THE PHYSIOGRAPHIC INTERPRETATION OF THE NAUTICAL CHART.

by

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In a number of instances recently the writer has been asked for his opinion, as an engineer experienced in the technique of nautical chart production, with regard to the probable accuracy of data carried on the charts of this and other nations and to the validity of certain physiographic deductions which have resulted from studies of such data.

The recent prevalence of seismic disturbances having their centers in ocean areas, has resulted in efforts to determine the relation, if any, between the disturbance and the slopes of the area in which it originated. Likewise, the recent application to hydrographic surveying of certain methods developed during the war for the location of submarines, has greatly expanded the field which it is feasible for the hydrographer to occupy in a reasonable time, resulting in a sudden accumulation of data in considerable volume applicable to hitherto unexplored areas of the ocean floors. These accumulations have been seized upon eagerly by physiographers, and have been productive of numerous requests for assistance in correlating them with pre-existing data for the same or adjacent areas.

These and other similar inquiries incident to the consideration of problems having to do with the configuration of our continental shelves emphasize the need for a statement of the limitations to which the charts are subject, and of the cautions which should be exercised by the scientist who uses them in his geophysical studies.

The critical evaluation of a chart demands an intimate and detailed knowledge of all the factors involved in its production. Therefore, the present discussion will be limited in its application to the charts produced by the Coast and Geodetic Survey, since it is only with regard to those charts that the writer can speak with the necessary measure of authority. It is believed, however, that the standards of accuracy of the Coast and Geodetic Survey have always been the equal of the best contemporaneous practice of the charting agencies of other nations and, in consequence, that the following statement may be accepted as indicating, in a general way, the limitations to which all charts are subject.

The Coast and Geodetic Survey would be the first to assert that such limitations exist. We frequently observe a tendency, manifested by the presumably critical scientist or engineer scarcely less than by the layman, to accept the publications of the Survey as "gospel truth", worthy of unquestioning acceptance for even the most precise purpose. Such a manifestation is as embarrassing as it is flattering. The Survey has always adhered scrupulously to a high ideal of accuracy; in fact the most serious criticism which it has ever been called upon to meet, was that its work is done too thoroughly and therefore at too great cost. Accuracy, however, is a relative matter, and that which was ample to ensure the safety of the shallow draft sailing vessel of the clipper ship era, may well be inadequate to meet the exacting requirements of some special physiographic problem.

There is a group of fundamental facts which must form the basis for any just appraisal of the chart. They afford alike the explanation and the justification for both its merits and its deficiencies.

The purpose of the chart is primarily utilitarian. It is the product of the obligation incumbent upon each maritime nation, to furnish its shipping the information necessary to guide it safely through the waters it must traverse. All nations subordinate every other purpose to this one. For example, in the field, surveys must be made first of the shoal areas which may contain dangerous obstructions, rather than of the deeps whose exploration admittedly would produce information of great scientific value, but which are of minor interest to the mariner. Similarly, in the drafting room, the mercator projection is used as the framework for the chart because that projection is particularly adapted to the mariner's needs, and in spite of the fact that for general purposes it is less suitable than others available.

The task of surveying the waters of the earth is such a stupendous one that the combined effort of all participating nations has scarcely made a beginning of its accomplishment. This being the case, it follows as a necessary consequence of the purpose of the chart, that such surveys as have been made have as a rule been confined to the proximity of the land, and that as we proceed seaward from any shore, the survey becomes progressively more open, the soundings more widely spaced, and the whole product more of an approximation. Important harbors and channels whose depths are but little in excess of the drafts of the vessels using them are sounded with a thoroughness which reveals even minor irregularities in the configuration of the bottom. Coast-wise areas of moderate depths are examined less minutely, yet in sufficient detail to insure that no considerable difference in depth will pass undetected, and to permit of drawing generalized depth curves accurate as to position and general trend, but in which minor irregularities are omitted. With a greater departure from the shore and deepening of the water, the sounding lines become progressively more widely spaced and, when beyond sight of land, subject to uncertainties which will be discussed in detail later, so that by the time the outer limit of the surveys has been reached the data frequently have become approximations to an extent which must be taken into account when utilizing them for any precise purpose.

To illustrate with a single example: in a resurvey of the Atlantic Coast now in progress by the Coast and Geodetic Survey, the section extending from abreast Chesapeake Bay entrance to the Straits of Florida is one in which moderate depths extend far offshore, and where no great and abrupt inequalities in depth need be anticipated. This area is being covered by a primary system of sounding lines for which the specifications, although varying somewhat depending on the distance of certain characteristic depth curves from the shore, in general prescribe a spacing of sounding lines approximately as follows:

(*a*) From the shore to the 10-fathom curve, lines spaced ¼ mile apart, crossed by lines at right angles spaced 2 miles apart.

(*b*) From the 10 to the 15-fathom curve, lines spaced ½ mile apart.

(*c*) From the 15 to the 25-fathom curve, lines spaced 2 miles apart.

