U. S. DEPARTMENT OF COMMERCE
JESSE H. JONES, Secretary
COAST AND GEODETIC SURVEY
LEO OTIS COLBERT, Director

Special Publication No. 205
(Second Edition)

CARTOGRAPHY

A REVIEW AND GUIDE

For the Construction and Use of Maps and Charts

Revised Edition
1943

BY

CHARLES H. DEETZ
Senior Cartographic Engineer

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1943

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington, D. C. - Price 65 cents

National Oceanic and Atmospheric Administration

ERRATA NOTICE

One or more conditions of the original document may affect the quality of the image, such as:

Discolored pages
Faded or light ink
Binding intrudes into the text

This has been a co-operative project between the NOAA Central Library and the Climate Database Modernization Program, National Climate Data Center (NCDC). To view the original document, please contact the NOAA Central Library in Silver Spring, MD at (301) 713-2607 x124 or www.reference@nodc.noaa.gov.

LASON
Imaging Contractor
12200 Kiln Court
Beltsville, MD 20704-1387
January 1, 2006

CONTENTS

Chapter V.—Elements of Direction and Its Related Terms—Different Ways of Defining Direction

Chapter VI.—Technique of Construction

ILLUSTRATIONS

PREFACE

In view of the growing interest in maps and charts as brought about by the interrelation of countries and communities, the purpose of this publication is to supply in outline form the underlying principles of constructive cartography. It is also intended to illustrate the development of the scientific system of today and the educational value of this branch of human activities.

A knowledge of the horizontal and vertical location of places and the configuration of the earth's surface are essential factors in carrying on the major activities of a nation. Such information as relates to land surfaces is given on the modern topographic map; the submarine relief and the navigational routes of travel and commerce are supplied by the nautical chart, and, in a similar manner, the needs of air travel and air commerce are served by the aeronautical chart.

A nation of vast resources and industrial developments can well afford to provide maps and charts for the extension of its highways, railroads, and airways in all directions; for the harnessing of its rivers to furnish water power and irrigation; and for providing means of protection against the overflow of river banks and the encroachments of the sea upon its beaches. In the interests of navigation the mariner requires charts that supply not only the necessary accuracy in delineation and facility for use, but charts that are in keeping with the development of a nation's ports, its commerce, and the ever changing natural conditions.

It is the purpose of this book to trace briefly the attempts made through the ages to depict on paper acurate geographic information which will lead to a better understanding of the terrain and the sea, their history and relationship, their characteristics and phenomena. It will also outline what are now considered the best methods of securing and utilizing map data and to indicate how to use the maps and charts after they have been constructed and printed.

The manual entitled "Rules and Practice," relating to construction of nautical charts (Special Publication No. 66, U. S. Coast and Geodetic Survey), has been embodied only in part in the present publication on cartography. This manual sets forth the methods and details entering into the compilation of nautical charts in the Division of Charts of the Coast and Geodetic Survey. Its purpose primarily is to secure completeness, uniformity, and simplicity in the general appearance of the chart.

The new publication deals rather with cartography in general. It should serve the compiler who applies his technical knowledge and skill, and is limited in the coordination of maps to the information available; it should also serve those who by their labors in the field produce the material from which maps and charts are constructed, and it should point out conditions and restrictions under which map-producing organizations are functioning.

CARTOGRAPHY

Chapter I.—HISTORICAL AND CRITICAL REVIEW

INTRODUCTION

Cartography may be defined as the science and art of expressing graphically, by means of maps and charts, our knowledge of the earth's surface and its varied features. It combines the achievements of the astronomer and mathematician with those of the explorer and the surveyor in presenting a picture of the physical characteristics of the earth's surface, which may be extended to include many of the activities of mankind involving exact and organized knowledge of the earth's phenomena.

A map is merely a means toward an end. Its purpose is to assist man in coping with his environment. It serves as a useful medium for making geographic products available and for stimulating new fields of research. In the compilation of the map, therefore, the aim should be primarily to provide for the reading of it by the synthetic method insofar as the actual physiognomy of the globe is represented. It should present in the most readily understandable form certain groups of facts and relationships from which its user can deduce conclusions pertinent to the subject of his study.

Whoever has a knowledge of cartography is convinced that it is more difficult to compile a good map than it is to write a book. In the latter situation one does not need seriously to torment himself with precision because where ideas fail it is easy to shirk obstacles by the skillful use of words.

In anticipation of the criticism that the above statement will inspire, it may be added that it is taken in part from Eckert's Kartenwissenshaft [1] and in part from a passage in Goethe's Faust.[2] The present writer himself concurs in it only to a limited extent. In order for either the book or the map to be a contribution of true and lasting value, it must be a new presentation of truth, and whatever merit either possesses must result in spite of and not in consequence of any deviations by its creator from the absolute integrity which should pervade his product.

To a limited extent, however, the statement is correct. Absolute truth, even within the most limited and concrete fields, is a com-

[1] * * * Davon ist jeder Sachkenner überzeugt, dass eine gute Karte herzustellen schwieriger ist als ein Buch zu schreiben, wo man mit Worten manche Klippe leicht vermeiden kann.—Eckert.

[2] Nur muss man sich nicht allzu ängstlich quälen ;
Denn eben wo Begriffe fehlen,
Da stellt ein Wort zur rechten Zeit sich ein.—Goethe.

The latter quotation may be translated as follows :

All anxious torment is of no avail,
For there where comprehensions fail
A word comes forth in timely need.

plex matter of such infinite ramifications that it is beyond the capacity of the finite mind to encompass it. Our nearest approach, whether it be in the book or the map, is at best an approximation. That approximation, however, can be more readily and more nearly attained through the medium of language than through the insufficient stereotyped forms which alone are available to the cartographer.

An author can amplify and qualify. He may beautify his sense by the boldness of his expression. He can state not only his axioms, but also exceptions and variations to which they are subject. He can state that one theory may be accepted as demonstrated while another is as yet speculative. In short, the spoken or written word affords him so ample a medium for giving form and concreteness to thought that any deficiency in his product results from a failure of clear and correct thinking rather than from the lack of a vehicle of expression.

The cartographer finds himself in a different situation. He must meditate and aspire to cast his material to meet the requirements of a given standard and form. He is obliged in his various operations to follow strictly the mathematical and analytical laws upon which the surveys and framework of the map are based.

It may be said that the map is the technically adapted model of the component surveys of the parts of the earth represented in miniature; and one should not fail to recognize the prototype from its picture or its details, accepting the whole as a certificate of scientific reproduction.

EARLY HISTORY OF MAPS

Although maps or sketches existed before the time of Homer, generally accepted as about 900 B. C., such sketches were naturally quite deficient in geographic values, and the development in cartographic knowledge from that early period to the present day has kept pace with the other arts and sciences of civilization.

As Homer is the traditional object of ancient idolatry and genius, the world as conceived by him, in the Iliad and Odyssey, constitutes a reference picture upon which a comparison may be based.

In his conception, the earth is a round disc encircled by a great river, Oceanus, which is a purely mythical stream and, according to the rude ideas of that early age, circulates around the terraqueous plain. Of the Atlantic or Indian Oceans he doubtless has no knowledge at all. The sky is a great concave roof propped up by pillars which the mighty Atlas upholds, and under his care the heavens and earth are held asunder. On this large flat disc of the earth is a sort of belt or zone of which he appears to have a definite notion. This included Greece in a rather detailed account to be mentioned later. The peoples and topography of a number of the adjacent countries and islands are known but the distant places are vaguely indefinite and beyond the belt the earth is a myth.

FLOATING ISLANDS OF THE AEGEAN SEA

Ancient geography was closely related to mythology as illustrated in the belief that several of the islands of the Aegean Sea were not fixed in the modern sense, and of these Delos was supposed to have floated under the surface of the sea until made to appear and stand firm by order of Poseidon (by the Romans called Neptune), who fastened it with powerful columns and adamantine chains to the bottom of the sea. Once fixed in its place, the island continued, according to popular belief, so firm as even to be unmoved by the shocks of an earthquake. This was accomplished in order that the island might receive Jupiter's beloved Latona, and become the natal place of Apollo and Artemis or, in Roman mythology, Diana.

Referring to the group formerly called Aeolian Isles, it was either the island Strongylus or Lipara concerning which we have the following lines in Pope's translation of the Odyssey:

> At length we reached Aeolia's sea-girt shore,
> Where great Hippotades the sceptre bore,
> A floating isle! High raised by toil divine,
> Strong walls of brass the rocky coast confine.

Aside from the mythological aspect of the world's greatest epic, Homer in his Catalogue of the Ships and Places (Iliad II, 586–1071) gives an account of the people, princes, and countries founded upon the real transactions of those times, and by far the most valuable piece of history and geography left us concerning the state of Greece in that early period. Greece was then divided into several dynasties, which the author has enumerated under their respective princes, and his division was looked upon as so exact that we are told of many controversies concerning the boundaries of Grecian cities, which have been decided upon the authority of this part of the Iliad.

The following instances of subsequent boundary adjudication may be cited: The city of Calydon was adjudged to the Aetolians notwithstanding the pretensions of Achaia, because Homer had ranked it among the towns belonging to the former. Upon the plea that he had placed the Abydonians in possession of Sestos, the latter was assigned to Abydos. When the Milesians presented their claim to Mycale, a verse of Homer carried it in favor of the Milesians, and the Athenians were put in possession of Salamis by another verse which was cited by Solon for that purpose. In so high estimation has the Catalogue been held that there have been laws in some nations for the youth to learn it by heart.

While geographers of the following millennium have contributed to our knowledge of the world in their days, the condensed outlines of Homer in poetic form almost approaching a gazetteer of place names, are hardly excelled until we reach the period of Ptolemy (A. D. 87–150).

According to Plato and other ancient writers, there was situated in the Atlantic Ocean, over against the Pillars of Hercules, an island known as Atlantis, which was larger than Asia or Africa. This island with its inhabitants was said to have disappeared in a convulsion of nature.

As geographic knowledge and literature took their rise through extensive commerce and the founding of colonies, the geographic horizon became enlarged, and the necessity of utilizing the knowledge acquired for the purpose of discovering the form and constitution of the earth was apparent.

To Aristotle (B. C. 384–322) is given the distinction of founding scientific geography. He demonstrated the theory of a spherical earth although the idea is credited to Thales who preceded him by several centuries. The latter was probably the first who looked for a physical origin of the world instead of relying upon mythology.

To Eratosthenes (B. C. 276–196), the keeper of the library at Alexandria, Egypt, we are indebted for the first serious attempt to determine the circumference of the earth. His method consisted in comparing the length of a north-and-south arc in linear units with the angular equivalent determined from a difference in latitude. His result is stated to have been remarkably accurate but unfortunately it was not accepted by later geographers. This method of using meridional arcs was employed until about the middle of the nineteenth century when the invention of telegraphy made possible the determination of differences in longitude with an accuracy comparable to that of difference in latitude and thus removed the necessity of confining geodetic operations to arcs of the meridian.

NOTE.—The telegraphic method of determining differences of longitude was originated by the Coast Survey in 1846, two years after the first transmission of telegraphic messages over wires. During the long interval since that time the method has gradually been brought to its present high state of perfection. For a historical note on this subject see Appendix No. 2, U. S. Coast and Geodetic Survey Report for 1897, pp. 202–203.

In June, 1922, the U. S. Coast and Geodetic Survey made its first field longitude determination by means of the radio method. The Bureau has used this method exclusively since that time because it gives high accuracy at low cost with almost complete freedom in the choice of station locations. Radio time signals are also used in astronomical determinations of azimuth as they take the place of the local astronomical time determinations which were formerly required.

Mathematical cartography is indebted largely to Hipparchus (ca. B. C. 160–120), the mathematician and founder of scientific astronomy, who placed it on a firmer basis and applied astronomic methods to mark the position of places on the earth's surface. He is also recorded as having invented trigonometry and as having devised the stereographic and orthographic projections for maps. In mathematical cartography he has therefore a direct appeal as being one of the pioneers of the science and the one person who gave us the first solution for the development of the earth's surface upon a plane.

Although Strabo (ca. 50 B. C.–A. D. 24) in a way set the pattern for geographers to follow, it is to Ptolemy (Claudius Ptolámaeus, A. D. 87–150), however, that we are indebted more than any one else for having concentrated in his *Geographia* the sum of all geographic learning.

Although he derived much of his knowledge from Marinus of Tyre who closely preceded him, Ptolemy is the one outstanding figure in early map-making. He devoted himself first to the mathematical branch of the subject and later embodied in his *Geographia* a catalogue of places arranged according to their geographic positions, including in his work the principles for the scientific construction of maps. It is believed that the original work was accompanied with maps because they are referred to in his eighth book. It is also known that maps actually delineated according to his books appeared a century or more later.

Thence, Ptolemy's work passed across the middle ages without notice of its existence. Its discovery and translation from the Greek original into Latin by Angelus in 1409 appeared in print in 1475 when it exercised a dominating influence upon geographic ideas, and formed the starting point of the science in modern times.

As the *Principia*, in which Newton formulated the first principles of mechanics, furnished the solid basis for his school of science, so perhaps to a less extent, the *Geographia* of Ptolemy served as a groundwork for future cartographers and cosmographical science.

During the long period between Ptolemy's original contributions and the subsequent revival and embodiment of his knowledge in the fifteenth and sixteenth centuries in maps drawn on the basis of his *Geographia*, and in the atlases then bearing his name, the knowledge of the earth's globularity became obscured, and popular belief prevailed again in the flat or disc theory of the earth. The few examples of opinion expressed in maps and literature indicate a rather grostesque distortion of facts with a considerable admixture of fable and fancy in regard to the features of the earth's surface.

The Middle Ages saw geographic knowledge die out in Christendom though it retained through the Arabic translations of Ptolemy a certain vitality in Islam. The verbal interpretation of Scripture led Lactantius (*ca.* A. D. 320) and other ecclesiastics to denounce the spherical theory of the earth has heretical.—Encyclopaedia Brittanica.

Preceding the Ptolemaic revival and extending through it, we should not fail to notice a period of certain improved cartographic contributions known as the *Portolan Charts* (*ca.* 1300–1550). These were the product of Italian and Catalan chart makers. They came into being with the introduction of the nautical compass and were primarily intended for navigators. They were compiled from the exploratory surveys of the time, carrying loxodromic (rhumb) lines, notes, and descriptions. No projection was used on these charts, but the coasts of the various countries were drawn from the viewpoint of correct relations as based on bearings and distances actually run between points, the charts being to all intents mercatorial.

The first known reference to the properties of the magnetic needle is found in 1187, and the compass was doubtless in existence in a primitive form earlier than the thirteenth century. Notable improvements were introduced by Peregrinus in 1269, and by others in the following years. With a reasonable assurance of a safe return, navigators were now enabled to venture out of sight of known landmarks, thus making practicable the exploration of the seas.

It is no longer believed that Columbus discovered the variation of the magnetic needle from true north, as there is strong evidence that makers of sundials in Germany as early as 1450 had access to such knowledge and modified their instruments appropriately, and that certain maps containing such information were published about 1492. An early map on which the variation appeared was one of Palestine in 1532. This feature of so much navigational value apparently was not applied to a marine chart before 1595.

MODERN CARTOGRAPHY

The acquisitions to knowledge of the world through the voyages of Marco Polo and the increasing trade to the east, the invention of printing in the fifteenth century, the discovery of America by Columbus, the voyages by Magellan and others, the correction of the prevailing system of astronomy by Copernicus—all contributed to the new era of map-making in the fifteenth and the beginning of the sixteenth centuries, and from them followed an orgy of cartography for 200 years. There were the German and Italian schools of the sixteenth century; then came the Dutch and Flemish schools of the sixteenth and seventeenth centuries as represented by Mercator, Ortelius, Hondius, Blaeu, and Janson. The French school and the English school closely followed these.

During the period from the middle of the sixteenth to the beginning of the eighteenth century the decoration and coloring were done by experts; indeed, for a long time this was a regular profession developing into something highly artistic and ornamental. There are examples in which as much space is given to marginal embellishment as for actual delineation of cartographic material, thus adding much to the beauty of the maps of the period. This ingenious device, however, often served as a vehicle for masking the insufficiency of geographic knowledge.

GERARDUS MERCATOR

Gerhard Krämer, better known by his Latin surname Mercator, is by far the foremost in the development of modern cartography. He was born in Flanders in 1512 and was a graduate of the University of Louvain. With an exceptional talent he devoted his life to the betterment of maps, improving and formulating a new device in their mathematical framework, abolishing much of the old symbolism and eliminating unsuited detail. The first known map bearing Mercator's name is a map of the world in 1538 on an equal-area projection. Another world map in 1569, on the projection which is named after him, appeared as an original creation and made him famous, transmitting his name to future time. It was the first projection in which the meridians are straight and equally spaced parallel lines and, at right angles to them, the parallels are straight parallel lines, "their distances apart increasing towards each pole in proportion to the lengthening of the parallels with reference to the equator."[2a] This system is now universally employed for nautical charts, and will be so as long as ships sail the loxodrome.

It has been stated that Mercator's nautical chart stands alone in map history, isolated from his many other works, as a violent departure and pronounced improvement over methods existing before that time. In contemporary judgment he was styled as "*in cosmographia longe primus*," and he was the chief of his generation in putting in order the accumulating stores of geographic facts.

ORTELIUS

Ortelius was a contemporary and friendly rival of Mercator, and next to him stands as the greatest geographer of his period. His *Theatrum Orbis Terrarum* issued in 1570, was the first modern atlas,[3] or rather the first systematic series of maps in engraved form after a long period of mostly individual and developmental efforts. He was assisted in this venture, it is said, by Mercator who in the meantime withheld his own collection from publication.

The surveys of precision and the more exact scientific knowledge of later centuries have offered less scope for the propensity to fill in blank spaces and disguise geographic poverty with a drapery of

---

[2a] Quotation from Mercator. Original text in Latin.

