „
Santander and Alicante	..	..	..	..	..	2·986 „

The mean level of the Baltic, as ascertained by careful observations carried on between 1846 and 1875 at fourteen stations, is 1·64 feet higher at Memel than it is on the coast of Holstein.†

The spirit-levellings conducted by the officers of the Ordnance Survey, and discussed by Colonel A. Ross Clarke, R.E.,‡ tend in the same direction, for they show that the sea surrounding the British Islands does not stand at a uniform level. By connecting the mean level of the sea at Liverpool by means of lines of spirit-levellings with the mean level of the sea at other points of the coast, it was found that there existed measurable if not very considerable differences. In Ireland, where 22 stations at which the mean level of the sea had been determined by tidal observations were connected by lines of spirit-levelling, similar results were obtained. The extreme difference of level was thus found to exist

* ‘C. R. des séances de la com. perm. de l’Association géodésique internationale,’ La Hague, 1882; ‘Nivellement der trigon. Abtheilung der preuss. Landesaufnahme, V.’; Bourdeloue, ‘Niv. de la France,’ 1864.

† Hagen in ‘Monatsberichte Berlin Academy,’ 1877.

‡ ‘Abstracts of the principal lines of Spirit-levelling in Ireland, England and Wales, and in Scotland,’ 1855, 1861; ‘Account of the principal Triangulation of Scotland,’ 1858.

between Rispond, on the northern coast of Sutherlandshire, and Kilbaha, at the mouth of the Shannon. At Rispond the mean level is 1·736 feet above the mean level at Liverpool, at Kilbaha it is 1·442 feet below it; the extreme difference thus amounting to 3·178 feet.

I have attempted to illustrate the results obtained as to the level of the British seas by means of a little map. These results, however, are merely preliminary, for although we may accept the spirit-levellings as absolutely free from appreciable error, as errors arising from variations of gravity may be supposed to balance each other, the tidal observations were hardly in a single instance carried on during a sufficient period for obtaining the true mean level of the sea, and vulgar means were in many instances accepted for want of true means furnished by self-registering tide-gauges.*

Still, these observations, defective as they undoubtedly are, appear to portray the leading features of the case, and reasons why the sea should be piled up in some localities, while it is depressed in others, at once suggest themselves. That winds, currents, the horizontal configuration of the land, and the depth of the sea are more potent factors than bold coasts or proximity to lofty mountain ranges becomes at once apparent.

These differences are of sufficient magnitude to prevent our accepting the mean sea-level at large as a datum of reduction when dealing with surveys and levellings of the minute accuracy now aimed at, and really attained, in most countries of Europe. This would not, however, prevent our accepting the mean level of the sea at any particular spot for a datum-level to which altitudes as well as depths might be referred, unless, indeed, we should accept the surface of a spheroid determined by Captain Clarke as most nearly representing the surface of the British seas.

In Central Europe the zero-mark of the tide-gauge at Amsterdam (which is 0·4623 feet above the mean level of the sea) has been generally accepted as a datum-level, and I see no reason why the datum-level of the Ordnance Survey of Great Britain should not find acceptance for the whole of the British Islands.

The altitudes inserted upon the Ordnance maps of Great Britain are reduced to an assumed mean sea-level at Liverpool, which is 0·068 feet above the true level, as recorded by a self-registering tidal gauge placed against St. George's Pier. In the Ordnance maps of Ireland, on the other hand, all altitudes are referred to low water at spring tide, as observed at Poolbeg Lighthouse on April 8th, 1837. In order to reduce the altitudes on the Ordnance map of Ireland to the Liverpool datum-

* Mean level of the sea at Fleetwood above true mean level at Liverpool, according to Ordnance Survey (three months observations) 0·563 feet; according to Admiralty observations (nine months) 1·506 feet. At Liverpool the difference between the true mean and a vulgar mean, derived from maximum and minimum records, amounts to 0·366 feet.

level, they must be increased by 8 feet, as shown by trigonometrical measurements.

Having once adopted the datum-level of the Ordnance Survey there can arise no difficulty in giving a hypsographical delineation of the land-surfaces. The Ordnance Survey furnishes nearly all the materials that are wanted. Only in one respect will it be found to be deficient, viz. in data as to depressions covered with water, such as lake- and river-beds. Supplementary surveys will in most instances be required with reference to them, and we conceive that the results should be reduced to the accepted datum-level, instead of being referred to a variable water-surface.

We shall next have to consider the utilisation of Admiralty charts in the production of bathy-hypsographical maps. We have seen that the errors likely to arise from a disregard of differences in the mean level of the sea at different localities are but trifling in amount. On a map drawn on a small scale they would not show at all, and wherever the depth of the sea is considerable, they could not be ascertained by our present methods of surveying, as soundings taken from a boat cannot be expected to yield results equal in precision to those of a spirit-level. Incomparably far more considerable are the tidal movements of the ocean, having a range of between four and 40 feet along different parts of our coast.