(*d*) From the 25 to the 100-fathom curve, lines spaced 4 miles apart.

On these lines the soundings are taken as rapidly as the depths permit; in less than 10 fathoms about 35 to 60 to the mile, between 10 and 20 fathoms, 20 to 35 to the mile, 20 to 50 fathoms, 5 to 19 to the mile, and 50 to 100 fathoms, 1 to 5 to the mile. Any indication of shoaling revealed by these primary systems of lines is further examined later.

Thus an area five miles square near the 5 fathom curve would contain about 5000 soundings, while the same area at the 100 fathom curve would contain not exceeding 15. In order to preserve legibility, only a small proportion of these soundings are shown on the published chart, but it should be remembered that all soundings are utilized for drawing depth curves. The latter are therefore not interpolated as they would appear to be if it were assumed that the chart contained all the soundings taken.

The outer limit of the work as a rule does not lie seaward of the foot of the continental shelf. Beyond that line little has been accomplished. The great ocean areas are practically unsounded except in the vicinities of islands or of actual or reported shoals.

The standards of accuracy prevailing to-day were impossible of attainment a century ago when the Survey began its task. The art of hydrographic surveying has developed just as have other arts and sciences during that period. In the matter of equipment alone the total progress is ample to justify the differences in accuracy which will be found to exist. The sailing ship has given place to the steamer, the hand-manipulated hempen sounding line to the steel piano wire carried on a motor driven reel, and both to the super-sensitiveness of radio-acoustics. The radio time signal is now broadcasted daily, insuring the accuracy of our chronometers to a small fraction of a second, and thus making it possible to fix our astronomic positions with a certainty previously undreamed of. To evade a frank acknowledgment that these and many other improved facilities have increased the accuracy of certain kinds of hydrographic surveying, simply because such an acknowledgment means an admission that the corresponding work of earlier periods was more or less inaccurate as measured by present standards, would be a stupidity of which the Survey has never been guilty.

A hydrographic Survey consists of a collection of soundings, each of which involves two separate and distinct operations: (1) the measurement of the depth and (2) the determination of the point at which the measurement was made. The value of the survey depends upon the accuracy with which these two operations are conducted. Each is subject to various uncertainties which fluctuate with changes in existing conditions, and which will be discussed separately at this point.

The immemorial method of sounding in deep water has been to bring the vessel to a complete stop and lower a weight to the bottom, recording the length of line unreeled in the process. Possible errors in the measurement may result from the lift of the waves, the overrunning of the wire after the lead has reached the bottom and, most important of all, the drift of the vessel from its position directly above the descending lead, which must be lowered at moderate speed in order to be under control at all times. The effect of these errors is to give recorded depths greater than true depths. The percentage of error usually will be in inverse ratio to the depth, particularly if the latter be great and approximately known in advance of the sounding. A probable error of about two per cent in depths of 100 fathoms and of one per cent in 1000 fathoms, is a reasonable assumption for carefully executed modern work of this character. The errors in soundings taken many years ago will be somewhat greater than those given above, largely because of the inferior apparatus then available. It would be very difficult to assign numerical values to these early errors: on the average they probably were about double those here given.

The above method is slow, laborious and costly, because the vessel must be stopped for each cast. Therefore various devices have been produced for sounding without reducing the ship's speed. These devices determine the depth by recording the compression of an imprisoned column of air lowered to the bottom. While these pressure tubes are a great convenience to, and have long been extensively used by the merchant marine, the Coast and Geodetic Survey has considered them too inaccurate and untrustworthy to meet the more exacting requirements of hydrographic surveying. Recently, however, the Survey has perfected a tube which contains none of the defects of the commercial types (*). This tube is now in constant use in depths less than a hundred fathoms. Special precautions are taken in their use: each tube is calibrated separately for each day that it is used, and for each cast two tubes are used which must agree with each other within certain prescribed limits. Occasional vertical casts are taken to compare direct and indirect measurements. The Survey concluded some time ago from a study of the data then accumulated, that the accuracy of this method was little, if any, inferior to that of the vertical wire measures. The writer recently has given the matter some further study. Among other things he compared the simultaneous depth measures obtained from the tubes used for each sounding. The comparison was made of a group of soundings selected at random from each day's work on two surveys made by two different parties. Each measure had been corrected separately for temperature and barometric pressure. The average difference between the shoaler and the deeper sounding of each pair on one survey was 1.7 per cent of the depth in depths ranging from 15 to 90 fathoms, and on the other 1.1 per cent of the depth in depths

(*) See description in following article.

ranging from 13 to 70 fathoms. The mean of the two simultaneous measures, which is used as the sounding, would therefore appear in general to have a possible error of less than one per cent, this conclusion being based on the assumption that the calibration to which each tube is subjected on each day that it is used, takes satisfactory account of the systematic errors.