[3] The first use of the word *Atlas* as applied to a collection of maps is due to Mercator who adopted it from the Greek mythology and gave it a place in cartographic nomenclature.

the decorative art. The effect of the wild beasts, marine monsters, and impassable marshes which occupied the blank spaces of the maps of the earlier period was expressed by Jonathan Swift in the lines:

> So geographers in Afric maps, with savage pictures fill their gaps,
> and o'er unhabitable downs place elephants for want of towns.

With the advance of cartography as a science, its opportunities as an art have in many respects suffered a decline in not permitting that freedom for impromptu compositions enjoyed by the engraver and decorator of the classic period of Ortelius and his contemporaries. Improvements have been noteworthy, not only in methods of survey and methods of projection, but new methods of expression, either by conventional signs or by the medium of color, have played a conspicuous part in this field of progress.

CARTOGRAPHIC DEVELOPMENTS

Among the useful devices in surveying, the introduction of the planetable deserves notice. This instrument, uniquely adapted to the rapid delineation of topography, dates back, in an early stage of development, at least to 1512. It is also certain that the Romans made use of an instrument not unlike the planetable. During the sixteenth century the instrument was variously described. Subsequent improvements by Leonhard Zubler of Zürich in 1607, by William Leybourn (1626–ca. 1700), and again by P. M. N. Benoît (1791–18—) have brought the planetable essentially to its present form.

The telemeter, as an important adjunct to the planetable, was brought to notice in the Coast Survey Report for 1865. It had been introduced about that time and was found to be "a facile and useful substitute" for the chain as a measuring instrument under certain conditions. Later improvements have made it indispensable in topographic field work.

The sextant, useful alike to the astronomer, navigator, and hydrographer, after successive improvements came into general use about the beginning of the eighteenth century.

Among the methods of topographical expression, contour lines have been of material value in the representation of the third dimension. They were first introduced in connection with sea-bed soundings by the Dutch surveyor Cruquius in 1729. Their use as applied to surface forms in topography was first suggested by Laplace in 1816, and they have since been the medium for the more precise expression of certain physical conditions. An adaptation of the same idea is seen in the mapping of isotherms as introduced by Humboldt in 1817, and in the linear representation of certain magnetic elements.

In various ways, by use of symbols, shading, or other graphic representation, a more comprehensive view than was formerly possible can be given for forces and movements of different kinds as, for instance, in weather maps or oceanographic charts. Extending this procedure, we can, by use of colors, chart the successive stages of various changing conditions.

Further improvements may be expected in a clearer and more harmonious understanding by map-producing agencies of the use of conventional symbols, and in the treatment of outline and relief through the use of colors. Variations of color and the use of layer coloring and shading are now playing an important part for representing different features on the map. The pictorial process thus available offers a substitute for descriptive writing. By utilizing contours and depth curves for the placement of a layer system of tints, the effect of relief can be obtained in hypsometrically and bathymetrically colored charts.

The modern use of color, however, imposes more care upon the cartographer in the design of the map than when he is dealing with black and white, and the successful use of several colors can not be obtained by the careless flinging of one color adjacent to or upon another. The maxim applied to art applies equally to cartography: "He who does not go for beauty seeks the mystery of art in vain." Qualifying the above statement, however, we must recognize instances where the brilliancy of severe effect may be desired in order to stress important features and where sharp distinction can be obtained only through a combination of tones which are not perfectly harmonious.

As in musical composition we may obtain, by the employment of dissonance, a desired effect or clash, such effect is after all accomplished only through the careful design by the artist composer. In color selection likewise, when departure from consonance is desired for special reasons, the needed contrast should be effected through careful design and avoidance of results that are amateurish.

NOMENCLATURE

The adoption of the spelling of the names of cities of foreign countries in conformity with the usage prevailing in the countries themselves, as far as Latin characters will permit, may well be considered as another forward movement in world mapping. The more familiar anglicized name as derived from general history and literature in desirable instances is now placed parenthetically below or following the local form.

The retention of the name of a foreign country as it is known to us has an undisputed advantage and is observed in general practice, but for facilitating mail, commerce, and travel, the distinction between the name of a foreign country on the one hand and its towns and geographic features on the other, has a significance that cannot be disregarded. The American tourist or letter mail leaves for Italy, not Italia, but when once in the country of destination, the towns of interest are not locally recognized in their anglicized forms. Corruption in names had its origin in periods of the past when education was not up to the general standard of today, and for this reason maps can serve a most useful purpose in the growing intercourse of countries by clearing up some of these mysteries of nomenclature.

Closer attention has been given in recent years to the art of lettering maps by the use of special types for different features. The use of variations in roman and italic or light block letters as designed for the better presses, has contributed both to the classification of unrelated groups of material, and to the artistic effect of the map or chart. The placing of names becomes a study in itself and a name should be so pictured as to be readily visualized and no search required to pick up the whole of it. Interest in lettering (see p. 76) and improvement in style should always be fostered, as they contribute in no small way to the usefulness and artistic appearance of the map.

The map being both pictorial, as representing a surface, and scriptorial, as representing the written details and explanations, the cartographer's product calls for a combination of picture and book.

PROCESS OF REPRODUCTION

As wood-engraving, copperplate engraving, lithography, and photolithography have been developed and each in turn has served its purpose, so the new process of reproduction by photolithography from aluminum plates is at the present day coming more generally into use, either as a process in itself, or in connection with the reproduction of copper engraving. It is not because this new process as an art is equal or superior to engraving on copper, but as a matter of expediting production and decreasing distortion, it has succeeded others. It is doubtful if any modern process can ever match the work of some of the old engravers (see figs. 6, 7, 8, 29), whose delicate touch and medium of expression attained the highest degree of beauty in graphic art. At its highest stage of development, black was really black and the number of impressions from a plate was limited. But is there anything in art more distressing than a worn-out copperplate? And, if the plates of the vignettes of the French engraver Ficquet permitted but six or even a lesser number of impressions, one can readily explain the illegibility of some of the old charts where too many impressions were pulled before new printing plates by means of altos and bassos became available. In some instances too, where repeated corrections were made in any one place, plates were worn thin even to the point of actually cracking. In some establishments the face of the printing plate is protected by an electrolytic deposit of chomium, in order to minimize this constant wearing of the surface and thus retain sharpness of line.

In the new aluminum process the large amendments are prepared on glass negatives, and it becomes a simple matter to assemble the sections required for a new printing plate. Aluminum plates have been used to the extent of 25,000 or more impressions, all equally good.

In the utilitarian tendencies of the present day, that method of reproduction is best which expedites publication, lowers the cost, retains clearness and legibility, and reduces distortion in the printed chart to a minimum. Consideration of this subject is given under the caption *Reproduction*, page 37.

INSTRUMENTS AND METHODS

Mention should here be made of recent developments in supplying cartographic material as brought about by new instruments.

In many early surveys the horizontal and vertical controls were defective, or at least inadequate when judged by our present standards and requirements. Improved instruments and methods have made it practicable to execute the field work more rapidly and more accurately. The development of marvelous computing machines has made it possible to solve intricate mathematical problems in adjustment of control which would have been well-nigh impossible with older methods. The adoption of a uniform datum by Canada, Mexico, and the United States marks an epoch in geodetic surveying. Similar action among other nations would be desirable and would eliminate one of the problems of the cartographer in adjusting surveys by different governments each still operating under its own system of control.

A few years ago a readjustment of the network of triangulation of the United States and Alaska was made, and the name of the datum was changed from *North American datum* to *North American datum of 1927*. This datum is determined by the position of the station Meades Ranch, Kans., and by the Laplace azimuths throughout the network of first-order control. If a station has its position determined by a continuous computation from Meades Ranch and based upon the readjustment of the net, it is said to be on the North American datum of 1927.

Hydrographic surveying also has made wonderful strides. In the execution of the earlier hydrographic surveys only sailing craft or pulling boats were available and the quality of the work suffered accordingly, especially in point of completeness. Modern methods applied to field operations and continuous refinement in apparatus have brought about results both qualitative and quantitative in their scope. Soundings in shoal water and in ocean depths are obtained with a facility and an accuracy impossible in the early days. The use of echo-sounding methods makes it simpler to measure sea depths than land elevations and in addition gives a reasonably true profile of the bottom. A sounding which formerly took hours can now be obtained in an instant. In the coming years we may expect extensive contributions to our knowledge of sub-oceanic relief and oceanography, a cartographic field which, up to this time, has been conspicuous for its paucity of information. By the use of the wire drag[4] certain important critical depths which were little better than matters of surmise as formerly determined now become established facts with less effort than would be required by the uncertain method of groping with the lead line.

The problem of determining the exact position of an ascertained depth has been in practice rather complex and difficult. A recent letter from a field party states that the leadsman while feeling with the hand lead for the least depth over a rock covered by 2 fathoms of water found 12 fathoms depth when he moved his hand 2 feet horizontally. In recent years means have been perfected which promise to overcome former crudities and to revolutionize offshore work in this respect. Determination of position, whether by means

---

[4] The wire drag as developed by the Coast and Geodetic Survey consists of a wire maintained in a horizontal position at any desired depth by means of weights suspended by cables from floating buoys and by floats attached to the wire at regular intervals. A proper tension is then placed on the wire when towing. The upright cables are wound on drums on the tops of the buoys, so that the depth of the wire can be changed as desired.

The wire drag is towed by a vessel at each end and will catch on any obstruction extending above the depth at which it is set. Upon meeting an obstruction the drag at once indicates the strike and points out the location, the position being shown by the line-up of the buoys between the obstruction and the launches. A detailed examination is then made by the surveying party.

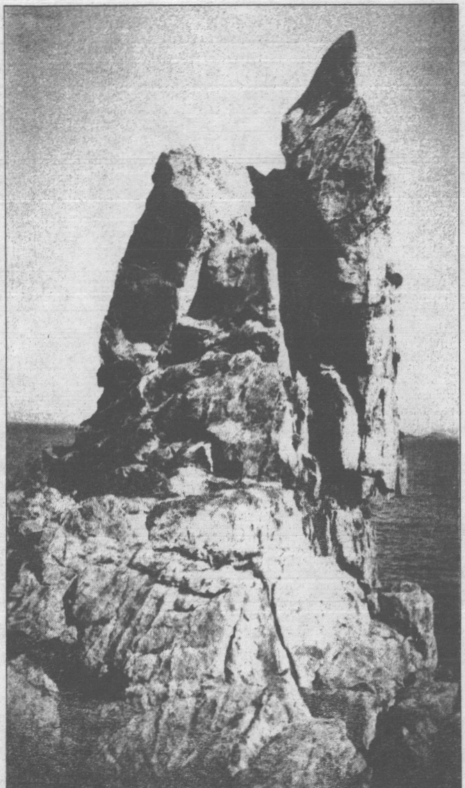


FIGURE 1. — FINGER ROCK, SITKA SOUND, ALASKA.

Northern end of Torsa Island, Sitka Sound, Alaska.
Approx. latitude 56° 51!1 N.; longitude 135° 25!7 W.

Photograph by U. S. Coast and Geodetic Survey.

Pinnacle Rocks of this character, covered by a few feet of water, are common in this locality.

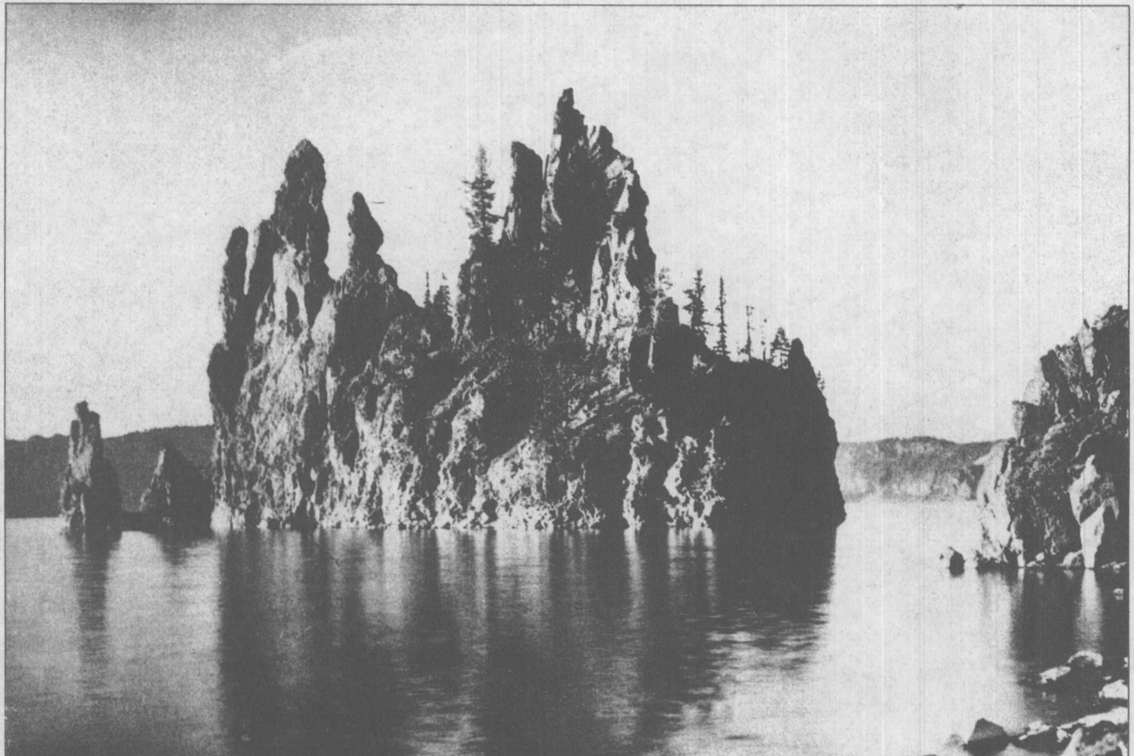


Figure 2.— PHANTOM SHIP, CRATER LAKE, OREG.

Submerged menaces to navigation similar to the above group of pinnacles have been discovered by wire-drag surveys and their positions accurately charted.

of fixed signals, navigationally by dead reckoning [5] or astronomic observations, or by radio acoustic ranging method, has attained a degree of precision formerly unknown.

The radio acoustic method of position finding has been used successfully in the offshore work of the United States Coast and Geodetic Survey. In one test run of over 180 nautical miles directly off the coast of Oregon, consistent distance measurements were obtained during the entire course. Radio acoustic ranging thus enables us to determine positions at sea beyond the visibility of shore signals and has superseded dead reckoning and astronomic locations, and even positions by fixed signals where weather conditions affect the visibility.

On the Atlantic coast, where comparatively shoal water extends well off shore, it has been found advantageous to supplement radio acoustic ranging with the taut-wire apparatus for establishing control. This apparatus, of British manufacture has been used economically and successfully by the United States Coast and Geodetic Survey in establishing traverse loops in lieu of the quadrilateral system of triangulation by radio acoustic ranging. For description, see Chapter 4, Sp. Pub. No. 143, Coast and Geodetic Survey, revised 1942 edition.

Radio time signals for astronomic work, the use of current meters, anemometers and carefully rated patent logs in connection with dead-reckoning work, and the use of anchored signals at great distances from shore, have converted hitherto unsatisfactory processes into something approaching an exact science, and have made it necessary to move depth curves by as much as 5 miles from their previously determined dead-reckoning locations.

In topographic surveying, aerial photography promises to revolutionize methods. A great advance has been made from the earlier stage of rough mosaics, and topographic maps can now be made by aerial photography which are true to scale and which show the relief by contours at any desired interval. Aerial photographs contain a wealth of information which taxes the ingenuity of the cartographer to select the essentials and yet use the material to the fullest advantage.

The development of these new methods introduces new problems for the cartographer. The use of the wire drag brings up the question of indicating channels thus verified; the use of echo-sounding methods requires a careful scrutiny of the results and has brought up the question (considered by the International Hydrographic Conference) of the depth unit to be used on charts. The various uses and tests to which maps and charts are now subjected, the new instruments and devices employed in aerial and nautical surveys, a more extended use of the decimal system—all these and future problems make catography an attractive field for simplification and progress both as a science and as an art.

---

[5] When impossible to obtain the position of a ship by any other means, it is computed or plotted from the last determined position, using the compass courses and distances run by log, and allowing for effects of current and wind. Positions and distances thus obtained are subject to error because of uncertainties of the elements involved. Determination of position in this way is termed "dead reckoning."

Chapter II.—CLASSIFICATION AND ANALYSIS

USE OF MAPS FOR PHYSIOGRAPHIC STUDIES

As cultural features are controlled by favorable topographic and hydrographic configuration, so a good map in presenting different phases of surface and geologic structure will serve important purposes in economic enterprises. The appearance of dunes from wind-blown sand, the presence of marshes, and the paucity of streams without valleys have their characteristic significance, and if properly portrayed in the map the latter will be much more useful to the geologist and the physiographer than would otherwise be the case.

Maps are again useful in the representation of physiographic conditions of localities where a river with its alluvial load meanders widely over the adjacent flats, as in the lower Missouri, Arkansas, and Mississippi Rivers. Here the impeded current produces curves so pronounced that cut-offs are always imminent. The current cuts in on both sides of the narrow necks of land so that when any one of the latter is separated, the river will abandon the loop for a more direct course. The river choked with sediment eventually reaches the sea through a complex network of channels. New deposition of material modifies the alluvial fans of an already existing delta. Frequent surveys and maps illustrating the ever-varying conditions of such areas are necessary in order to formulate methods of regulation.

THE EVOLUTION OF SHORE FORMS

Comparative maps are an important tool in the search for the laws governing the evolution of shore forms. They help us to ascertain and measure fundamental conditions, and to devise methods for checking the encroachment of the sea upon improved properties. A record of successive changes brought about by wave and storm action contributes to our knowledge of this hidden evolution, the extent of the various attacking forces, and the resisting power which the shores offer. Such a record reveals the probable sources of the erosional material carried and the side of its eventual deposition.