Our Admiralty charts are primarily designed for the use of seamen, and the soundings which they give are naturally referred to low water at ordinary spring tides. This low water is the "datum for reduction," and as the spring rise, or main spring range, varies even within short distances, this "datum for reduction" is by no means a "datum-level" but represents in reality an inclined plane. In the British Channel, for instance, the spring rise varies between 23 and 40 feet, and consequently the mean level of the sea differs from the "datum of reduction" adopted by the Admiralty surveyors to the extent of from 12 to 20 feet. It is quite clear that quantities like these cannot be disregarded if we desire to delineate the bed of this channel by means of horizontal contour-lines confining planes equidistant from the plane representing the assumed mean sea-level, or with the "datum-plane" of the Ordnance Survey. In some of the sea lochs of Scotland, where the sea has a depth of hundreds of feet almost with a stone's throw from the land, and where the range of the tides is as a rule circumscribed, these differences would not show very conspicuously on a map, and still less so out at sea, where the tidal oscillations, proportionately to the depth of the ocean, are hardly appreciable. On the other hand, where the depth of the sea increases gradually, the tidal range becomes a very important factor, and in order to exhibit at a glance the difference between the contours as universally laid down on charts (with low water as the datum for reduction), and the contours on a bathygraphical map constructed in accordance with my suggestions,

I have prepared two diagrams designed to illustrate the surface features of the sea-bottom along that part of the south coast of England which extends from Selsea Bill to Brighton. Along that coast the difference between low water and the mean water-level varies, according to locality, between eight and 10 feet, and we may assume that this difference grows less as we depart from the land, until about 12 miles out at sea it is reduced to six feet.

The upper diagram has inserted upon it the contours or "fathom-lines," as they appear upon the published Admiralty chart. On the lower diagram I have inserted the same contours, taking the datum-level of the Ordnance Survey as the datum for reduction. A comparison of the two will show very appreciable differences. There are no doubt many parts along our coasts where these differences would be less, but elsewhere, as in the Bristol Channel, the Humber, or the Scottish firths, they would be far greater. At all events, it is clear that though we may neglect the ascertained differences in the mean level of the sea without seriously impairing the correctness of our delineation of the sculptured surface of the sea-bottom, we cannot neglect taking a careful account of the tidal range.

These, then, are the principal points to be considered in the preparation of bathy-hypsographical maps.

As to the materials available for such a map of the British Islands and of the surrounding seas, they include, as a matter of course, the Ordnance and Admiralty Surveys. The former, as soon as they shall be completed, will enable us to prepare a hypsographical map with a fulness and accuracy of detail certainly not to be surpassed in the case of any other country of equal extent. Supplementary surveys will no doubt be required if we desire to present also the features of lake- and river-beds, but some of these have already been made by local bodies or authorities, whilst others are in progress. The Admiralty Surveys furnish us with charts of nearly the whole of the surrounding seas on a scale of a least one mile to the inch. It is only when we proceed to a combination of the Ordnance and Admiralty Surveys, and even then only when it is desired to produce a map on a large scale, that the necessity of some further surveys makes itself felt. It is necessary, above all things, to devise a system of tidal observations which would accurately determine the relations between the Ordnance datum-level, the mean level of the sea, and low water. Observations of this kind would have to be carried on for five years if thoroughly trustworthy results are aimed at, and they ought to be made simultaneously at the largest possible number of stations. But once engaged upon work of this kind, the desirability of extending it and developing it into a complete survey of the British seas forces itself upon our attention. Surveys of this kind have been carried on with considerable success under the auspices of the Governments of Austria, Germany, Denmark, France,

and the United States, and it surely behoves the leading maritime nation of the world to take the lead in a work of this kind, and to carry to a satisfactory completion the labours so successfully begun in 1860 by the *Bulldog*, and since continued in the *Porcupine*, the *Lightning*, the *Valorous*, the *Knight Errant*, and the *Triton*. A "Survey of the British Seas," conducted by a Committee of the British Association, would most certainly yield valuable results in many departments of science.

But although I consider that further surveys are required before a combination of the Ordnance maps and Admiralty charts can be effected in a thoroughly satisfactory manner, I nevertheless believe that some useful cartographical work could be done even now. I more especially refer to the production of a general map on a scale of say 1:200,000, and of large-scale maps of certain estuaries and of other localities for which detailed surveys, quite sufficient for the purpose, are already available. The leading features of bathy-hypsographical maps, such as I suggest, would be as follows:—

1. All heights and depths would be referred to one and the same datum-level, altitudes being printed in Roman characters, depths in Stump.

2. The features of the ground would be shown by means of horizontal contours, which would enable the compiler to limit himself to the introduction of a comparatively small number of carefully selected figures.

3. The intervals between the contours would be tinted to bring out the relief of the ground.

4. The line along which land and water meet at ordinary spring tides would be clearly marked.

5. The foreshore and all sandbanks which uncover would be clearly indicated as on ordinary Admiralty charts.

6. The spring rise of the tide would be given as in Admiralty charts.

7. Roads, railways, and other features calculated to obscure the physical features of the ground would be omitted.

It need hardly be pointed out that a physical outline map of this character could be easily utilised for illustrating the hydrographical, the geological, and other features of the country.

BATHYGRAPHICAL MAPS of Part of the ENGLISH CHANNEL.

- N^o 1, *The Contours express the Depth below Low Water.—*
N^o 2, *The Contours express the Depth below the Datum Level
of the Ordnance Survey.—*

E. G. Ravenstein, del.

GRAPHICAL MAPS

of Part of the
GLISH CHANNEL.

express the Depth below Low Water.—

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W & A K Johnston, Edinburgh & London.