The latest method of measuring depths in the deeper waters of the ocean is known as echo-sounding. This method is an adaptation of devices developed during the war for the detection of submarines. Very briefly, it consists in the accurate measurement of the time required for a sound wave to travel from the ship to the bottom and be reflected back to the ship. The depth can then be deduced from the known velocity of sound in sea water, corrected for variations from the standard velocity resulting from differences between existing and normal conditions of temperature, density and salinity.

The method is still in the experimental stage. Two different types are at present being studied by the Coast & Geodetic Survey. Each of these already gives results of sufficient accuracy to justify its use, but each requires further development to correct present deficiences. The principal difficulty to be overcome is that at present the soundings taken are normal to the slope of the bottom, and therefore vertical only when the bottom is nearly horizontal. (A slope of six degrees or less does not appear to result in appreciable errors).

The method is too newly developed to justify any discussion of its present accuracy. It is worthy of mention at this time rather because of the promise it holds out to the scientist of affording, in the near future, a feasible means of exploring the great ocean deeps. The rapidity with which soundings can be taken will permit of examining interesting submerged areas with a minuteness not to be thought of under any previous method. Already one of the types referred to gives a continuous indication of the depth, subject to the limitation noted, and we can confidently hope that future developments which include the removal of that limitation will enable us to produce a contour map of a rugged sea bottom with an accuracy superior to that with which we map the topography of a mountainous region to-day.

A record of the depth is of no value to the mariner unless we know the position at which the depth was measured. This determination of position is therefore the second factor requiring consideration.

When the sounding is taken within sight of land, the position is determined by measuring the angles between known points on shore. The strength of these determinations varies somewhat with the geometric conditions involved but as a rule we can assume a degree of accuracy in the locations satisfactory for any purpose for which the depth measures should be used.

When the land is invisible, the determination of position becomes much more complicated and difficult, and unless unusual precautions are taken, there will be a correspondingly greater uncertainty in the results. The method ordinarily used in navigation to-day, and in the hydrographic work of the Survey prior to a few years ago, involved astronomic determinations or dead reckoning or a combination of both.

In the dead reckoning method the vessel either starts or ends at a known point. She will run for hours or days without a "fix", the approximate position at any moment being derived by plotting, forward or backward from the known position, the course steered and distance logged, corrected by the mariner's best guess as to the effect upon his vessel of wind, waves and currents. As all these effects are uncertain and variable, it is obvious that before many hours a small vessel such as is used for surveying, and particularly the small sailing ships of an earlier day, may be hopelessly "at sea", and any further soundings taken valueless because of excessive uncertainties in their positions. Where the vessel starts at one known point and ends at another, the intermediate run will be adjusted between the two, but such an adjustment is still subject to all the uncertainties resulting from probable variations in the factors causing deviation from the recorded course and distance. This method, therefore, has never been used by the Coast Survey except in default of a better. Yet the controlling necessity of accomplishment and the fact that in areas remote from the land and from any danger, results subject to small errors are adequate for the mariner, have compelled its use at times in spite of its known inaccuracies.

Positions determined by astronomic observation are better than those derived from dead reckoning, but by no means absolute. Such positions are subject to uncertainties resulting from variations in the chronometer error, or in refraction, or from indefiniteness of horizon, which cannot be taken account of in the computations. The writer has known carefully observed simultaneous altitudes of two stars on opposite sides of the zenith taken under conditions which seemed normal to the observer, to result in positions five miles apart. Even to-day, with the chronometer error eliminated by the radio time signals, the careful navigator usually will assume a possible error of not less than two miles; in other words, that his vessel may be anywhere within a circle of two miles radius of which the computed position is the center.

Combinations of these methods controlled the offshore hydrography executed by the Coast Survey prior to 1914. In that year was begun a complete resurvey of the Atlantic continental shelf which has since been prosecuted as rapidly as facilities permitted. For this resurvey much more accurate methods of fixing positions were developed. The hydrography, beyond the limit of visibility of shore objects, is now controlled by rows of buoys planted section by section over the area to be sounded. Elaborate methods are used in fixing the positions of these buoys with the result that the probable error in location is about 15 meters to the mile. These unusually precise results apply only to work executed during and subsequent to 1924; during the previous decade the method, while much more precise than any previously used, was still in the development stage, and had larger and variable errors not susceptible of being covered by any brief comprehensive statement.

Transmission of sound through sea water, whose application to the measurement of depth has already been noted, has also been applied to the determination of position. Briefly, a submerged bomb is fired at the ship, the instant of firing being recorded on a chronograph aboard the vessel. The sound wave, on reaching the shore, is picked up by a hydrophone. This operates a relay at the shore station which sends a radio signal back to the ship, where it is recorded on the same chronograph. All operations are automatic, and all transmissions are instantaneous except the sound from ship to shore; therefore the elapsed time on the chronograph between the sending and receipt of the signal measures the time required for the sound to reach the shore and, in consequence, the distance. Three shore stations are used, giving the ship's distance from three known points, hence, its position with a check. The method must still be regarded as in the developmental stage. Certain fundamental problems require further study, and their solution will undoubtedly result in greater accuracy. Tests indicate that at present the method is slightly inferior to that of measuring the angles between visible objects, but superior to the buoy control method.