Nature's process in forming the coast line is complex, depending upon the configuration of a locality and the activity of the elements. The incessant attack of the sea upon points of land projecting into the water, cuts away material which is transported to other places and deposited as accretions to existing forms or as contributions to the formation of shoals and bars. The forces contributing to this evolution of shore forms are the action and interaction of winds, waves, tides, and currents upon easily eroded beaches. In this process of erosion the material gathered and transported from neighboring places or the bottom of the sea, requires a new distribution. Natural forces thus working in variety and effectiveness upon inlets through sand formation create a constantly shifting arrangement of channels or, as is frequently the case, the migration, opening, or closing of an inlet and a readjustment of shore forms.

In localities where there is little drainage into coastal bays and where tidal currents are not sufficiently strong, coastal bars formed by wave and current action may eventually close up the entrances, thus shutting in the water bodies and converting bays into lakes or lagoons. The continuation of this process results in the formation of a new and regular coast line. In other cases of shore development, the bars and adjacent coastal features suffer simultaneous recession due to the destructive forces of wave action; associated lagoons become contracted or completely extinguished and the new shore line eventually reaches the intial inner shore line resulting, in its mature stage, in a more simple pattern.

This brief statement on shore processes and development is but a suggestion of the scope and significance of the subject which has an important bearing on the protection of our beaches. The general history and discussions of the shore cycle has become the subject of careful study which will lead to a better understanding of the phenomena of the terrain and the sea, and their bearing on the problems of the engineer.

GEOLOGY AND GEOLOGICAL CHARACTERISTICS

There rolls the deep where grew the tree;
  O, Earth what changes thou hast seen!
There where the long street roars, hath been
  The stillness of the central sea.

The hills are shadows, and they flow
  From form to form and nothing stands,
They melt like mists the solid lands,
  Like clouds they shape themselves and go.

—*Tennyson.*

Geology may be regarded as a related and contributing science to geography and cartography. Historical data and the development of physiographic expression as derived from geological facts are enlarged in their spheres of significance when pictorially presented in cartographic form. Through a knowledge of geology, maps will offer their readers more accurate information either of an incidental or essential nature; maps will enable them to follow clearly the evolution of certain phenomena through the geographical and technographical changes, and will suggest possible repercussions on modern life. As a frontier science in various ways, geology thus lends expression and usefulness to the interpretation of form and structure as a fundamental part of the map and chart. Geology, in past years largely confined to studies of land areas above water, is on the threshold of a wealth of material to be supplied by recent developments in echo sounding which will provide a picture of the hidden under-seas areas. The cartographer who is cognizant of the whims of Nature as found in her sculpture of mountains, streams, and coasts, is thereby better qualified to portray these features in map form.

In the following quotation from *Earth Features and their Meaning* by William Herbert Hobbs, certain geological movements and characteristics are so beautifully expressed that it would be useless to state them otherwise:

Man is ever prone to emphasize the importance of apparent facts to the disadvantage of those less clearly revealed though equally potent. The ancient notion of the *terra firma*, the safe and solid ground, arose because of its contrast with the far more mobile bodies of water; but this illusion is quickly dispelled with the sudden quaking of the ground. Experience has clearly shown that, both upon and beneath the earth's surface, chemical and physical changes are going on, subject to but little interruption. "The hills rock-ribbed and ancient as the sun" is a poetical metaphor; for the Himalayas, the loftiest mountains on the globe, were, to speak in geological terms, raised from the sea but yesterday. Even today they are pushing up their heads, only to be relentlessly planed down through the action of the atmosphere, of ice, and of running water. Even more than has generally been supposed, the earth suffers change. Often within the space of a few seconds, to the accompaniment of a heavy earthquake, many square miles of territory are bodily uplifted, while neighboring areas may be relatively depressed. Thus change, and not stability, is the order of nature.

A fairly correct idea of the form of the bottom of the sea may be conveyed by defining it in general terms as the under-water extension of the land surface. The combined results of a topographic and hydographic survey of a locality serve to establish the close relationship in the character and relief of the two provinces, the land and the sea. These relations are strikingly illustrated in many localities. In order, therefore, to obtain a true picture of nature and an aid in the interpretation of the surveys, a knowledge of the forces which have operated in the past is most useful in a comprehensive study of present physiographic conditions.

We have numerous instances where the movements of ice sheets and glaciers in the Eastern States and Alaska have left detrital material which, in its present-day form, both on land and in the adjacent waters, has peculiar characteristics.

On the coast of Maine, where the work of the ice sheet is recorded in marked featural forms, the unbroken and frequently unmodified under-water extension of these topographic details is a fact vital to the successful hydrographic development of the region. Parts of the moraines of southern New England still persist in the form of tills or boulders, as kames, drumlins, or pot-holes, and are characteristic both of the topography and the adjacent submerged relief. The aggregations of ground moraines, or drift deposited by the ice-sheets, are apt to occur in elongated ridges, called drumlins, which run in the general direction of the rock striation; that is, the path of the ice movement. Drumlins generally, and especially those in the vicinity of Boston, Mass., are beautifully ellipsoidal in configuration, and contours derived from them should be in the form of approximately smooth ellipses, with their longer axes in the direction of ice movement; for example, Orient Heights and Deer Island.

In a survey of Deer Island by two different parties in the same year, the one featured the contours as beautifully symmetrical curves, while the other featured them as irregular and shapeless lines. Although when superimposed the curves of the two surveys were not far from coincidence, yet the topographer who was familiar with geology presented a true picture of nature which was not grasped by the amateur.

The path of glacial movement is well defined in Alaska, where its general direction as observed on land, continues under water, and is picked up by the hydrographic surveys. With a knowledge of this direction, as obtained from the topographic surveys, the experienced hydrographer can look for peaks, knobs, or ridges continuing onward in the adjacent waters. When glaciers advance into water their ends break off and the detached masses float away as icebergs. Many of these bergs, on account of the effect of melting and wave-cutting, lose their equilibrium and are overturned as they float, dropping their earthy debris far beyond the land. Isolated shoals which may seemingly appear as erroneous soundings, frequently owe their origin to glacial movement. The rejection of such soundings from the evidence of surrounding depths in the immediate locality is therefore inadvisable. A knowledge of geology, especially as relating to terminal moraines, the nature of kames with their hillocks and serpentine ridges, their accompanying hollows and troughs, and other attendant phenomena, is essential to a faithful delineation of natural forms.

In comparison with the peaks, mounds, and symmetrical ridges which have their origin in the glacial drift of past ages, we should not fail to notice phenomena of another kind which are due to forces active at the present day. The action and interaction of strong ocean currents due to the configuration of adjacent land masses, as in the waters in the vicinity and eastward of Nantucket Island, Mass., give rise to features which are similar to fluvial deposits but formed in another way. In these localities which are subject to unusual and swift current movements from different directions, we find areas or middle-grounds sometimes more or less stable, and at other times shifting and rapidly changing. Fanlike ridges or finger formations, mounds, and knobs appear under the surface of the sea and assume an importance to be designated with the names of banks and shoals. In the prolongation of the axes of such ridges, or in parellelism, we may look for lesser ridges and peaks detached from the main group. By change in their directions and extent, these forces with their accompanying swirls and encounters, cut new depressions and channels with a consequent translation and transfer of sand accumulations. A periodic examination of such areas rests upon a knowledge and appraisal of these changes, at least insofar as they concern navigational possibilities and dangers.

A cartographer, in compiling a map where sunken dangers are numerous, suspected lesser depths in a locality where a survey indicated 30 feet or more. Suggestion for an examination was made in consequence, and a subsequent detailed survey revealed rocks at a depth of only 11 feet below the surface. Many other instances of this type may be cited where surveys have been inadequate and a knowledge of the geological formation of the surrounding locality was absent either in the original planning of the work or in its execution.

At New York Harbor entrance the submerged gorge of the ancient Hudson has a close relationship to the matured and picturesque palisades of today.

The submarine valleys off the coast of California, before their effective charting, were the cause of steamship disasters. The unknown and unsuspected greater depths obtained there by mariners indicated to them ship's positions remote from the coast and free from nearby danger.

The similarity of topographic to hydrographic relief in many localities is very striking and often the submerged feature is a stronger type than its relative on shore, especially where it has been preserved in its original form from weathering or erosion, transportation or deposition of material by waves, currents, and ice.

The extrusions of fluid rock have been discovered on the bottom of the sea in the form of dikes of an extent perhaps greater than their representatives on land .

On the other hand we find unrelated types of cataclysmic origin, generally due to faulty or volcanic upthrust; also in certain localities we find the work of the coral polyp.

Along the bottoms of fiords vacated by still active glaciers, may be noted the successive pauses of their retreat as marked by well-defined terminal moraines, a detail frequently encountered in the estuaries of Prince William Sound, Alaska.

Yaqutat Bay in Alaska was changed by a single seismic uplift by as much as 47 feet in one place between two adjacent surfaces formerly on the same level. The Bogoslof group has been the scene of repeated volcanic upheavals followed as often by a more or less complete obliteration of the features. On the island of Camiguin, Mindanao Sea, Philippines, a remarkable volcano rose from a level plain in 1871 to a height of about 1,800 feet in four years' time. The summit of the volcano as determined by topographic methods in 1910 was found to be 1,910 feet.

Wave-lifted and current-borne material is adding to and lengthening the beach at Fire Island Inlet and has driven Rockaway Point westward by more than 4 miles since 1835. Wave-lifted and current-borne material has extended the north point of Monomoy Island about 3 miles in 60 years, while at Assateague Anchorage on the coast of Virginia, Fishing Point has moved southward along a curved extension of over 4 statute miles in 66 years, and converted an open bight into a natural harbor or refuge.

Wind-waves and currents have left their impress on the submerged areas of the Central Atlantic States in the formation of new shoals, the movement of old features, and the entire disappearance of others. On the Atlantic and Gulf Coasts there are many examples of entrances opened and others closed during brief storm periods of considerable violence. Other violent and rapid changes are often cyclic in their recurrence.

Among rare and interesting features of perhaps greater importance to the geologist than to the hydrographer are the submarine springs of Florida. A striking example is located about 2½ miles off the Florida coast, between St. Augustine and Matanzas Inlet. The general depth surrounding the spring is 55 feet while in the throat of the spring a sounding of 130 feet has been obtained, but with some difficulty as the outflow from the spring is so great that it is difficult to hold the sounding boat in position, and the up-rush of water through the outlet of the spring doubtless makes it impossible for the lead to reach the bottom. The flow is such that the surface of the water appears to be higher over the spring, and fresh water can be recognized readily even in rough weather although the surrounding water of the Gulf Stream is of a high degree of salinity. At the bottom of the spring there are stones, live shells, and yellow clay, the surrounding bottom being mud and sand.

Another example is at Tarpon Springs, Fla. At the head of an arm of the Anclote River, which is a tidal estuary, having a general depth of 2 to 4 feet, there is a submarine spring in which a sounding of 125 feet has been taken. The outflow from the spring is sufficient to exclude the salt water of the Gulf from the arm.

Near the entrance to Sabine Pass there are persistent oil spots or slicks. The oil-covered areas are several miles offshore and are used as a refuge by shipping under stress of weather as there is never a break within their limits. Similar spots have been reported offshore in this general locality along the coasts of Louisiana and Texas.

Hydrographic surveys and explorations have thus in many ways extended the field of the geologist beyond the confines of the shore and have established the close relationship and frequently even the common cause and identity of effect between the agencies and their resulting forms.

Much additional work is still needed to cover the highly diversified continental shelf of varying width and generally of moderate depth and slope terminating in a more or less marked escarpment descending to oceanic depths.

In recent years, with the help of radio acoustic ranging and echo soundings, hydrograhic surveys have been extended beyond the Atlantic continental shelf, and a number of old stream valleys have been revealed on the steep slope of the shelf. One of these valleys east of Chesapeake Bay has been traced out to general depths of about 1,500 fathoms.

These valleys and the general topography of the slope indicate subaerial erosion, and a better knowledge of these conditions will have considerable effect upon existing geological theories. As to the extensive profound basins of the oceans very little has as yet been accomplished in the delineation of subaqueous ridges and valleys marked by peaks and canyons as in subaerial relief.

MISSISSIPPI RIVER

The Mississippi River with its drainage basin estimated at 1¼ million square miles presents no unusual features in its upper courses but has certain marked characteristics as it traverses its flood plain. The alluvial deposit in the lower section above New Orleans is estimated at 40 to 50 feet of depth above the quaternary bed and is adapted to relatively easy cutting or erosion.

With the lesser gradient here imposed upon it, the river meanders over the plain in its diminished velocity. When the sediment or detrital material supplied to a stream is less than its capacity and the bed is alluvial, the stream scours out its bed; when the supply of sediment exceeds the capacity of a stream, the bed formation is not reached by the current and, in the case of the Mississippi River during flood period, the stream's capacity becomes overtaxed and deposition occurs. Under these conditions if the general slope descended by an alluvial stream is relatively gentle and if its flow is through fine alluvium, the stream will meander in an intricate manner.

It has been stated that a free stream does not tolerate a straight channel, and if a straight channel of moderate width be given to a stream the current will swing rhythmically to the right and left, and, if the banks yield, will develop meanders. This rhythmic condition may have its origin in the current's constant pursuit of points of least resistance as brought about by the lack of homogeneity in the river's banks, irregularity of its bed, or wind-waves.

The current of a stream may attain a velocity where it is more than a transporting force and becomes a detaching force; and, when some portion of a river's bank a little softer than the rest is excavated the current will be deflected obliquely to the other side which will be similarly excavated. Thus curves will be initiated, and with erosion progressing where the current impinges on the outer or concave side of the curves, deposition will take place in like proportion to build up the point on the inner or convex side where the current is slowest.

When sinuosities are thus introduced in a medium that is sufficiently yielding, they tend to increase in an effort to establish an equilibrium between the erosive forces of the current and the resistance of the confining stream bed or banks. The effort to arrive at a final equilibrium means merely a further development of sinuosities. The meanders thus created will then migrate rhythmically according to laws of their own, and bars are fixed according to the meanders.

Frequently the erosive forces[1] of the stream succeed in cutting through the narrow necks between contiguous loops, causing the latter to run into each other and the river to break through. A cut-off is then formed and the old loop is abandoned for a direct channel. The resultant course, however, is not due to an effort to establish an increased gradient but is incidental to the extension of the windings of the river and their final encroachment upon one another.

The crescent-shaped lakes or lagoons which are thus thrown off are common in the flood plains and swamps of great rivers. They are the old or abandoned river beds which in time become more or less silted. In the reaches below Baton Rouge, the river by artificial aid holds its channel in a less tortuous course, and at places above and below New Orleans, attains depths of as much as 226[2] and 193 feet, respectively, in its narrowest parts, proceeding on to the sea in a channel more nearly straight. The Delta is marked by several passes through which the river reaches the sea. The deposits of river-borne sediment add to the extension of the Delta into the Gulf, where in the past 60 years an area of approximately 100 square miles has been built up above high water.

In the lower Mississippi and other similar localities the forces operating result in physiographic changes. Accurate maps are needed to record the constant changes in the river channel, and to furnish a base upon which plans may be placed for flood control and other improvements.

---

[1] It has been stated by Le Conte that the *erosive power* of water, or its power of overcoming cohesion, varies as the square of the velocity of the current. In this process, the resistance to be overcome is cohesion. On the other hand, the *transporting power* of a current, or the weight of the largest fragment it will carry, varies as the sixth power of the velocity. In this case the resistance to be overcome is weight. In many cases of removal of slightly coherent material the resistance is a mixture of the above-mentioned resistances, and the power of removing material will vary at some rate between V^2 and V^6.

[2] Opposite West Point, N. Y., where the Hudson River is at its narrowest, a depth of 216 feet has been obtained.

THE SHORE OR LITTORAL

The shore or littoral is the zone where two physical provinces meet and where changes of form take place rapidly. It is the end of the visual continent and the beginning of the submerged margin of its seaward extension. It is the theater of tidal action and coastwise currents. In this coastal belt, charts will enable us to visualize what is not seen. Submerged surfaces, rocky pinnacles, and other hidden dangers to navigation will be revealed, and the essential features of channels, bars, spits, and other hydrographic facts will be ascertained.

In view of the great and rapid changes, this comparatively narrow strip is second to none in importance to the navigator, the engineer, and the geographer. Successive topographic and hydrographic surveys serve as records of progressive changes, and are indispensable in the solution of the problems of harbor improvements, channel development and maintenance, shore protection, reclamation projects, and the adjudication of riparian disputes. Changes in configuration are frequently characterized by striking continuity. In other instances again they are characterized by variation or periodic change. In order to comprehend their rate and magnitude, the important laws involved can be arrived at only through a sufficiency of systematic surveys. With accurate and sufficient data the coastal forms and submerged margins of the continent become available for intensive study in natural phenomena and special subjects.

In order to solve the important problems of emergence and subsidence of the coastal regions, precise levels along the coast should be continued to the shoreline, and permanent bench-marks established for eliminating the uncertainty due to tidal planes of reference established by insufficient observations. Such benches will offer advantages in a study of coastal changes, subsidence, or emergence, by their connection with the control system of the interior fast land which is not likely to be affected by such processes, and will furnish valuable reference data for determining variation and periodic changes in our shoreline and the characteristics of such changes. Through a series of continuous or intermittent observations a closer relation of cause and effect may thus be established.

The insufficient material available at the present day for the study of shoreline changes, in many instances defies quantitative analysis. With a precise level datum and progressive surveys, better material will be available for the determination of the extent of these changes and the laws governing them; the intervals for resurveys will be so established that the chart will at no time be misleading. Although occasionally observations and surveys may have relatively little immediate use they have their potential value in the practical problems of a near future, provided they are of standard accuracy and sufficient detail.

THE CONTINENTAL SHELF

This term is generally applied to the belt adjacent to the coast line and not extending beyond the 100-fathom curve. However, in certain sections of the world the undersea extension of the land masses is so gradual that no typical escarpment into the abysmal area of the ocean floor is noticed within 500 fathoms. It is generally the case that where the continental shelf is wide, the coast is flat; and where the shelf is narrow, the coast is bold and rocky, and it follows then that a good bathymetric chart is indicative of the nature of a coast line.