When the data accumulated by the surveying parties reach the Washington office of the Survey they have always been subjected to a careful scrutiny to reduce the inaccuracies. Such a scrutiny was particularly necessary to the work done prior to 1914. They were first plotted, making careful allowance for all factors tending to produce differences between the true and the assumed positions. Where a portion of the work began and ended at known positions, the closing error was distributed throughout the run on the basis of the conditions prevailing while the work was in progress. Frequently the major system of parallel sounding lines was crossed by a second widely-spaced system at right angles to the first. In such cases, it is obvious that wherever two lines crossed the soundings should agree, and that their failure to do so was an indication of the need for adjustment. Depth contours were drawn and studied, and any parts anomalous to the known physiographic relief were subjected to further scrutiny to eliminate or reduce the anomalies. New work received was compared with all pre-existing data applicable to the same locality, to the end that the soundings finally charted should be the coordinated product of all available information. This scrutiny, in modified form, is applied to present-day results, in spite of recent progress in insuring the accuracy of the field work.

In short, the cartographer spreads before him all pertinent data, and by careful study seeks to harmonise every part. There is, however, a clearly defined limit beyond which he does not go. He is not permitted to make an "office survey"; that is, arbitrarily to change the field data to conform to his own individual notion of what is correct. On the contrary, there must be a definite, tangible reason deducible from the records to justify every adjustment that he makes, and if such justification cannot be found, the disparities must remain. The effect of this office verification, therefore, is to reduce the amount of existing errors, but not entirely to correct them.

A factor which becomes noteworthy when our purpose is to study the configuration of a limited area of the ocean floor, is that the relation between adjacent charted soundings is not necessarily a constant one. This fact can best be established by a specific example. In the simplest case of one complete and systematic survey of the area, the surveying vessel, sterting at a known point, steamed seaward on a course approximately normal to the shore, stopping at five minute intervals for a sounding, until the seaward limit of the area was reached, say 40 miles from the starting point. For convenience, call this sounding line *A*. At a net speed of four knots, 10 hours were required to complete the line. The vessel then turned at right angles, ran four or five miles, then turned again and headed shoreward on line *B* which was run as nearly as possible parallel to *A* and continued shoreward until land objects became visible and a fix could be obtained. She then turned as before, ran the necessary distance, again fixed her position and headed seaward on line *C* corresponding to *A*, and returned shoreward on line *D* corresponding to *B*, until a fix was again possible.

This, in brief, was the simplest and best method of off-shore hydrography in use prior to 1914. Regarding it the following points are obvious:

(1) During the running of any pair of lines as *A B* there was an accumulation of error of position whose net amount was measured by the difference between the dead reckoning and observed positions at the inshore end of *B*.

(2) This error could be distributed throughout the lines.

(3) If, during the run the factors causing the deviation remained constant in their effect upon the vessel, the adjustment would be an accurate one and each sounding would fall substantially in its true position. Any change in these factors during the run would make the adjustment correspondingly imperfect. Unfortunately it was seldom possible to justify any assumption of constancy, and in consequence there was, as a rule, more or less uncertainty as to the accuracy of the adjustment.

(4) This uncertainty would be proportional to the distance from the nearest observed position, and greatest at the seaward ends of the lines.

(5) The accumulation of error being gradual, the errors in the relative positions with respect to each other of any two adjacent soundings on any line, would be very small.

(6) Since each pair of lines is subject to its own independent adjustment, the relation between any pair of soundings on lines *B* and *C* would be less accurately established than that between the corresponding soundings on lines *B* and *A*. This disparity also increased with the distance from the fixed positions and was greatest at the outer ends of the lines. The outermost sounding on *A* was distant only 4 miles, or one hour's run, from the outermost one on *B* and, in consequence, while both may have been considerably in error as to absolute position, the two errors were approximately the same in extent and direction; in other words, the relative positions with respect to each other were not greatly in error. But it was 21 hours run from the outermost sounding on *B* to the corresponding one on *C*, and in consequence the uncertainty with respect to their absolute positions applied also to their relative positions with respect to each other.

It will be seen, therefore, that of three soundings charted equidistant from each other, the relation between two may be well established, while that of the third to the two may be subject to considerable uncertainty.

Where, as is frequently the case, the total of available data applicable to an area represents a piecemeal accumulation over a considerable period of years as occasional opportunity offered, and worst of all where work of this latter character was performed by sailing ships which zigzagged back and forth on erratic courses at the dictation of variable winds, the relationships may become so complex as to defy precise analysis. The results of such work may have been kept within limits of uncertainty satisfactory for use by the mariner and yet be too uncertain to justify use by the scientist for the deduction of conclusions regarding local physiographic forms.

The errors with which we are primarily concerned are the residuals which remain after the office adjustment has been completed. No specific rule for appraising their magnitude can be laid down, since it depends on the date and layout of each individual project, and on the conditions under which the work was done.

Some indication of the probable errors of data appearing on the charts pertaining to areas at a considerable distance from the land, can be obtained by comparing the position of a characteristic depth curve, as determined by the recent, relatively precise survey, with the position as charted prior to the application of the modern work. Figure 1 affords such a comparison. In the figure, all soundings are in fathoms, and in each case the curve drawn as a solid line was determined by the recent survey, while the broken line is the same curve as previously charted.

The upper section of the illustration shows the 10-fathom curve located about 35 miles off Sabine Pass, Texas. The lower left hand section shows the 100-fathom curve abreast Chesapeake Bay entrance, about 65 miles offshore. The middle and right-hand sections show the 100-fathom curve extending continuously from abreast the mouth of the Savannah River to a little below St Augustine, Florida, and situated an average distance of about 70 miles offshore.

The recent surveys were all made subsequent to 1916. In no case was the earlier position of the contour determined by a systematically made survey. Those positions rest instead on a meagre accumulation of isolated sounding lines as occasional opportunity offered during a long period of years. The 100-fathom curve south of Cape Hatteras was located largely as an incident to investigations of the Gulf Stream, where accuracy of position was in large measure subordinated to other objectives.

It is not surprising, therefore, to find these early contours misplaced five miles or more in some localities. Rather, it is gratifying to see how well the sequence of adjustments has reduced the errors. Some of the closing errors of the dead reckoning work were much larger, even when supplemented by astronomic observations. In the extreme case which has come to the writer's attention the vessel, on making a landfall after some days spent in the Gulf Stream under conditions such that no astronomic fixes could be obtained, found its reckoning to be sixty miles in error.

The conditions under which the early work on the South Atlantic Coast was executed were probably as adverse as any pertaining to any part of the Coast Survey work. It is not believed, therefore, that misplacements of the