The force of the waves of the sea being most effective in low areas composed of soft material, and inroads become more apparent as large areas are easily modified or annexed. Where the coast line is bold and precipitous the inroads are retarded. In localities of this character, the fragments of rock which are eventually broken off and the particles of loose material are in part carried back by the receding sea, forming more substantial barriers against rapid encroachment than in localities where the material is more easily eroded. The less the resistance of a coast to storm and wave action, the greater the rapidity with which the sea progresses inland and deposits the material within its own domain.

Within the continental shelf certain localities are subject to geologic upheavals and depressions of trench-form. The history of these and their extent are more or less independent of the forces of erosion and sedimentation which have so greatly affected land forms, nor should they be associated with the attacks of sea waves along the coast line.

GEODESY

The geodesist determines the shape and size of the earth and executes the fundamental surveys required for the precise horizontal and vertical location on the earth's surface of certain control points which are used as a basis for the surveys of local areas. Ordinarily his work is done in areas which have not been adequately mapped, for his control surveys must precede the topographic surveys used in making the detail maps. Whatever maps are available, he utilizes to the fullest extent in order to plan his operations as economically as possible. He is often able to tell from a careful study of the maps of a region not only where his triangulation stations and bench marks may be most advantageously placed for future use but also whether contiguous stations as thus located will be intervisible. In this way a more economical reconnaissance is possible.

Good maps also serve the geodesist in certain geophysical investigations such as studies of earth movements in seismic regions and investigations of equilibrium conditions of the earth's crust. In the isostatic reduction for a gravity or deflection-of-the-vertical station the masses of all topographic features surrounding the station, their proximity, and directions are utilized from the best available cartographic information. In this way a more accurate figure of the earth has been determined and a more precise location of geographic positions or control points has been made available to the cartographer.

OCEANOGRAPHY

To the oceanographer the chart serves as a medium for constructing a picture of submarine relief and the location of physical forces operating in the vast expanse of the oceans. The chart enables him to correlate hydrographic investigations as to velocities, direc-

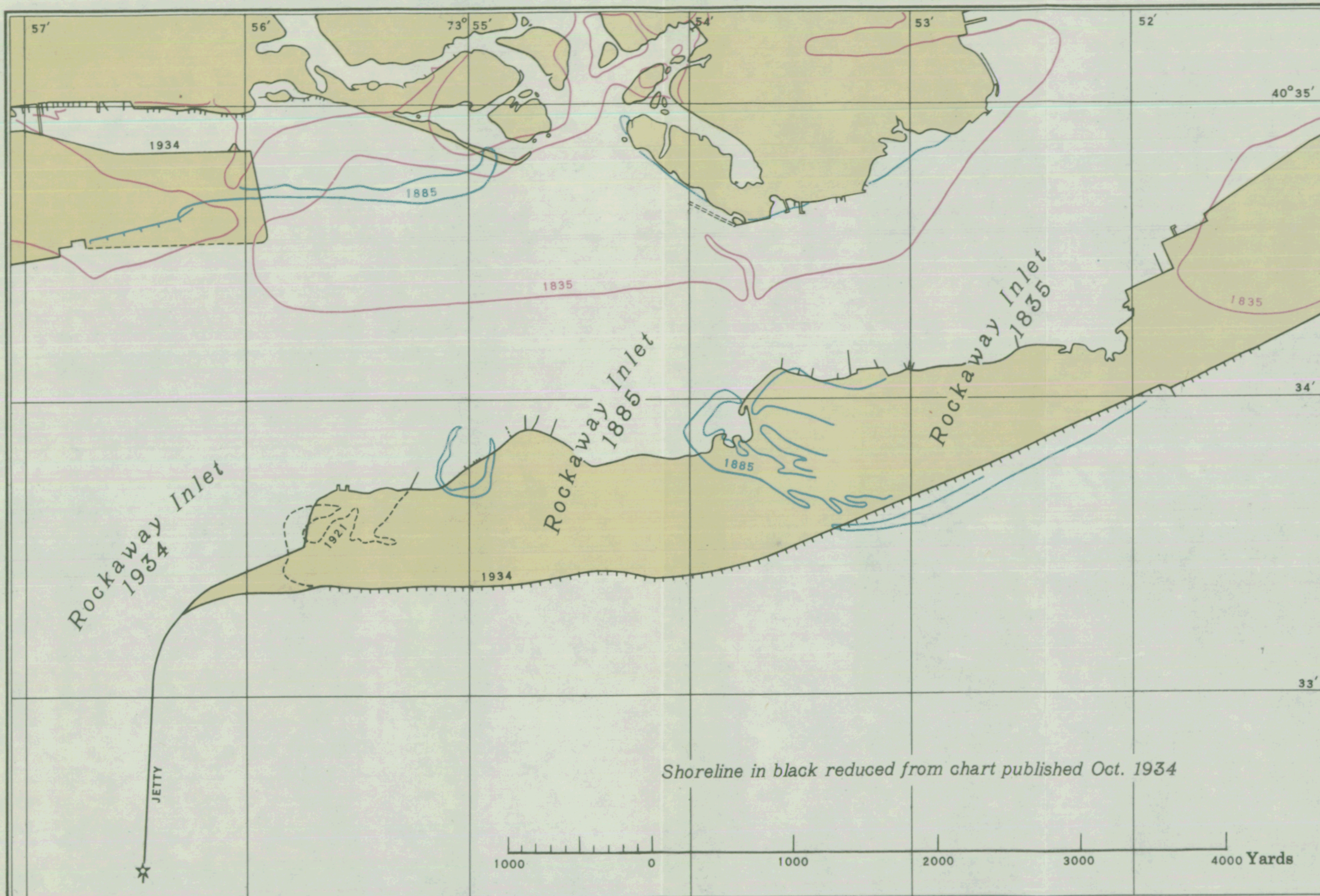


FIGURE 3. — ROCKAWAY INLET, LONG ISLAND, N. Y. — SHORELINE CHANGES, 1835 TO 1934.

The configuration of the Long Island and New Jersey shores of the approaches to New York Harbor is such as to afford the beaches a large measure of protection from attack except from the southeast quadrant. In consequence, we find the beach materials transported westward and northward respectively with a constancy not found in more exposed localities. Between 1835 and 1934 Rockaway Point has grown westward 7300 yards or $4\frac{1}{7}$ statute miles. Since 1921 opposing forces have steadily retarded the westerly migration of Rockaway Point, and farther advance has been checked through natural causes, the construction of training dikes, and the jetty of recent years.

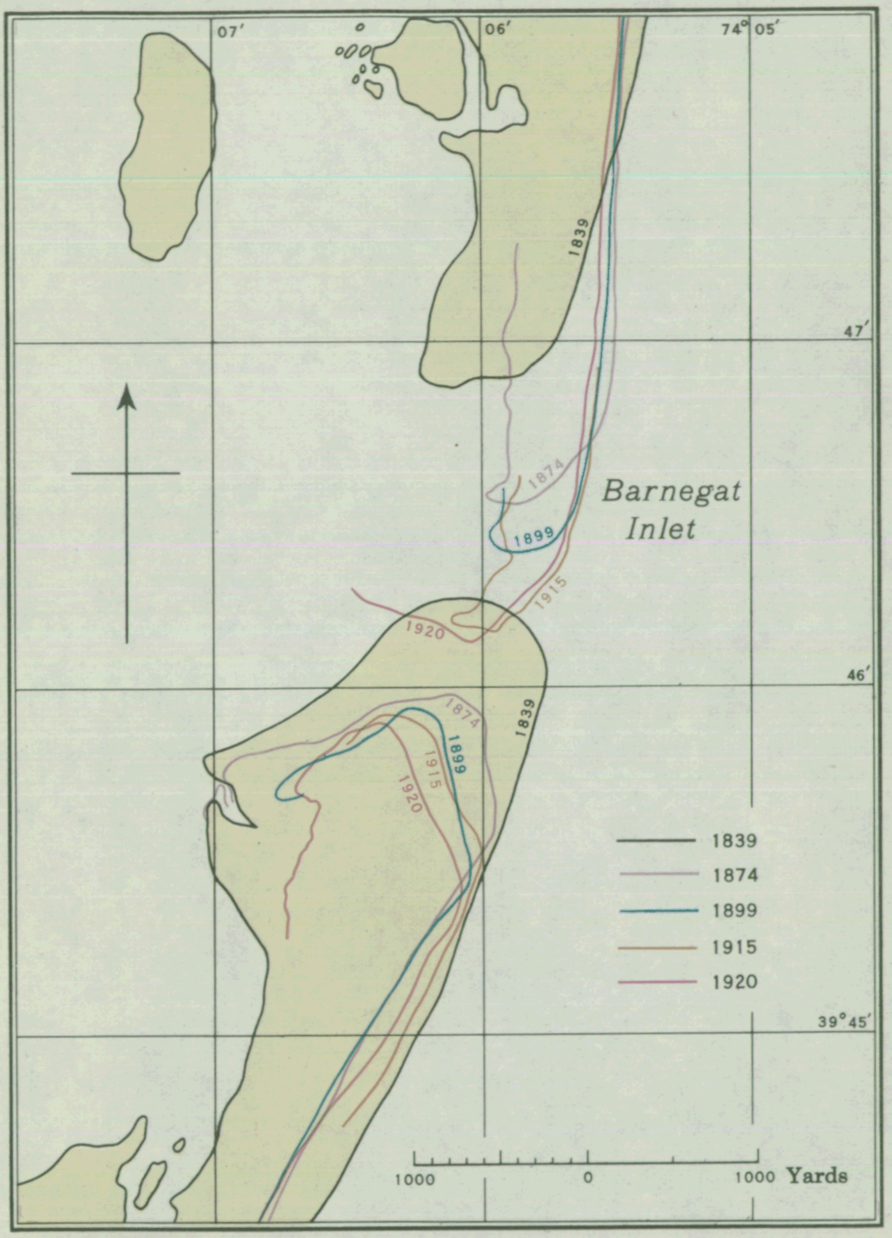


FIGURE 4 — BARNEGAT INLET, N. J. — MIGRATION OF SHORELINE.

Of the twelve inlets indenting the coast of the State, this is the only one whose history suggests a consistent migration in one direction. Various explanations of this anomaly have been advanced; the most probable one being that it is due to certain characteristics of Barnegat Bay rather than to any variation in the nature of the forces attacking from seaward.

tions, and variations of oceanic currents and drift; it enables him to classify the density of sea water, its salinity, chemical characteristics, and temperature. The chart has an economic and commercial value in furnishing a base for the location of banks for the development of fishing industries. The study of pelagic life is simplified, and a better knowledge is acquired of related or associated phenomena connected with accumulations on the ocean bed of myriad remains of microscopic sea life, cosmic dust, and volcanic material. Morainic boulders of submerged glaciated areas, submarine plateaus, and submerged canyons are revealed. Conclusions as to past geologic history are facilitated and phenomena interpreted.

Much attention has been given to the location and the measurement of the elevations of mountains and other physical features of the earth's surface, but until about the middle of the last century, "the bottom of what the sailor calls 'blue water' was as unknown as the interior of the planets of our system," quoting the words of Maury, a pioneer in the investigation of the depths of the ocean. Even at this date, the greater part of the seas and their coasts are as yet unsurveyed and, in consequence, commercial development and possibilities are delayed. Regions of thousands of square miles in extent have not been explored and are virtually unknown, especially is this the case in the Pacific Ocean, Indian Ocean, and the polar seas.

Geophysicists are frequently handicapped in their investigations by the lack of knowledge of the configuration of the ocean bottom. For example, in the course of the investigation of earthquakes, it was noticed that the epicenters of a great many of them occurred off the west coast of Mexico. This fact led to the conclusion that there must be a deep in this area, since it is well known that earthquakes frequently occur in the deeps of the ocean—an assumption which was later verified by soundings made by vessels of the Coast and Geodetic Survey.

The recent gravimetric observations made by the Dutch geodesist, Dr. Meinesz, in a submarine furnished by the United States Navy also showed the need for a more thorough knowledge of subaqueous relief in order to determine the relation between his observations and the depth of the ocean.

These few examples are specific instances in which a knowledge of the depths of the ocean would have been useful in studying problems of the geophysicist, but it is impossible to foretell what new direction a thorough survey might give to investigation, to say nothing of its practical benefits. The first attempts at obtaining the depth of the ocean found immediate practical application in the laying of the submarine telegraph, probably being the deciding factor in the success of the venture, for it is well known that a cable laid without a knowledge of the configuration of the bed of the ocean will not last very long.

To measure the depth of the ocean appears an easy matter, but until the development of the manufacture of piano wire, it was impossible to obtain accurate measurements. As late as 1870, charts of the North Atlantic Ocean showed depths in excess of 6,600 fathoms (39,600 feet) in places where later and more accurate determinations showed only 2,700 fathoms.

Deep sea soundings by direct methods, especially as obtained by early attempts, were frequently in excess of actual depths, the reason being due to several causes among which were: First, the older apparatus did not give a sufficiently definite indication of the plummet's having struck the bottom; second, during the taking of the soundings by the use of silk thread, especially prepared twine, and other materials, the undercurrents of the sea, the ship's drifting with the wind, and the weight of the line exerted enough force to cause bulges in the amount of line that was paid out, so that measured depths were always in excess.

Soundings with piano wire is a tedious operation, as it takes several hours to get a sounding of 4,000 fathoms or more, and, unless the crew is experienced in such work, frequent losses occur from the breaking of the wire, and very deep soundings are subject to the same errors as soundings with twine. By means of echo soundings and the frequency with which they may be obtained, it is possible to secure far more detailed information of the configuration of the ocean bed than by any other method. It is still necessary, however, to use vertical casts for obtaining samples of the bottom, sub-surface temperatures, and water specimens.

Data obtained by untrained observers are seldom of much value, and if all reported soundings and dangers were plotted on the charts, the waters of the ocean would be well nigh unnavigable. The need is for a systematic examination of the oceans by trained officers either of national organizations or scientific agencies.

In April 1927, an ocean depth of 35,410 feet was recorded by the German cruiser *Emden* about 40 miles east of Siargao Island, off the northeast coast of Mindanao, P. I., this being the greatest ocean depth of which we have knowledge at the present day. It exceeds the greatest known land elevation by 6,269 feet. In this trough of the sea, discovered by the German steamer *Planet* in 1912, a depth of 32,113 feet had been obtained 10 miles distant northwesterly from that of the *Emden*.

The renewed activities of the present day in the various branches of oceanography, promise to supply us with a more solid foundation for research as to the form and composition of ocean deeps. In this work the Scripps Institution of Oceanography of the University of California, at La Jolla, Calif., and the Woods Hole Oceanographic Institute are among the foremost organizations in America. The United States Navy and the United States Coast and Geodetic Survey are also contributing valuable data in connection with their hydrographic surveys and investigations.

Many other organizations are contributing and coordinating the data resulting from special investigations in various fields. Among these are the following: Conseil International pour l'Exploration de la Mer, Copenhagen; Svenska Hydrografisk-Biologiska Kommission, Sweden; and the International Hydrographic Bureau, Monaco.

"METEOR" EXPEDITION

One of the most noteworthy events in oceanography in recent years is the contribution of the German *Meteor* expedition which operated in the Atlantic Ocean from April 1925 to June 1927. This expedition was fostered by the *Notgemeinschaft der Deutschenwissenschaft* and the *Marineleitung*, and its investigations covered an immense area of hitherto largely unsurveyed sections in the Atlantic Ocean extending from 20° north latitude to the ice border of the Antarctic near 65° south latitude.

In the 14 east-and-west profiles of the bottom of the sea extending from Africa to South America, 67,400 echo soundings were obtained. The various operations of the expedition supply material of inestimable value to a thorough comprehension of the sea, not only in the configuration and peculiarities of its bottom but also in the physical and chemical properties of its water content and movements. A better knowledge of marine biology is opened up. The quantitative distribution of planktons (applied to animal and plant life that is carried by the water and has no locomotion of its own) has for the first time been ascertained to great depths for purposes of systematic study of the close relationship of biology and oceanography.

From the analysis of the samples of water and sediments so extensively taken along the continuous series of profiles, geology, mineralogy, and chemistry as related sciences, are also enlarged in their scope and kinship. The enormous amount of data collected relative to surface and subsurface conditions of the sea, the dynamics of its currents, its salinity and temperature, the extensive meteorological observations with kites and balloons, are contributions of great and lasting value. A better knowledge of the sea in its relation to, and its influence on, the atmospheric envelope is thus made possible.

The varied operations of the *Meteor* expedition have been so complete and resourceful that it is difficult to decide which branch of the work is the most outstanding. The answer by some would be that the contributions to oceanic circulation are the most useful. However, the results of this expedition are most gratifying in every branch of oceanography, and suggest possibilities of charting the sea with an accuracy almost equal to, and in some respects superior to, the mapping of our continents.

The scientific reports of this expedition will appear in 16 volumes under the direction of Dr. Albert Defant of the Institut für Meereskunde at Berlin.

"CARNEGIE'S" SEVENTH CRUISE

Under the auspices of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, a general magnetic survey of all the oceans had practically been completed in 1921. This comprehensive survey of the oceans together with contemporary magnetic surveys on land furnishes material from which a fairly reliable theory of the magnetism of the earth as a whole may be deduced and correlated with other geophysical phenomena. The program had been planned primarily for obtaining secular-variation data, including at the same time atmospheric-electric and oceanographic investigations. Meteorological observations of wind direction and velocity and the state of weather at sea were obtained in addition to the foregoing.

The elaborate program of the *Carnegie's* seventh cruise under the leadership of Capt. J. P. Ault was begun May 1, 1928.