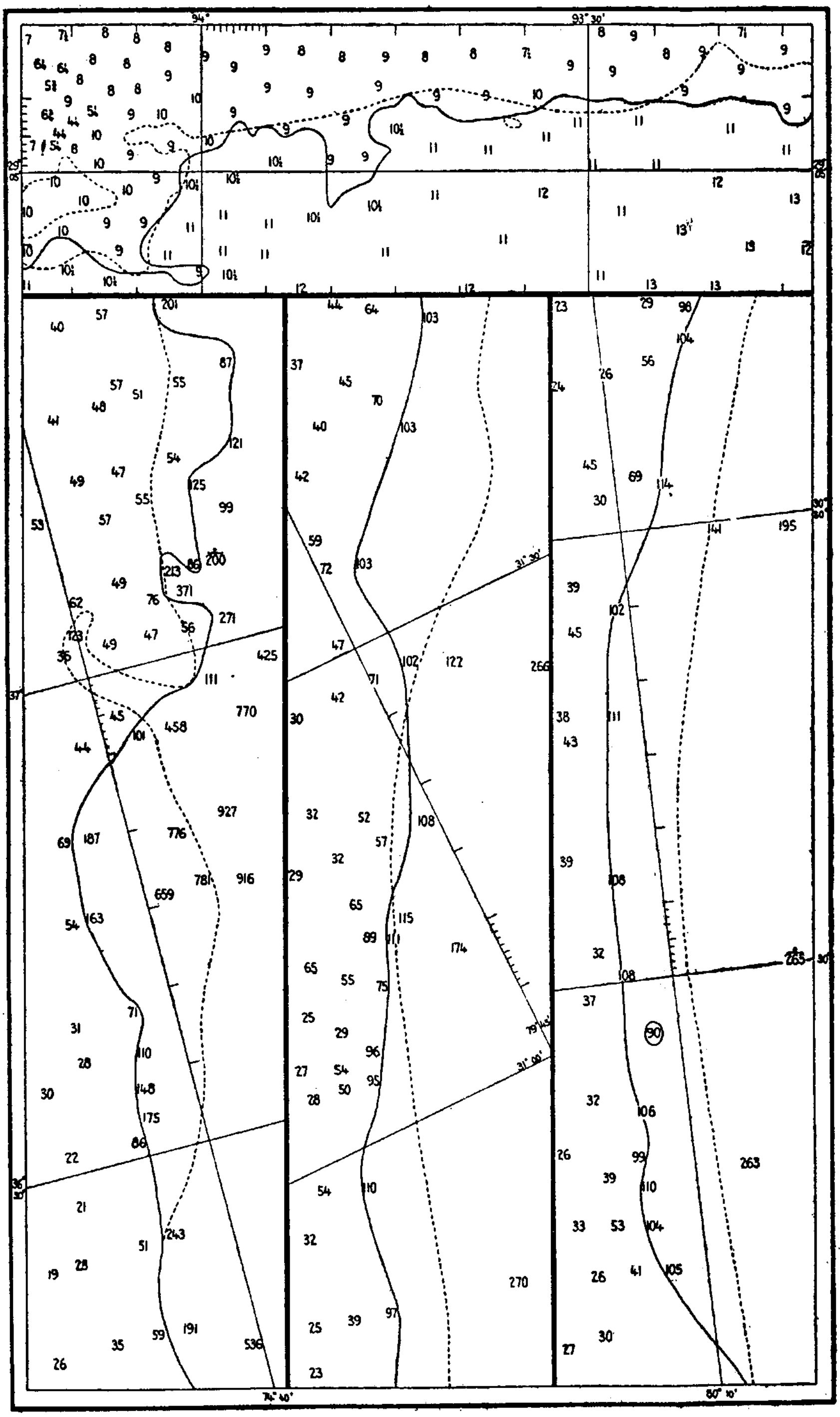

Fig. 1

depth curves in excess of those shown in the illustration need be anticipated along any part of our Atlantic Coast with the possible exception of the Gulf of Maine.

Another fruitful source of difficulty to the scientist results from the charting of reports received from mariners, hundreds of which are received by the Coast and Geodetic Survey every year. All chart-making agencies are guided by the principle that they should give the mariner the benefit of every doubt. Those agencies have learned by experience that the navigational methods of many mariners are only approximate ones, and that data furnished by them may be in error, as to depth or position, or both, by amounts far in excess of that permissible in the hydrographic surveys. They know that many of these reports, although undoubtedly made in good faith, will prove upon investigation to have no basis whatever in fact. Nevertheless, in cases where the information, if correct, would be of value to the mariner, its correctness is assumed, and it is charted until such time as an investigation can be made. Sometimes, but by no means invariably, it is qualified by the designation *P. D.* or *E. D.* (position doubtful or existence doubtful). And as years may elapse before an opportunity for investigation arrives, these data, once charted, are prone to remain on the charts indefinitely.

In the acceptance or rejection of information of this character the Coast and Geodetic Survey probably exercises a more exacting discrimination than most of the chart-making agencies of the world. It believes that the presence of erroneous information may do more harm than the absence of all information, and if all available evidence casts sufficient doubt upon the accuracy of the report, the data will not be charted unless failure to do so might result directly in disaster to shipping in the improbable event that the report is correct. Thus, much of the data reported by mariners or furnished by other agencies — in rare cases data covering extensive areas and obtained at great cost — are not charted because of obvious failure to conform to acceptable standards of accuracy. Nevertheless, the Coast Survey Charts, like those of every other nation, contain hundreds of soundings which cannot harm, but may assist the mariner, but which the scientist should regard with suspicion. Countless instances might be cited of apparently authentic reports which subsequent investigation has proven to be wholly erroneous. A few months ago a battleship of a certain nation reported having obtained soundings of 13 and 14 fathoms off the Californian coast, at a locality just outside the path of coastwise shipping where the charts showed 500 to 600 fathoms. This report was considered of such importance, and of such unquestioned authenticity that it was immediately charted and broadcasted to every port of the United States and to foreign countries. A Coast Survey vessel was ordered to make an immediate investigation of the spot. This vessel made a survey of the locality in such detail that it could not conceivably have missed a shoal of the kind reported, without finding the slightest evidence to substantiate the report.

A tragic event which occurred on the Pacific coast a few years ago illustrates how mistakes of this kind may occur. One of the large coastwise passenger ships was wrecked on that coast with the loss of the vessel and a number of lives. From the subsequent investigation it appeared that the vessel was proceeding in a dense fog by the method commonly practised under such conditions of relying on the lead to keep in deep water. She could have reached the place where she stranded only by crossing a considerable expanse of shoal water. Yet the officer at the sounding machine, at the very moment of striking and for some time previously, had been reporting no bottom at 100 fathoms. The most probable explanation seems to be that this officer, believing the vessel to be in deep water, allowed the lead to strike the bottom before he put his hand on the sounding wire to detect the signal which would be transmitted to him from the impact, and that the ship's speed was such as to unreel the wire at about sounding speed, so that to all appearances the lead continued to descend until checked at the machine.

Thus there is an element of psychology involved in our problem of physiography; a psychology which affords a possible explanation for the third and last example which will be given.

This example, the most interesting of its kind which has ever come to the writer's attention, is illustrated in Figure 2. Some time subsequent to 1900 the Survey began receiving reports of shoal areas from 10 to 17 miles southeastward from the South Pass of the Mississippi River, directly in the track of the large ocean vessels bound to or from the river by way of the