During this cruise of the *Carnegie* several uncharted submarine ridges and deeps were discovered. This work of deep-sea sounding was accomplished with the sonic depth-finder and comparisons made in many instances by piano wire and pressure-thermometers. In addition to soundings in the North Atlantic a number of important contributions to the configuration of the ocean floor in the Pacific have been announced. About 100 miles off the coast of Ecuador a submarine ridge was discovered in November 1928, and named *Carnegie Ridge.* Samples of bottom showed lava, obsidian, and globigerina-ooze. Another ridge or fold named *Merriam Ridge*, and a deep named the *Bauer Deep* were discovered in the South Pacific in the early part of 1929. The bottom from Callao to Tahiti is reported as very irregular, multiple echoes received indicating at times as many as six surfaces.

During the year 1929, additional knowledge of the ocean bottom was announced in a determination of the slope at Wake Island and in the discovery of *Fleming Deep* in latitude 23°.8 north and longitude 144°.1 east, where a depth of 8650 meters is reported.

At oceanographic stations, calculations of density, dynamic depth, pressure, and specific volume were made for determination of velocities of layers of water. Biological work and chemical studies in the inorganic field are also noted, and it is believed that Cruise VII has yielded much valuable material to enrich many branches of geophysical and oceanographic research which will be of material aid to the cartographer and navigator, especially in regions heretofore unexplored.

On November 29, 1929, in the harbor of Apia, Western Samoa, a gasoline explosion took place, as a result of which Captain Ault lost his life, and the vessel, together with all its instrumental equipment, was destroyed. Thus the extensive program of the last cruise of the *Carnegie*, which up to that time had yielded most valuable contributions to our knowledge of the oceans, was brought to an abrupt termination with about half of the projected cruise completed.

In the general plan of a magnetic survey of the globe and in oceanographic research the nonmagnetic ship *Carnegie* had covered 300,000 nautical miles. Her voyages involved 20 years and her cruises embraced the seven seas.

OTHER EXPEDITIONS

The Dana expedition, 1928–30, was supported by the Carlsberg Foundation, Denmark's largest scientific fund. It included extensive oceanographic observations in the tropical parts of the Pacific and Indian Oceans, and parts of the Atlantic Ocean.

The Snellius expedition, 1929–30, was planned by the Society for Scientific Research in the Dutch colonies, and the Royal Geographic Society of Holland. The field of operations covered the waters of the East Indian Archipelago; 32,000 soundings were taken and a more accurate delineation of the bottom relief was obtained. Geologically, the gravity researches by Vening Meinesz were of interest in showing this to be a region of strong gravity contrasts.

The *Ramapo*, United States Navy, between October 1929 and January 1933, crossed the North Pacific Ocean between latitude 12° and latitude 47°, twenty-five times, recording 15,000 sonic soundings, mostly in uncharted areas.

The Woods Hole Oceanographic Institute, of Woods Hole, Mass., has contributed extensively to physical oceanography. The results of the *Nautilus* expedition in 1931, the research ship *Atlantis*, and the many scientific papers which appear frequently are published by the Massachusetts Insitute of Technology. A joint Harvard and Woods Hole expendition has recently succeeded in taking fossil-bearing rocks at great depths from the cliffs of the North American continental shelf. The evidence seems to confirm the theory that the deep ocean valleys in the shelf were formed by rivers which flowed into the Atlantic before subsidence took place.

CURRENTS

A knowledge of currents is necessary in the execution of hydrographic surveys and in the plotting of field sheets. In strong currents accurate soundings and their location can be obtained with hand-lead or machine only when sounding lines are run parallel with, and in the direction of the current. A better control for surveys based upon dead-reckoning is obtained by applying to the plotted positions of the ship a correction for the set and drift of the current. A knowledge of currents serves as a key in the reading of a map or chart; their graphic record tells a story in the evolution of shore forms and in the study of geologic changes.

As navigation in certain dangerous localities is sometimes hazardous on account of currents, the verification of a ship's position in thick weather, by means of charted soundings, becomes a valuable aid to safety. Unknown currents may set a vessel off course or alter its assumed position along the track. In foggy weather when terrestrial and celestial objects are not visible for fixing positions and when the navigator is unable to make allowance for current effect, charts that are incomplete in this information may lead to disaster.

The existence of an unknown submarine valley northward from one that was charted near Cape Mendocino, Calif., together with a lack of knowledge of local currents, contributed to the stranding of a vessel. By a knowledge of currents the development and maintenance of channels in harbors and harbor improvements is faciltated. Important also is the knowledge of currents on account of their possible effect on the time and fuel required for a voyage and on the maneuvering of a vessel in restricted waters.

SPECIAL PURPOSE MAPS

In addition to the official topographic maps of the prominent nations of the world, considerable geographic interest and activity are displayed in maps which may be classified under the above title. While maps of this class have many characteristics in common, there are in each case special requirements for the uses which they are intended to serve. Among the class of maps which come under the designation of special purpose maps and which today have an importance all their own, are the aeronautical charts.

AERONAUTICAL CHARTS

These charts constitute a practically new development in cartography and their primary object is to provide, in as simple and characteristic form as possible, for the needs of the aviator. These needs include his ready solution of certain problems of direction and distance and a comprehension of intervening terrain at a glance. The features to be stressed are those relevant to his purpose. The airway route must be clearly defined, and prominent landmarks whether natural or otherwise conspicuous, such as the general trend of railways and highways, their intersections, and the positions of industrial landmarks must be clearly shown or emphasized. Sinuosities of streams should be generalized and minor roads and detail that may confuse the aviator should be omitted. Simplicity is desired so that the aviator may grasp at a glance the relative location of the places in which he is interested and which will serve him in maintaining his course.

As aeronautical charts require special consideration of geographic fundamentals, the merits of a suitable system of projection and proper control become significant in respect to facility of laying out courses, fixing features, and measuring distances. Special emphasis by the use of color on prominent landmarks or aids to navigation, and the additional use of color for gradients of elevation serve as a ready means for securing position and orientation. By thus stressing the essentials, the relationship between prominent objects is more clearly visualized.

Aeronautical charts in the United States as constructed by the United States Coast and Geodetic Survey of the Department of Commerce are based on the Lambert conformal conic projection. This system was adopted after careful study of all projections, as offering the best facilities for determining location, direction, and distance— the fundamentals of navigation. For these purposes the advantages offset those of the Mercator system used primarily for laying off courses at sea where landmarks are frequently unavailable. In fact, the aeronautical chart serves a double purpose in that it has, besides its special use, the advantage of a more nearly true scale and a relatively true representation of the terrain and its cultural features, and can be utilized for general purposes.

In the Lambert projection the meridians are straight lines and azimuths are readily laid off. A true course angle is properly measured with the meridian nearest halfway between starting point and destination. Corrections for estimated magnetic variation as shown on the chart and for deviation as given on the compass card of the airplane can then be applied in order to obtain the compass course.

The charts issued by the Department of Commerce are hypsometrically tinted in variations of color for the different gradients and are supplied with a key of conventional signs. The character of the aviation fields is shown by symbol, and the aids to navigation and other necessary details are indicated by symbol and color so as to be readily and adequately interpreted.

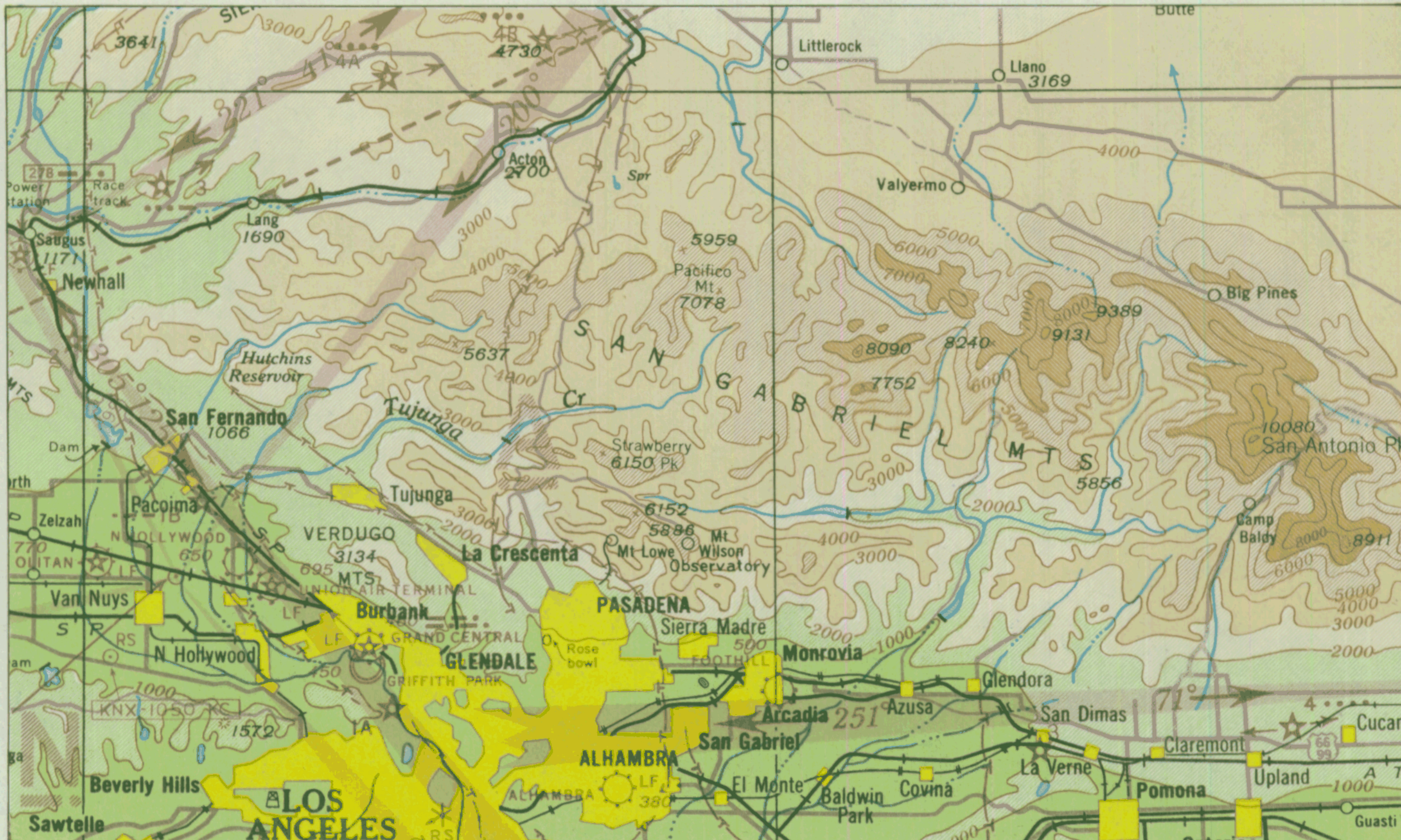


FIGURE 5.— PART OF AERONAUTICAL CHART — LOS ANGELES, CALIF.

Compiled and printed at Washington, D. C. by the Coast and Geodetic Survey.

WEATHER MAPS

The Weather Bureau performs a systematic and continuous service in the interest of agriculture, commerce, marine and air navigation. Through the medium of the electric telegraph, radio, and other forms of communication from various stations, supplemented by reports from other countries and ships at sea, weather maps and other meteorological data become an important adjunct in the use of charts, especially in the maritime interests and in air navigation.

Weather maps, based upon simultaneous observations taken at many places, are issued daily in the United States at the various Weather Bureau offices. In addition, manuscript maps are issued at the airway stations at frequent intervals. The Bureau also enters various data on maps to show progressive changes in weather conditions from day to day and from month to month.

Problems of standardization in base maps, their projection, and symbols, are in many respects similar to those of other cartographic bureaus. A base map of North America has been prepared, which is an extension of one used by the Canadian Meteorological Service and is based upon the Lambert conformal projection with standard parallels at 30° and 60° north latitude. In the problem of arriving at a suitable projection, an equal-area projection may be considered objectionable because shapes of barometric pressure fields would be distorted in moving across the map; on the other hand, on a non-equal-area map, variation in the scale of the area and extent of the pressure fields may be considered equally objectionable.

MAPPING FROM THE AIR

By reason of the economy of time and money, the use of aerial photographs has stimulated a demand for geographic knowledge. Extensive surveys are in progess and are being planned, which, with future development of mapping cameras and of aviation, indicate that it is economically practicable to survey the lands of the earth in much less time than had ever been anticipated. In former methods of surveying, usually by planetable, the mapping was done for the special uses in mind, in the effort to save time and expense, and consequently much information was omitted which might be useful for other purposes.

Modern cameras within a few seconds of time now take photographs which, under a suitable stereoscope, furnish three-dimensional models of sections of the earth's surface. These models may be made available in turn for the cartographer, the engineer, and the scientist. Each specialist can examine the photographs for the particular data that he needs—data not necessarily contained in a general map of the locality.

It is the original record with its unlimited amount of detail, undistorted by biased interpretation, which is the principal advantage of the method. With control established, a later photograph can be taken at small expense, and by comparison with a previous one, the changes in configuration will be easily recognized. In localities undergoing rapid changes, natural or artificial, photographs taken

509014°—43——3

at suitable intervals will thus be available for anyone who can, for purposes of study, approach the data afresh unhandicapped by the mental slant of the topographer or those who have measured the data before him. Legal disputes over boundaries, riparian rights, and land ownership may be solved more readily and economically if photographs showing the questions in dispute are available. In certain localities where it is difficult to establish the waterline at varying stages of the tide, photographs taken at high or low water often give a definite record at much lesser expense than any other means of surveying.

Large errors and omissions which have heretofore crept into surveys are less likely where overlapping photographs are used. The method is especially useful in localities more or less inaccessible and where no other method is economically practicable. Even where present needs do not apply, the material thus obtained can at a later date be assembled as an unchallenged record.

Based on ground control and with field inspection the aerial photographic surveys of the United States Coast and Geodetic Survey are accepted and registered as topographic surveys and are used in compiling charts just as planetable surveys are used. The aerial photographic surveys are compiled on sheets of cellulose acetate, and are then reproduced by photolithography on paper. At the same time a number of extra copies are printed at cost of paper and printing for distribution to engineers and others interested in large scale maps.

Recent development has been toward the use of wide-angle, single-lens camera for aerial photography, and the multiplex in mapping; but as far as aerial photographs alone are concerned, multilens cameras offer a marked advantage in time and cost.

The 5-lens camera developed by the Army Air Corps has photographed 3,600 square miles on a 1:40,000 scale in less than 3 hours, at a cost of only 20 cents a square mile for operating expenses and photographic materials. A 9-lens camera has been designed by the Coast and Geodetic Survey and has been used for several years in mapping along the coasts. This camera and its accompanying transforming printer produces a composite photograph 35 inches square, covering an area equivalent to 20 single-lens or 4 five-lens photographs of equal scale. The camera has an equivalent focal length of 8¼ inches, and a field of 130 degrees. Together with its accessories it weighs about 600 pounds. This camera is capable of photographing in a single flight 25,000 square miles on 1:40,000 scale.

NAUTICAL CHARTS

In connection with chart and mapping activities as outlined in the preceding pages, the one indispensable adjunct to national development is found in the nautical chart. Its construction embodies technical knowledge in which mathematical science of various kinds has been reduced to the minimum necessary for the comprehension of the mariner.

Parallel with the introduction of the mariner's compass, the early Italian and Catalan map makers, from 1300 to 1550, utilized the discoveries in the science of navigation and marked the real beginning of the nautical chart. Progressive development, through pioneer work and specializing in various capacities, has placed the nautical chart upon a scientific and practical status, and has given it a leadership in precision that is seldom attempted in other branches of map construction.

There is this distinction between the nautical chart and maps in general: that, while the latter may serve as a reference picture for engineering and other purposes, the nautical chart, in its special and accurate delineation, is meant seriously to be worked upon, so that a ship's course may be laid off with accuracy and ease and positions readily ascertained; it must embody the best information with necessary detail and yet with simplicity; it must maintain current information for the mariner which is in keeping with a nation's ports, its commerce, and ever-changing conditions; and it must be an instrument for the navigator to avoid the destruction of life and property.

Our rapidly expanding development and the corresponding demand accompanying this accelerated rate of growth; the development of shipping resulting in increased length, draft, speed, and values; submarine requirements; the construction of new waterways and channels; the building of bridges; the changes due to natural and other agencies operating to modify features already charted—these and other causes result in the need of a knowledge of the configuration or true conditions of today. This implies not only constant revisory work but an extension of the work into localities as yet unsurveyed.

The maritime public is no longer content with inadequate surveys nor the obscure charting of navigable waterways, and it becomes the province of the expert cartographer not only to check up thoroughly all the field operations but to present them so as to be of practical value. While in former years, due to insufficient surveys and charts, rocks and shoals have been christened after the names of steamers wrecked upon them, such nomenclature is not desirable. The *Great Eastern*, the largest steamer afloat in her day, has a rock named after her near Montauk Point, N. Y.; the palatial steamer *Pilgrim* of the Fall River Line had a monument in East River, N. Y. This danger has been removed and the name expunged from the charts. Too many other similar instances might be cited.

The cartographer's technical qualifications are not confined to the compilation alone; he is expected to be prepared to meet the problems of geodetic control, the mathematical properties of map projections, and the elements of the varied field operations. The results of the methods of compilation at the present day as well as the processes of publication are satisfactory in meeting the critical needs of the navigator. Many of the men engaged in this work have become specialists and have attained prominence in other engineering pursuits as well as in the world of art.

Chapter III.—COMPILATION OF MATERIAL

MATERIAL ENTERING INTO THE CONSTRUCTION OF A MAP OR CHART

Before a map is drawn, the information to be shown on it should preferably be obtained from a survey made with such detail and accuracy as will satisfy the scale on which the map is to be published. If the map is to be one of small scale it will manifestly be impossible to show the smaller hills and valleys, and matter of minor importance; if the map is to be one of large scale, a greater amount of information is necessary not only for immediate needs, but for presenting a groundwork for probable future requirements.

The scale of a survey is largely governed by local conditions and future needs rather than by the requirements for an immediate chart. Surveys made by the Coast and Geodetic Survey are in most cases on a scale much larger than the published chart, and for this reason the charts can be doubled in scale with a fair degree of accuracy.

In view of the fact that it is an easy matter to put anything on the chart but very difficult to find sufficient reasons to remove things once that they are added, it is desirable to omit in the first place miscellaneous items and objects of a transitory nature.

When street systems in cities are shown, they should be based on landmarks located by triangulation. The use of uncontrolled city surveys is apt to cause plotted points to appear in positions quite evidently out of relation with the street system. This disorder is not so evident on maps and charts of small scale where a symbol may be employed in which orientation of streets shown by single lines only is sufficient. Such a symbolic representation of streets, except for its area covered, has little cadastral value and is not suited to maps of large scale.

ORIGINAL SURVEY SHEETS—TOPOGRAPHIC AND HYDROGRAPHIC

A topographic survey should enable us to visualize clearly the scene or country surveyed. It should be a complete miniature landscape, supplying the means for a mechanical reconstruction of field conditions.

The conventional signs should be intelligible as to natural features, culture, and industrial enterprise. The distribution of population should be clearly shown as to sparsely settled and built-up centers.

The contour interval and drainage system should be comprehensive in presenting the general character of the country and the productive usefulness of localities as determined by marsh, natural flatness, rolling, or mountainous condition. The contour interval should also be sufficient to facilitate the engineering needs for town planning and for determining easy slopes for transportation problems, such as roads and railroads.

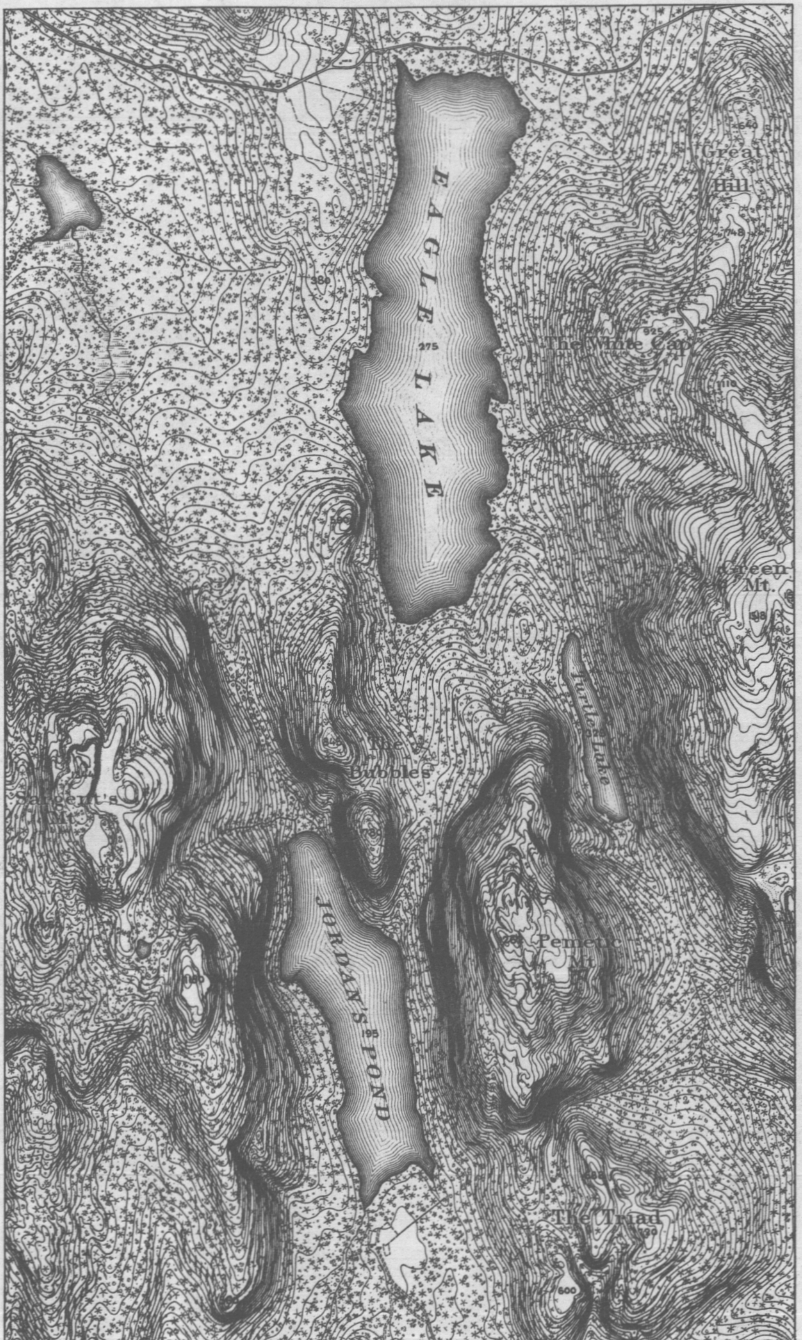


FIGURE 6. – MT. DESERT ISLAND, MAINE.

Part of U. S. Coast and Geodetic Survey chart No. 306, scale 1:40,000, engraved in 1885.

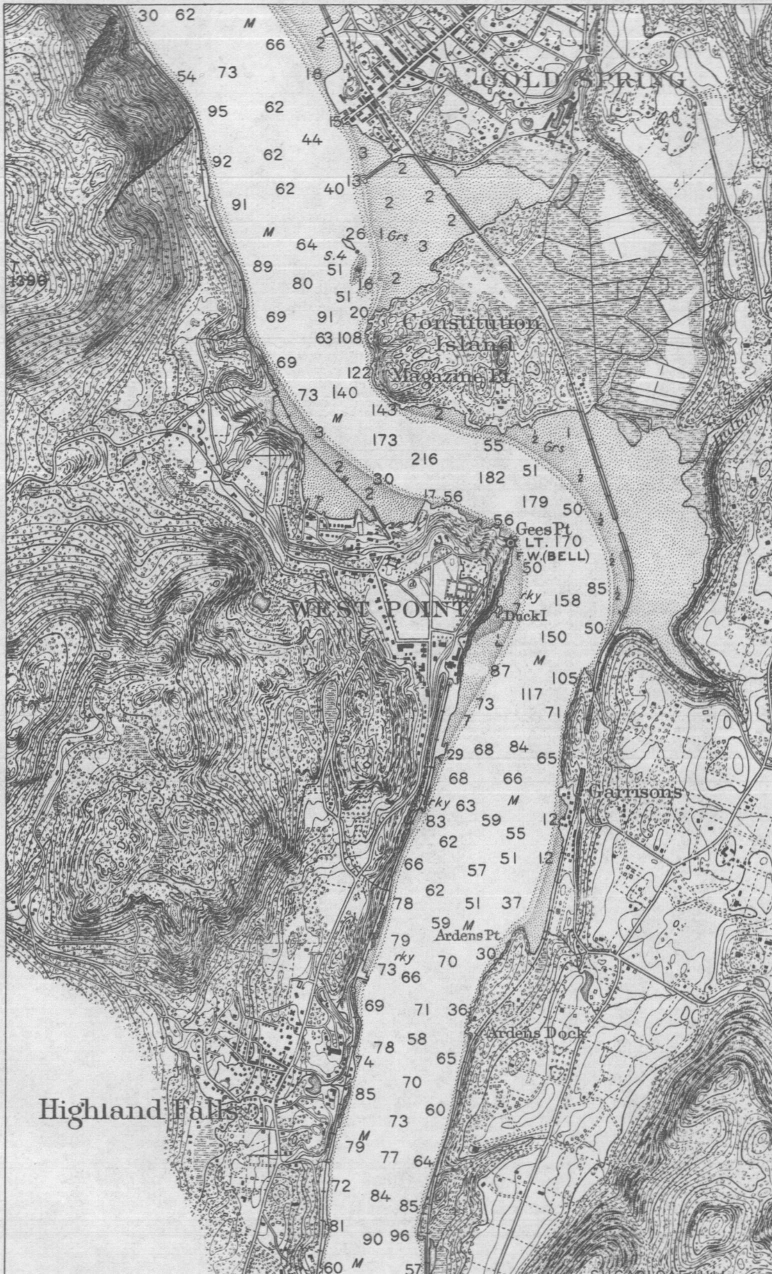


FIGURE 7. — HUDSON RIVER N. Y. — VICINITY OF WEST POINT.

Part of U. S. Coast and Geodetic Survey chart No. 282, scale 1:40,000, first published in 1907.

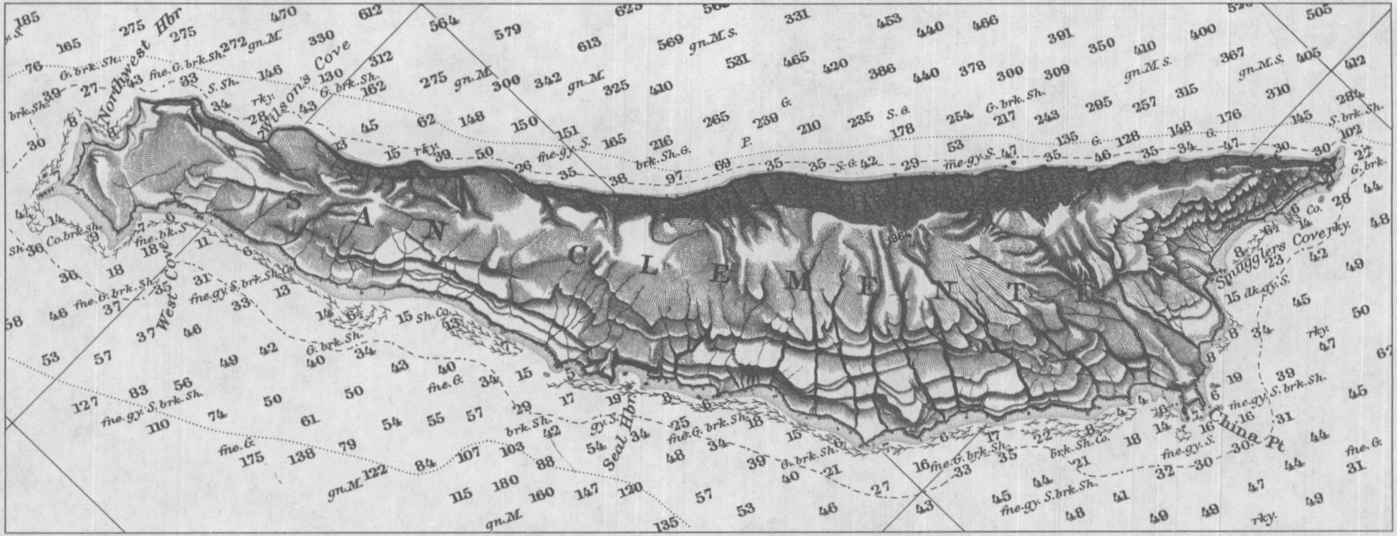


FIGURE 8.— SAN CLEMENTE ISLAND, CALIF.

Part of U. S. Coast and Geodetic Survey chart No. 5100, scale 1:200,000, published in 1890.
An illustration of artistic engraving of the old school.

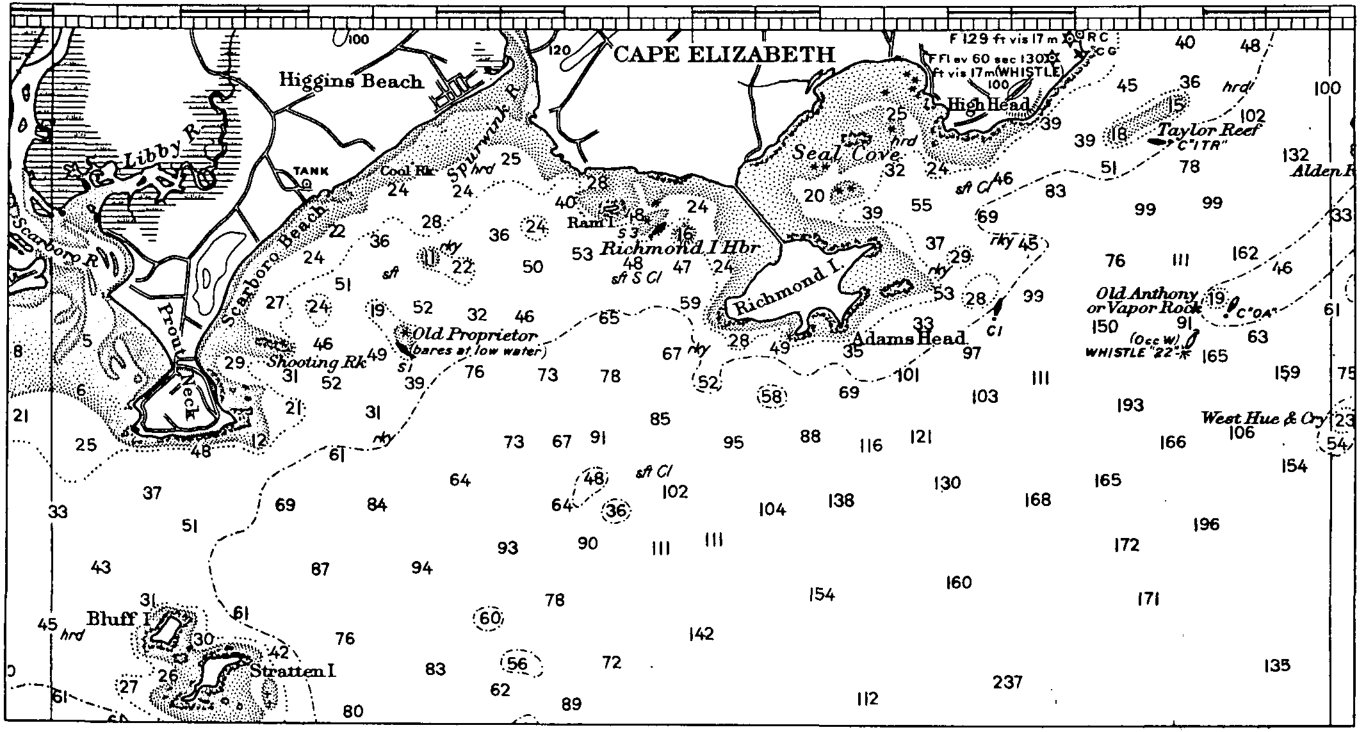


Figure 9. — Richmond Island Harbor, Maine.

Part of U. S. Coast and Geodetic Survey chart No. 1205, scale 1:80,000, first published in 1924.

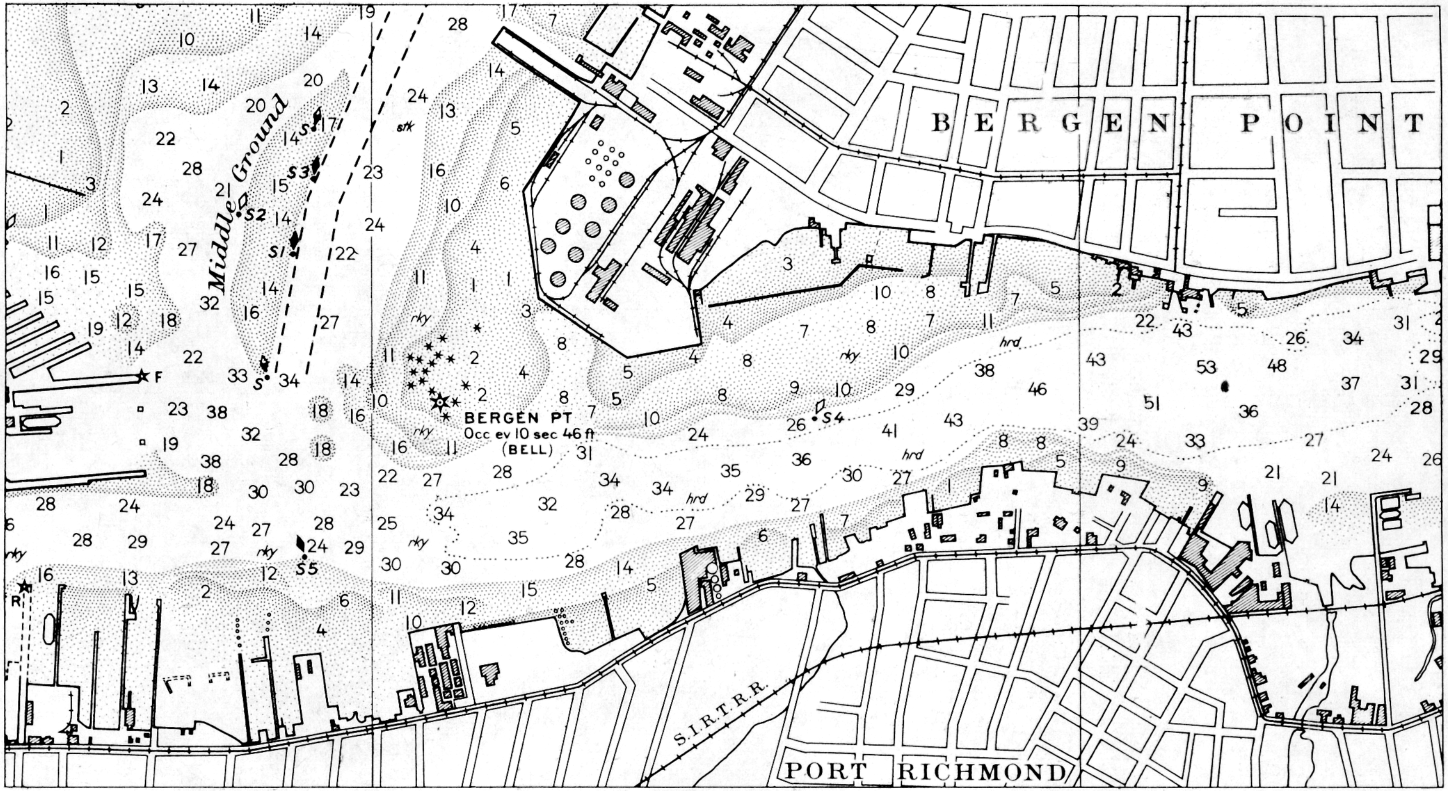


Figure 10. — Kill van Kull, N. Y. and N. J.