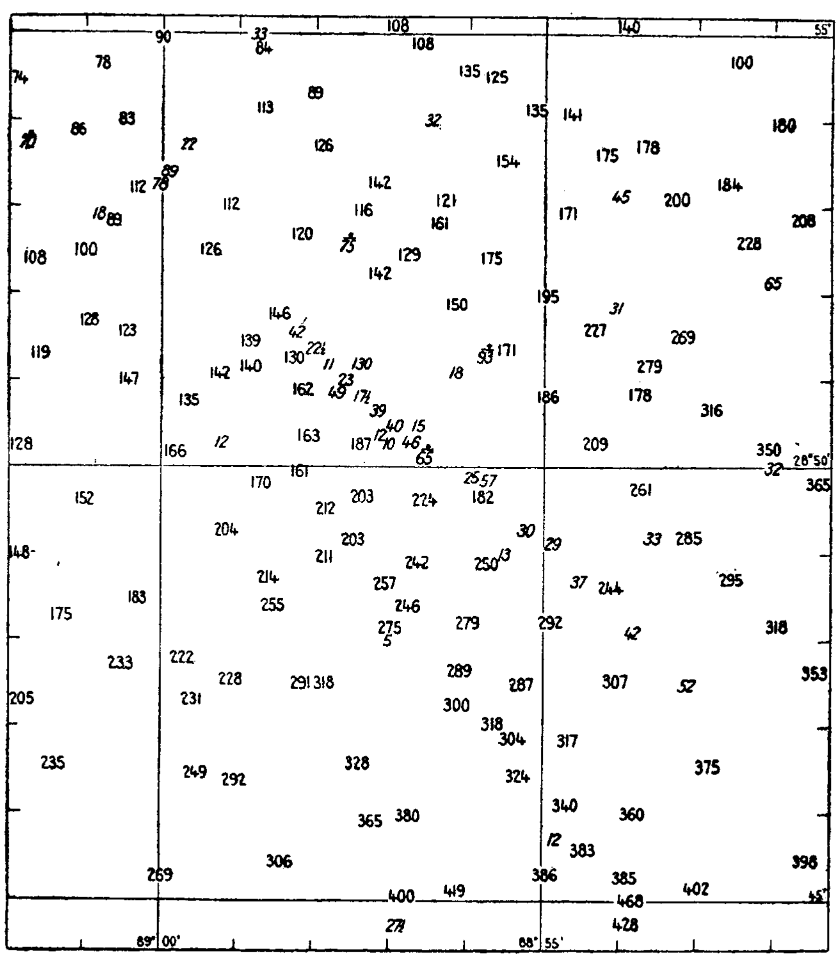

Fig. 2

western end of the Florida Keys. Those reports were received in considerable numbers over a period of several years. They were most convincing in character; discoloured water would be noted and a sounding would be taken; the sounding or rather, as a rule, a series of them at short intervals, would show shoal water and the lead would bring up samples of the bottom.

On four different occasions a survey vessel was sent to investigate the locality. In each case no trace of the reported shoals could be found, but instead the new soundings confirmed the depths already charted. Not only were hundreds of soundings taken in these examinations, but in addition the survey ship steamed many miles back and forth across the area towing a submarine sentry which would have given instant notice had it encountered a shoal. As the reports almost without exception indicated shoals several miles in extent, it is inconceivable that these surveys could have missed them had they existed at the time the surveys were made.

Some of these reports are shown in Figure 2 by the oblique figures, while the vertical figures show the depths found by the surveys. It will be noted that a series of parallel lines, trending in a northwest-southeast direction, can be drawn through the reported soundings, these lines representing the track of the reporting vessel. In this way the soundings of each report can be segregated from their neighbours. It can be seen, for example, that one vessel reported a series of 8 soundings covering a distance of 2 miles, with depths ranging from 11 to 46 fathoms.

One is averse to doubt such circumstantial evidence, yet the evidence of the surveys is even more convincing. Each reader is at liberty to deduce his own explanation. It is possible to justify both reports and surveys by assuming a sequence of volcanic disturbances; Bogoslof Island at once suggests itself as a precedent. Two objections, however, can be urged in opposition to this explanation: the remoteness of this spot from any region of known volcanic activity, and the improbability that such disturbances could have occurred here without furnishing other confirmatory evidence.

Another possible explanation is the psychological one already mentioned. It is known that a gentleman in New Orleans, believing in the existence of a shoal in this locality, asked the masters of vessels regularly calling at that port to be on the lookout for it. We have just noted a well-authenticated case in which a ship's officer, believing the vessel to be in deep water, reported deep soundings when she was practically on the beach. It is equally possible that the opposite situation could occur and that other officers, believing they should be in shoal water, in entire good faith reported shoal soundings when they were not getting bottom at all. This possible explanation gains in credibility when we recall that undoubtedly many other vessels, in response to the same request, searched for the shoals without finding them.

Space does not permit of an extended discussion of doubtful conclusions reached by scientists as a result of a too confiding use of these data. A single example will be mentioned, because it so beautifully illustrates the moral which this paper seeks to teach.

One of the most interesting physiographic features of our continental shelves is the submarine valley of the Hudson River. As a result of various scientific studies it has been visualized for us in terms of a grandeur which dwarfs anything we can see to-day. Deep narrow gorges with vertical walls, and waterfalls of great height have been ascribed to it. While the more vivid descriptions have been intended to appeal to the popular imagination, they have adhered with reasonable fidelity to the more soberly stated deductions of various geologists, merely adding the touches of colour necessary to give animation to the picture.