Part of U. S. Coast and Geodetic Survey chart No. 285, scale 1:15,000, first published in 1925.

A hydrographic survey should enable us to visualize the water areas and subaqueous terrain. It should reproduce as far as possible a true picture as to depths, contours, and bottom characteristics, and supply the navigational needs of depicting safe routes and the location of hidden dangers. It should contain a clear picture of submarine conditions and should be supplemented with tidal data and information regarding currents. It should facilitate engineering operations by supplying the information necessary for constructing profiles and for forming estimates in the various problems of commercial and harbor development.

ELEMENTS OF CONTROL

The first requisite of the material to be used is to provide a definite fix of the locality to be mapped in its relation to the earth's surface. With latitude and longitude given by a projection on which geographic positions are referred to the latest standard datum, the exact position of a locality is known. If no projection is available, but a geographic position and a true north line are shown, the material can be oriented so as to meet ordinary requirements, but where accuracy is desired, original material should furnish such additional control as will provide for the elimination of errors in the shrinkage and distortion of paper. For this purpose, in the absence of a projection, several geographically determined points, or distances between objects in different azimuths are desirable.

For purposes of direction only, an arrow (or magnetic meridian) showing the amount of variation with the date of survey, will serve in a general way for orientation purposes, but it should be clearly noted as to whether the arrow is *magnetic* north or *true* north.

The geographic reference datum for the horizontal location is supplied by the geodesist. He determines the size and shape of the earth, and the precise location of control points with reference to latitude and longitude. The initial reference line for latitude is the equator. For longitude the meridian of Greenwich has been so extensively adopted that its general use will some day probably be universal.

DATUM PLANES FOR LAND ELEVATIONS AND CONTOURS, AND FOR SOUNDINGS AND BATHYMETRIC CURVES

In order that a survey may be comprehensive, both these planes should be definitely determined in order that series of surveys may be definitely correlated. As different planes are employed both in topographic maps and hydrographic charts, a statement of the plane used in any particular survey or locality is necessary in order to utilize given material.

The basic datum for vertical location is furnished by tidal planes of reference. For general reference the most satisfactory plane is mean sea level since it is the most accurately determined of all tidal planes and since the other related planes may be derived from it with sufficient accuracy for practical purposes by a knowledge of the range and inequality of the tide.

On nautical charts, however, mean high water is used as the datum plane for elevations, partly for the convenience of the mariner since the high water line gives the truest conception of the appearance of the shore, and partly for the simplification of the survey, because the mean high water line generally can be closely approximated by noting the vegetation, driftwood, discoloration of rocks, or other visible signs of high tides.

On the topographic maps of the United States Geological Survey the plane of reference is mean sea level with an appropriate statement given, where a vertical plane differs from mean sea level.

In the construction of works for coast protection, the highest monthly high water is a datum of importance and is generally derived from the average of highest high waters over a long period.

For the soundings and bathymetric curves, a plane must necessarily be employed which insures a factor of safety, and consequently a low water plane is more satisfactory, as the chart will then show, in a general way, the least depth a mariner may expect regardless of the stage of the tide.

Although a zero sounding does not correspond to a zero contour in the use of two separate planes of reference, the mariner is interested not only in the depths below low water but also in the elevation of land objects above high water. The use of the two different mediums is therefore desirable on the nautical chart. Between the two planes of reference lie the beach, rocks, and other features which bare at low tide, and are indicated by sanding and other symbols.

Mean low water has been adopted by the Coast and Geodetic Survey for the whole of the Atlantic and Gulf coasts of the United States, including Puerto Rico and the Atlantic coast of the Panama Canal Zone. On the Pacific coast of the United States, on account of diurnal inequalities, a plane of mean lower low water has been adopted. Likewise, on the charts of Alaska, Hawaiian Islands, and the Philippines, the plane of mean lower low water is employed. On the Pacific approaches to Panama Canal the soundings are reduced to mean low-water spring tides. As different low-water planes are necessary to conform to the types of the tide in different localities of the world, the soundings of any given chart are reduced to the plane adopted for the locality.

APPRAISEMENT OF SURVEYS AND OTHER CHART MATERIAL

The usefulness and accuracy of a map or chart depend, first of all, upon the material entering into its construction and the proper appraisement of such material, and secondly, upon the intelligence with which the essentials are portrayed. No general rules governing appraisement can be laid down, as different problems present different solutions, the real solution in the end being dependent upon the technical training and experience of the cartographic engineer who is the author of the compilation and who is qualified to check the mathematical and physiographic details embraced in the geodetic, topographic, and hydrographic operations of the surveys.

Charting material derived from various surveys and agencies may differ in the value of its contents, each survey having its special value in the purpose which it was intended to serve, regardless of its frequent lack of control and inaccuracies in features not relevant to the original purpose. The skill of the cartographer is naturally reflected in the accuracy of the information he has put on the chart after a careful appraisement of the material at hand and the selection and adjustment of the various contributing factors.

It may be interesting to note, for instance, that the material entering into the construction of a 1:80,000 scale chart of Buzzards Bay, Mass., consisted of 61 topographic sheets, 94 hydrographic sheets (each sheet being 30 by 52 inches in size, and in scales 1:10,000 or 1:20,000), 116 surveys by other organizations, and data for the charting of 444 buoys, beacons, lighthouses, and light-vessels, besides many sheets of geographic positions, and information as to improved channel depths, tides, currents, magnetic variation, etc.

It is of the utmost importance in nautical charts, upon which the safety of navigation depends, that the routes of travel at sea be clearly defined. Inasmuch as a relatively small amount of the material obtained in the hydrographic surveys can be embodied in a given chart, and as these surveys may differ as to date and degree of accuracy, frequently overlapping one another and subject to changing conditions natural or artificial, the decision as to what shall be retained or rejected is evidently serious and can only be reached by one who has a knowledge of physical hydrography and field methods of surveying. It is a severe test of efficiency to reconcile these discrepancies when the original information is discordant and when at the moment no actual check on field conditions is available. The evaluation of hydrographic material entering into the construction of a nautical chart imposes on the cartographer a responsibility for accuracy which is beyond the requirements of ordinary mapping.

With a study of the physical characteristics of a hydrographic area in Buzzards Bay, Mass., the shoalest depth over a pinnacle rock might have been obtained through a closer examination at the time of the survey. A depth of 31 feet surrounded by depths of 35 to 37 feet was in itself an indication that was neither noticed nor investigated. Later on a ship struck the center of this rocky formation and revealed a depth of only 18 feet. The cartographer, by studying the material, should detect indications of dangers overlooked by the field parties. Other phases of this subject will appear in the following chapters.

CHECKING CARTOGRAPHIC MATERIAL

In reducing or applying any of the surveys available, the cartographer should see that the survey sheets have been properly verified as to projection; that the triangulation and tidal datum have been examined and adjusted; that positions of signals, plotted sounding lines, and soundings have been accurately located; that the development of hydrography has been complete; that rocks, shoals, and other dangers to navigation have been satisfactorily determined; and that a comparison has been made with previous surveys for possible deficiencies and for a study of the nature and extent of physical changes.

The descriptive reports supplementing the field work should be consulted for purposes of any specific instructions that they may contain, especially as to the completeness of the survey, the characteristics of the locality surveyed, the relative importance of prominent objects, and other details not appearing on the sheet.

PROJECTION OR FRAMEWORK OF THE MAP

The parallels of latitude and the meridians of longitude constitute the framework of the map, and are the means by which every detail is placed in its exact or correct relative position. In case there are several surveys of a given locality, the latest survey having the best control as based upon actual triangulation should be used first. If the selected control sheet does not happen to be the latest survey, it may afford control to other surveys not connected with the triangulation.

TOPOGRAPHY, HYDROGRAPHY, AND AIDS TO NAVIGATION

With the compilation of topographic and hydrographic detail proceeding as far as possible in the order of value and date, the material from other surveys and sources can be applied to complete the drawing. The positions of permanent lighthouses, beacons, and prominent objects should be plotted from their geographic coordinates. Buoys, range lights, and other aids to navigation furnished by the Bureau of Lighthouses, being subject to changes, should not be applied until the drawing is otherwise completed. Changes in channels and aids are frequently made at the last moment and, in order that their placement may be in up-to-date form, their position cannot be fixed until all other information is incorporated on the chart.

Besides the representation of features mentioned above, the finished charts contain much information in condensed form relative to the variation of the magnetic compass, tides, currents, and characteristics of the lights, and descriptive notes concerning improved channel depths and other pertinent subjects.

PROJECT AND SPECIFICATIONS

Before the compilation of a map or chart is undertaken, it is customary to decide upon a project and to draw up the specifications and details. The latter include the following: the title which is explanatory of the locality to be mapped, the limits and neatline dimensions, the scale, the system of projection, the plane of reference, the units of elevation and depth, and the details as to generalization of outline and relief.

In laying out projects for charts to meet local demands, it is advisable to consider the possibility that such charts, whether continuous or interrupted, may become units of a future greater scheme. Too great an assortment of scales, sizes, units, reference planes, and general treatment, while locally satisfactory, may cause confusion. Charts, in many such cases, can be made equally serviceable when scales and other data are made to conform to a scheme in which uniformity has been taken into consideration.

PAPER AND SCALE MAINTENANCE

The paper used in the compilation should be well seasoned and meet the tests of strength and minimum distortion from hygrometric conditions or age. Improvements of recent years in this field of experiment have added much to the facility of reproduction of drawings and the maintenance of true scale. By mounting three-ply bristol board on aluminum plate, the serious annoyance of paper distortion has been overcome. In this process, aluminum is preferred because of its light weight and durability. A fine grade of bristol board is mounted on both sides of the plate, and in order to prevent buckling and preserve flatness in the metal mount, it is necessary that the top and bottom sheets of paper be of the same quality and grain and similarly placed. By being so mounted on metal, the drawings will remain flat and retain their original scale. The undeniable advantages of true scale for all time eliminate the old argument that other errors of various kinds are not serious because they are so small as to be within the errors caused by hygrometric changes in the paper.

CONSTRUCTION OF A PROJECTION

In the construction of a projection based upon *X* and *Y* coordinates or, as in the Mercator projection, upon computed intervals of latitude and longitude, the best results are obtained when the framework of the projection is based upon two axes as near the center of the sheet as the selected interval of latitude and longitude will permit.

The first line representing one of these axes is a central line drawn in the longer direction of the paper. An intersecting perpendicular at the accepted center of the map should then be constructed by the ordinary method of arcs. In order to obtain results as accurate as possible, the outer or limiting projection lines should then be constructed. In case of maps having many projection intervals, it is well in the next place to lay off from the center, projection lines which fall about half way to the outer or limiting projection. In the Mercator projection the distances to these lines should be checked from the limiting projection lines; in the polyconic projection the temporary construction lines should be checked in the same way. Subdivisions should then be laid off and checked according to their computed values.

The construction of a polyconic projection is illustrated on pages 8–9, Tables for a Polyconic Projection of Maps, Coast and Geodetic Survey, Special Publication No. 5. The construction of a Mercator projection is illustrated on pages 110–112, Elements of Map Projection, Special Publication No. 68.

Although the tables of meridional distances, given to three places of decimals in Special Publication No. 68, will serve for the construction of Mercator projections with sufficient accuracy for all practical purposes, it is recommended that the following publication be used to avoid the necessity of occasional interpolation: International Hydrographic Bureau, Tables of Meridional Parts to five places of decimals, Special Publication No. 21, Monaco, 1928. In practice, however, it is found that the fifth place of decimals of the latter publication is unnecessary.

In certain projections, where the maps are of small scale, the arcs of the parallels can be constructed by radial distances and the longitude intervals by means of chords.

REDUCTION METHODS

In the preparation of maps and charts, the original surveys and other material utilized generally appear on scales varying according to the necessary precision which governed the purpose of the surveys. After assembling and appraising all these elements (see *Material Entering into the Construction of a Map or Chart*, p. 30, and *Appraisement of Surveys and Chart Material*, p. 32), different methods of reduction are available to meet the scale of a given map project.

The method of former years consisted of *reduction squares;* that is, squares drawn on transparent paper placed upon the original survey sheet were proportionate to the squares drawn upon the compilation in the same ratio as the scale of reduction (or enlargement) from survey sheet to compilation. The method is still found convenient where, by comparison with the published work, certain small corrections or additions can readily be visualized and applied without the need of a complete reduction.

The methods in general use, however, are those of *photography* and *pantography.* In the application of material in which the scale is different in opposite directions, due to distortion of the paper, it is found convenient in either of these two methods to use a reduction factor that will maintain true scale in one direction. This is better than a reduction factor for an average scale, as the error of distortion needs to be distributed in one direction only. All that is necessary is to divide the reduction and the drawing into a sufficient number of equal spaces or bands to secure junctions in the transfer.

Pantographic reductions made by carbon impression on transparent paper are generally in a condition to be transferred to the compilation by means of a burnisher.

One of the advantages of a pantograph over the photographic process consists in a facility of acquiring, in addition to the reduction, the generalization necessary to a given project. This instrument avoids the necessity of tracing the photographic reduction, and by its use unnecessary detail can be omitted more satisfactorily than from a reduced photo; but there are instances where photography may serve to advantage, especially is this the case where enlargement of the original material is desired.

It is also possible to obtain a reduction by photolithography on the under side of Doric or similar tracing paper. This reduction is pulled from the aluminum plate in black ink and can be burnished directly to the compilation. Due to the constituents of the tracing paper, the ink on such reductions has retained its transfer property for many months. For accurate reduction of complicated areas such as street systems, this process may be useful under conditions where all or part of the reduced detail is suited to the scale of the compilation.

GENERALIZATION BY SELECTION

As implied in preceding pages there is one connotation of the word "generalize" which must be carefully avoided in good cartography. *To generalize* should not mean to round off details without regard to characteristic expression, but rather to obtain clarity and emphasis through the selection of the important information while omitting detail that is unimportant. Too often the beginner in cartography, when told to generalize, will jump from showing fine and meaningless detail which make his drawing illegible, to rounding off characteristic forms until considerable doubt arises as to the identification of points, wharves, and reefs which are sharply defined in nature. The cartographer should be ever on guard to preserve useful characteristics as well as to omit the unimportant.

REPRODUCTION

Changes in the methods of chart production during the past 15 years have been radical and essential, particularly with respect to methods of printing. The chief concern of the day is, first, to place before the public the benefit of surveys and information before they become obsolete, and, secondly, to eliminate appreciable scale distortion inherent in former processes. Much has been accomplished in these two problems: the *first* has been accomplished through a lesser number of intermediate steps between the commencement of compilation and the printing of a chart, and by the distribution of various parts of the reproducing work among different individuals; the *second* has been accomplished by a new method, the description of which will follow:

Scaling errors of charts pulled directly from copperplates, in former years had errors of shrinkage and distortion of as much as 4 pecent. This error was not due to the copperplate itself but to the process of printing. By the present use of baryta paper an impression is taken from the inked copperplate, and by the photolithographic process a transfer practically true to scale is made to a sensitized aluminum plate, from which the chart is printed.

Scaling errors of charts by lithographic process from vellum drawings were also considerable. Due to unequal shrinkage or the meeting of opposites in granular texture, the forced matching of adjacent vellum sheets frequently caused great annoyance in the processes of reproduction and in the final result.

While serious attention has been given to errors of map projection, the greater errors of reproduction have heretofore too often escaped notice. In the present rigorous requirements of military operations and navigation, shrinkage and distortion errors of the magnitude of former years are too serious for the purposes which maps and charts are intended to serve, and are inadmissible in calculations. The new mechanical processes have indeed added in recent years as much glory to the progress of cartography as have the improvements in methods of survey and the mathematics of map projection.

The copper engraving medium or method which has the benefit of certain advantages, had formerly certain decided inadequacies. Modification in this method resulting in the saving of time in printing and in scale improvement were originated in the Coast and Geodetic Survey, as already noted on page 34. A new procedure in the copperplate process which offers facility in handling, consists in constructing a projection on copper which provides for cutting the plate into sections or quarters similar to the method used in the following chapter. This does away with the large-size plates of former years, thus enabling two or more engravers to work on the same chart at the same time.

PHOTO-ALUMINOGRAPHY

This method produces a chart that conforms perfectly to a desired scale. In this process as stated in a previous paragraph, page 34, sheets of high-grade bristol board are similarly mounted on opposite sides of aluminum plate, allowing spaces between the several sheets. The mounting on both sides prevents buckling and insures a permanently flat working surface. The practice of constructing the complete projection and the junction lines of sections (in halves or quarters) of a large chart upon a single plate of paper-mounted aluminum, has served not only to secure scale maintenance, but has made it possible to cut the original plate into its joining sections and to distribute the work more economically.

Each section with adjoining junction lines repeated is provided with convenient margins in the original mounting. It is then compiled and, after verification, the several parts or sections are sent to another branch of the service for purposes of photographic transfer to glass negatives. The finished cartographic work is then done by one or several lithographic artists according to the speed required in making the chart ready for publication. The film sides of the negatives are given a coat of asphaltum which permits the compiler's drawing to be clearly seen but which destroys its printing qualities, thus enabling the artist to cut-in or engrave through the asphaltum and photographic emulsion the configuration and lettering in a standard degree of finish. In the next stage, on nautical charts, the soundings and bottom characteristics are cut-in by a sounding-engraving machine.

After the negatives are cut they are process-printed and assembled on a sensitized grained aluminum plate. The usual long interval between surveys and their publication in chart form has thus been reduced to a minimum period of time in which the compiler and engraver have specialized in their individual fields.

By the new process of photo-aluminography the printed chart as it comes from the press is accurate in scale and free from distortion, but, in use, it will be found distorted to the amount that the paper upon which it is printed is later on affected by atmospheric conditions.