Most of these pictures have as their basis Spencer's studies of the valley. Those studies were based primarily on Coast Survey data, but with these data he arbitrarily combined information derived from other sources.

The aggregate of the soundings taken by the Coast Survey in this locality and used in the studies of Spencer and others were obtained at intervals during eleven different years ranging from 1842 to 1905, and in some cases by two or more parties operating independently during the same year. We have already seen the uncertainty in the relationships between soundings taken in this way. In no case of soundings on any one line, whose relative positions with respect to each other would be approximately correct, were the soundings taken sufficiently close together to indicate inordinately steep slopes. Insofar as deductions of such slopes were based on Coast Survey data they were derived from the juxtaposition of soundings whose relative positions were subject to the same uncertainties as their absolute ones.

Spencer's most striking deductions, however, resulted from his interpolation of certain extraneous information into the Coast Survey data. As he tells the story: (*)

> "But on the British charts I made a most astounding find of "three soundings of 459, 801 and 229 fathoms. The position of "the 459 and of the 801 soundings of the British chart so closely "coincided with those of the Coast Survey chart (**) at 213 and "345 fathom points that they could not have been represented on "the same charts. Thus the British chart showed no barrier to "the canyon and very greatly increased the known depth of the "narrow gorge, further defined by the 229 fathom point. The "extraordinary depth would have been startling had it not been "anticipated in all my long series of analyses of submarine valleys. "Both series of soundings were correct, the deeper ones having been "made by Lt. Com. E. L. TANNER (***) in 1883 in the Fish Com-"mission Steamer Albatross. The older soundings had been retained "on the Coast Survey charts."

It need not be doubted that TANNER obtained the depths reported, thus suggesting the probability that the trough continued to deep water beyond

(*) *American Journal of Science*, Vol. XIX. January 1905.
(**) *Coast Survey Chart* N° 8. B. A. Chart N° 2480
(***) *Hydrographic Notice to Mariners*, N° 56, 1883.

the edge of the shelf. But the locations both of his soundings and of those of the Coast Survey to which they were related were far too uncertain to justify the derivation of a "precipitous" slope connecting the two.

The Coast Survey would not assert that Spencer's deductions were incorrect It would merely point out the very great uncertainty to which they were subject. Assume three miles as reasonable possible errors for each of the soundings upon which Spencer's conclusions depend. Then, considering only factors inherent in the survey, each sounding might belong anywhere within a circle drawn from the assumed position as a center, with a radius equal to the possible error. Then, at one extreme. the 801 and 345 fathom soundings might have been over six miles apart, giving a slope of about four degrees. But since these circles overlap we have not precluded the possibility that the soundings actually were taken at the positions assumed, and that the precipitous slope actually exists. Therefore before any satisfactory conclusion could be reached it would be necessary to obtain additional soundings, or to take account of known factors foreign to the survey: for example, the geologic formation, or the angle of repose of the material of which the exposed surface is composed.

To summarize, the following rules should be borne in mind by the physiographer in his study of charted data. Their application to his work will make it much more difficult and time consuming, and in a sense more unsatisfactory, but he will find compensation for these adverse elements in the knowledge that he is arriving at a much closer approximation of the truth, which is the objective of all scientific effort:

1. Do not place unquestioning reliance in the charted data. Study them critically in the light of the limitations discussed, and appraise the probable accuracy of each item before basing any conclusion on it.

2. If practicable go back of the published chart to the data from which it was compiled. The chart itself gives little hint of the relative accuracy of its component parts.

3. Remember that no general rules can be applied to the accuracy of off-shore hydrography. Each item must be appraised separately on the basis of its date and the conditions under which the work was done.

4. Assume that with respect to any sounding taken out of sight of land, the measurement of depth is probably of a considerably higher degree of accuracy than the absolute determination of position.

5. Remember that although the absolute positions of two or more soundings may be considerably in error, their relative positions with respect to each other may be either approximately correct, or in error equally with the absolute positions.

6. Be cautions in making deductions in proportion to the minuteness of the relationships upon which such deductions are based.

7. Be particularly cautious in accepting data which can be traced to an origin extraneous to the Survey. Remember that as a rule such data are subject to greater uncertainties, and that they may even be wholly erroneous.

8. Finally, remember that the purpose of this statement has been to issue a warning against an implicit acceptance of all charted data and that necessarily, in order to make that warning effective, the various matters discussed have been presented in the worst possible light. Remember that the substance of the discussion applies only to the hydrographic work done out of sight of land. To apply to work of a different character the limitations to which this one special kind is subject, would result in conclusions quite as erroneous as if it were assumed that all results were absolutely correct. Even with respect to the offshore hydrography, the uncertainties suggested are believed to be the greatest which will be encountered, most of the work undoubtedly being subject to inaccuracies of lesser magnitude.