Chapter IV.—MAP PROJECTIONS

INTRODUCTION

A map is a plane-surface representation of a portion of the spherical surface of the earth. Inasmuch as a spherical or spheroidal surface is nondevelopable—that is, it cannot be spread out or represented on a plane without more or less serious distortions or deformations—any map covering a considerable portion of the earth's surface is not truly representative, but only an approximation of the earth's features in their relative positions, sizes, and shapes.

Imagine the difficulty in flattening a portion of a hollow rubber ball. The edges of such a portion will require stretching or tearing, or a combination of both; the middle part will require contracting; or a combination of all three processes may be necessary before the outer part will come into the plane of the central part. To flatten any large portion of the surface of a globe is equally impossible.

In our ordinary conception of a small portion of the earth we picture it as a plane or nearly as such. However, in mapping any great extent of surface, such as a large country or continent, we meet with serious difficulties which will introduce departures from absolute representation.

THE PROJECTION AND ITS USE

In order to locate points on the earth's surface we find it convenient to refer them to an imaginary network of meridians and parallels. In this way the position of any point is definitely fixed in its proper latitude and longitude. The corresponding system of reference lines of latitude and longitude which constitutes the framework of the map is known as the *map projection.*

The theory of map projections includes the mathematical analysis of the different systems in use, the development of the formulas, the nature and properties of different projections, their selection and construction. The term *projection*, however, is somewhat misleading, since many of those in common use are not projections in the geometrical sense. They are simply a one-to-one correspondence between the meridians and parallels on the spheroid and those on the plane of the map, that is to say, the relation is such that every element of each aggregate of the spheroid corresponds to one and only one of the map. The number of possible ways in which such a correspondence can be set up, is unlimited. All that is necessary is that the parallels upon the earth shall be represented on the plane of the map by an orderly series of lines or curves, and that the meridians shall be represented by another orderly series intersecting the first series. This necessary relation, however, should also provide for a unique orderly arrangement that will best serve the particular purpose for which the map is intended.

In almost any projection there are variations of scale introduced to bring about some desirable property, the spacings of meridians and parallels being arranged in such a way as to produce equivalence, conformality, or whatever condition is sought. These conditions are generally not arrived at from the sphere or spheroid in any perspective sense but by mathematical analysis.

It is necessary, therefore, to know the advantages of the various systems of map projection and the nature of their attendant deformations in order to solve any given cartographic problem.

The fundamentals of geography are naturally best grasped by means of a globe on which all areas can be correctly represented and technical terms and problems can be reduced to their simplest forms.

Although for areas within the limits of a hemisphere, the representation by a map may be utilized with a fair degree of accuracy in studies of natural phenomena, commerce, and world politics; when we attempt to map areas greater than a hemisphere, these facts can no longer be presented in their true light. On the other hand, as the area to be mapped becomes smaller, the problem becomes simpler, and the network of meridians and parallels in the plane of the map becomes more and more nearly the counterpart of the network of meridians and parallels of the spheroid.

CHOICE AND PROPERTIES OF PROJECTIONS

In the choice of a map projection, we must consider the properties most desired. As different projections have their own distinctive properties, and as certain properties are not necessarily exclusive but common to some of them, the exigencies of the problem at hand must generally be met by special study and, as a rule, that system of projection adopted which will give the best results for the area under consideration.

FACILITY OF CONSTRUCTION AND THE READY PLOTTING OR SCALING OF GEOGRAPHIC POSITIONS

In this class, the polyconic and Mercator projections are specially useful on account of the availability of general tables which have been computed for the spheroid. In the polyconic system, the arcs of the parallels are true to scale but the meridional intervals increase as the distance from the center of the map increases, and caution must be exercised, especially in small scale maps, in the plotting of points and in the measurement of distances, so as to provide for the difference in latitude and longitude scales. This meridional distortion is always of plus sign and is not appreciable in maps of a region of small extent.

The polyconic projection, while of no definite scientific value, possesses properties of convenience and use. It may be extended indefinitely in latitude, and in longitudinal extent it may be carried 500 miles from a central meridian before a meridional scaling error of 1 percent is reached.

The Mercator projection, on account of simplicity of construction and the advantage of straight lines of meridians and parallels at right angles to each other, also offers facility for plotting and scaling off points. The meridians being equally spaced, subdivisions of longitude are readily obtained. The parallels are perpendicular to the family of lines representing the meridians, and the spacings of the parallels are readily computed from the general tables. From the marginal subdivisions of a Mercator chart it is easy, by the use of a straightedge, to locate the bounding meridians and parallels of any unit of latitude and longitude. Geographic positions can then be plotted or determined by means of the scale of the latitude in question.

As the Mercator chart is a conformal representation and as its scale increases with the latitudinal extent, the usefulness of this system of projection, except for navigational purposes, is limited to areas of small latitudinal extent. The Mercator chart is also used when it is desired to include the greater part of the world in one continuous arrangement.

In other projections where special tables have been computed for certain localities, the plotting of points follows the system of projection, and, in the case of conical projections, is generally very simple as the meridians are straight lines and the parallels concentric circles.

PROPERTY OF CONFORMALITY

A conformal projection takes its name from the property that all small or elementary figures upon the surface of the earth retain their true shape upon the projection or map.

Definition of conformality: If at any point the scale along the meridian and the parallel is the same (not necessarily correct, but the same in both directions), and the meridians and parallels are at right angles to one another, then the shapes of all elementary figures on the map are the same as their corresponding areas upon the earth.

The popularity of this type of projection is evidenced by the use of the Lambert conformal projection in military maps, and in the mapping of areas and countries of predominating east-and-west extent. In connection with systems of rectangular coordinates as applied to the various States of the United States, it has been used extensively where the shape or configuration has greater longitudinal than latitudinal extent; by the additional use of two standard parallels of true scale, the errors of scale are reduced to a minimum.

In the case of States having a predominating latitudinal extent, the Transverse Mercator projection has been employed in a similar way. The latter system is also conformal, but instead of true scale along two standard parallels, exact scale is held along two small circles formed by planes parallel to the plane of the central meridian.

The best known conformal projections being the Lambert, the Stereographic, and the Mercator, their mathematical relation is interesting: When the tangent cone of the Lambert projection becomes a tangent plane at the pole, we have a projection of the spheroid that merges into the Stereographic projection; and when the parallel of tangency approaches the equator, the Lambert projection of the spheroid merges into the Mercator.

EQUIVALENCE, OR THE PROPERTY OF EQUAL-AREA REPRESENTATION

Equal-area representation implies that any portion of the map bears the same ratio to the region represented by it that any other portion does to its corresponding region; thus, in a map of the world, a coin placed upon South America will cover the same area as the same coin placed upon Greenland.

It is not entirely on account of the practical advantages of equal-area representation that this method of projection has acquired a popularity in atlas maps, but also on account of the fact that, in addition to this useful property, it is frequently possible to obtain a minimum scale error. These two properties combined in one projection therefore determine its selection in many cartographic problems. Such is the case of the selection of the Albers projection for a wall map of the United States where we have equal-area representation combined with a maximum scale error of only 1¼ percent. This system, with its two standard parallels of true scale, has in addition, at every point on the map, two diagonal lines or curves of true length scale, approximately at right angles to each other. These curves of true scale are termed isoperimetric curves. The compensation which provides for equal-area representation is necessarily brought about by scale variations of opposite sign in the meridian and parallel at every point on the map, thus accounting for two intersecting curves of true scale equally inclined to the meridian at every point, or, in effect, two families of true scale curves running in oblique directions through the map. Straight lines which lie approximately northeasterly or northwesterly, or their opposites, along the path of these curves are practically true to scale the more they approach parallelism with the isoperimetric curves.

There is thus, in this projection, a liberality of true scale property, not to be found in other systems. The convenience of straight lines in the family of meridians is another advantage over other well known equal-area projections in which both systems of lines are curved.

REPRESENTATION OF THE RHUMB LINE AS A STRAIGHT LINE, AS IN THE MERCATOR PROJECTION

The loxodrome or rhumb line is a line that crosses the successive meridians at a constant angle. A ship "sailing a rhumb" is, therefore, on one course continually following the rhumb line and will, theoretically at least, pass all points along that line exactly as they are charted. The only projection on which the rhumb line on the earth is reduced to a straight line on the map is the Mercator projection.

While the straight (or rhumb) line on a Mercator chart is not the shortest distance line between two points, the great-circle track, when appreciably shorter than the rhumb line, can be plotted by calculation or can be transferred from a Gnomonic to the Mercator chart by means of corresponding graticules of latitude and longitude. The great circle thus transferred to the Mercator projection becomes a curved line which may be divided into convenient sailing chords (or rhumbs) so that courses may be followed and the port bound for may be reached by the shortest practicable route.

The shortest line between any two given points on the surface of a sphere is the shorter arc of a great circle that joins them; but as the earth is a spheroid, the shortest or minimum line that can be drawn on its surface between any two points is termed a geodetic line. However, for ordinary purposes in connection with shortest sailing distances, it is customary to consider the earth as a sphere and the approximation is sufficiently accurate.

Although the use of the Mercator projection in world atlases has created erroneous impressions in the relative size of land masses, its simplicity and convenience for laying off courses as straight lines has contributed to its success in nautical charts.

The description, theory, mathematical analysis, and construction of the Mercator projection are given in greater detail in Elements of Map Projection, Special Publication No. 68, Coast and Geodetic Survey.

REPRESENTATION OF GREAT CIRCLES, OR LINES OF SHORTEST DISTANCE AS STRAIGHT LINES

The property that every great circle of the sphere is represented by a straight line on the map is found only in the Gnomonic projection. This is a perspective projection upon a tangent plane, the point from which the projecting lines are drawn being situated at the center of the sphere. Thus a straight line drawn between any two points on the chart is the actual projection of a line on the surface of the sphere, and correspondingly is an arc of a great circle. It is, therefore, the shortest *track line* showing at once all the geographic localities through which the most direct route passes.

The projection is used chiefly as an adjunct to the Mercator system by transferring to the latter the great-circle routes. Any route thus marked out will show at a glance if any obstruction—an island or danger—necessitates a modified or composite course as the best available practical course, or it will serve as a base for resolving long great-circle tracks into convenient sailing chords. It is also useful in planning long air flights, since a straight line drawn between terminal points will show which cities or airports are nearest the through route.

The defects of the projection appear in the excessive distortion of distances, areas, and shapes in the outer or bounding portions of maps covering a large extent of the earth's surface, as it is obvious that a complete hemisphere cannot be constructed on this plan.

On account of the angular distortion in a Gnomonic projection, a specially computed rose (except at the point of tangency) is necessary in order to obtain a true bearing or azimuth from a station. The problem may be simplified either by including on the chart, compass roses computed for important stations, or by supplying for the stations on any particular chart the Gnomonic azimuth tables such as are given in Special Publication No. 75, Radio-Compass Bearings, United States Coast and Geodetic Survey.

A base map of the United States on a Gnomonic projection has been published by the Coast and Geodetic Survey with point of tangency at latitude 40° and the center of longitude at 96°. The scale at the point of tangency is approximately 1 : 5,094,000. The meridians, being parts of great circles, appear on the chart as straight lines, and the parallels as conic sections. The conic sections are ellipses above latitude 50°, hyperbolas below latitude 50°, changing from ellipse to hyperbola in passing through the parabola at 50°.

TRUE BEARINGS (OR AZIMUTHS)

Among azimuthal projections most frequently seen in atlases are the Lambert meridional (or azimuthal) equal-area, the Lambert zenithal (or azimuthal) equal-area, and the Lambert polar equal-area, all three of which possess the important property that straight lines radiating from the center of the projection represent great circles in their true azimuths from it. Along the almucantars (or parallel circles from the center), the scale is too large, and along their radii the scale is too small in inverse proportion. The scale is increasingly erroneous as the distance from the projection center increases. The property of true azimuths combined with equal-area representation may thus be obtained from centers that are on the equator, at the pole, or at some intermediate latitude.

Among other azimuthal projections which are used for geographic purposes are the Stereographic meridional, the Stereographic horizon, and the Stereographic polar. In these three projections the centers may also be on the equator, at the pole, or at some intermediate latitude, but the property of conformality takes the place of equal-area. The property of true bearings from the center of a Gnomonic projection has already been described.

The subject of true bearings combined with true distance will now be considered under the following.

TRUE DISTANCES AND AZIMUTHS—THE AZIMUTHAL EQUIDISTANT PROJECTION

This projection takes its name from the fact that straight lines radiating from the center of the projection represent great circles in their true azimuths from it, and the distances along these lines are true to scale. The projection is neither equal-area nor conformal; but, since no projection can be devised which will give all azimuths or distances correct throughout the map, this projection serves certain special and useful purposes. Any important city can well afford to have a map constructed that will offer an easy means for measuring great-circle distances (or shortest routes) from its center to any other part of the earth's surface. With a periphery scale any bearing from the center may be read in degrees and the nature of intervening territory will be shown at a glance by a connecting straight line.

Several interesting charts have been published on the *azimuthal equidistant* projection—among them are nos. 5199 and 5199*a*, by the Hydrographic Office, United States Navy, one with the center at Washington, D. C., and the other with the center at San Francisco. The General Electric Co. has prepared, for the use of radio engineers, a map of the world on this projection with the center at Schenectady, N. Y. It is apparent that such a projection is useful at certain aeronautical centers; likewise in crystalloptics and other studies.

It is doubtful, however, whether for geographic purposes, the projection should be used for continents, as the projection-center in most instances would be a point of no cartographic interest, and the true scaling properties from such a point would be obtained at the expense of greater scale errors otherwise. The *Lambert azimuthal* projections are, for ordinary geographic purposes, more desirable in having besides their equal-area properties, a lesser maximum scale error in other parts of the map than the *azimuthal equidistant* projection.

TRUE DISTANCES AND AZIMUTHS FROM TWO POINTS

A doubly equidistant projection can be constructed on which distances from two points can be mapped as straight lines true to scale but the azimuths will not be correct from either of the points. On the other hand, true azimuths from two points can be obtained but the distances from either point to any other points will not then be true to scale. A projection may also be constructed in which the distances from one point and the azimuths at the other shall be correct.

Description and formulas for the first two cases are given by Sir Charles Close, in the following publication: Two Double, or Two-Point, Map Projections, Ordnance Survey professional papers, new series, no. 5, Southampton, England, 1922.

POLYCONIC PROJECTION

The Polyconic projection was devised by Professor Hassler, the first Superintendent of the Coast and Geodetic Survey, and possesses great popularity on account of mechanical ease of construction and the fact that a general table for its use has been computed.

The projection has no definite scientific properties but may be considered as compromising various conditions impossible to be represented on any one map or chart. It is sufficiently close to other types possessing in some respects better properties that its great tabular advantages determine its choice within certain limits.

For maps not covering a total longitudinal extent of more than 1,000 miles, see p. 40, this type of projection attains an accuracy that meets all general requirements. It is in general use for field sheets and is readily constructed by X and Y coordinates.

Its disadvantages become evident beyond the limits indicated above and it is not suited for the mapping of countries of wide longitudinal extent, unless it is computed and constructed in a transverse relation to suit the shape of the area involved. United States Coast and Geodetic Survey Chart No. 3080 covers the North Pacific Ocean on a transverse polyconic projection, scale 1:20,000,000. This chart is of interest from a geographic viewpoint as exhibiting in an approximately true representation a section of the earth of wide longitudinal extent.

LAMBERT CONFORMAL CONIC PROJECTION AND THE ALBERS EQUAL-AREA PROJECTION

These two projections are somewhat similar in appearance but different in their properties. Points in common are: Both are conic projections and both have two standard parallels of true scale; the projections being conic, their meridians are straight lines converging in the direction of the pole, and the parallels are concentric circles intersecting the meridians at right angles. On selected standard parallels, arcs of longitude are represented in their true lengths, or to exact scale.

Their differences are: In the former projection, the intervals of the parallels depend upon the condition of conformality; in the latter projection they depend upon the condition of equal area. In the Lambert projection the scale is too small between the standard parallels and too large beyond them; in the Albers projection the meridional scale between the standard parallels is too large and the scale along the parallels correspondingly too small, the reverse conditions existing beyond the standard parallels.

TRANSVERSE PROJECTIONS

It is frequently of interest from a geographic standpoint to exhibit in their true relations, important localities of which the general trend of the configuration is in a transverse (or oblique) relation to the normal representation of projections in common use. Such a representation is ordinarily based upon a great-circle axis other than the equator or central meridian, and the term *oblique* may well be disregarded, as an apparently oblique axis is actually a *transverse* axis in which only a part of the great circle appears.

A long narrow section of the earth's surface frequently permits no other choice of projection and a special computation therefore becomes necessary for each individual mapping scheme. This is a disadvantage but one which is not insuperable as is shown by the fact that such projections are being employed more extensively today than they have been in the past.

Since the increased demand for maps covering long-distance air routes, it is practically certain that transverse projections will be needed more extensively as time goes on. In order to meet the requirements of a transverse configuration, and in order to reproduce with greater fidelity conditions as they actually exist on the ground, much has been accomplished in recent years in the adaptation of some well-known projections to a transverse axis, and in thus supplying to a given zone the elements of strength or control not otherwise attainable.

In United States Coast and Geodetic Survey Chart No. 3080, North Pacific Ocean, referred to on page 45, the transformation resulting from the transversal of a polyconic projection provides true distances along the great-circle axis in the same measure as they are true along a central meridian of an ordinary polyconic projection.

Among other projections which have been similarly employed, is the Transverse Mercator (also known as the Gauss conformal projection), for strip maps covering the principal routes of the world. These were brought into use by Louis Kahn, were published by Ed. Blondel la Rougery, Paris, 1932, scale 1:10,000,000, and are intended specially for great-circle navigation. The Transverse Mercator is also employed in the surveys of Egypt and Madagascar, and more recently it has been introduced in the system of rectangular coordinates for some of the States of the United States. A transverse Mollweide equal-area projection has been devised by Sir Charles Close and appears in Hinks' Map Projections, 1921. Interesting examples of transverse cylindrical equal-area projections appear in the Nordisk Världs Atlas, Stockholm, 1926.

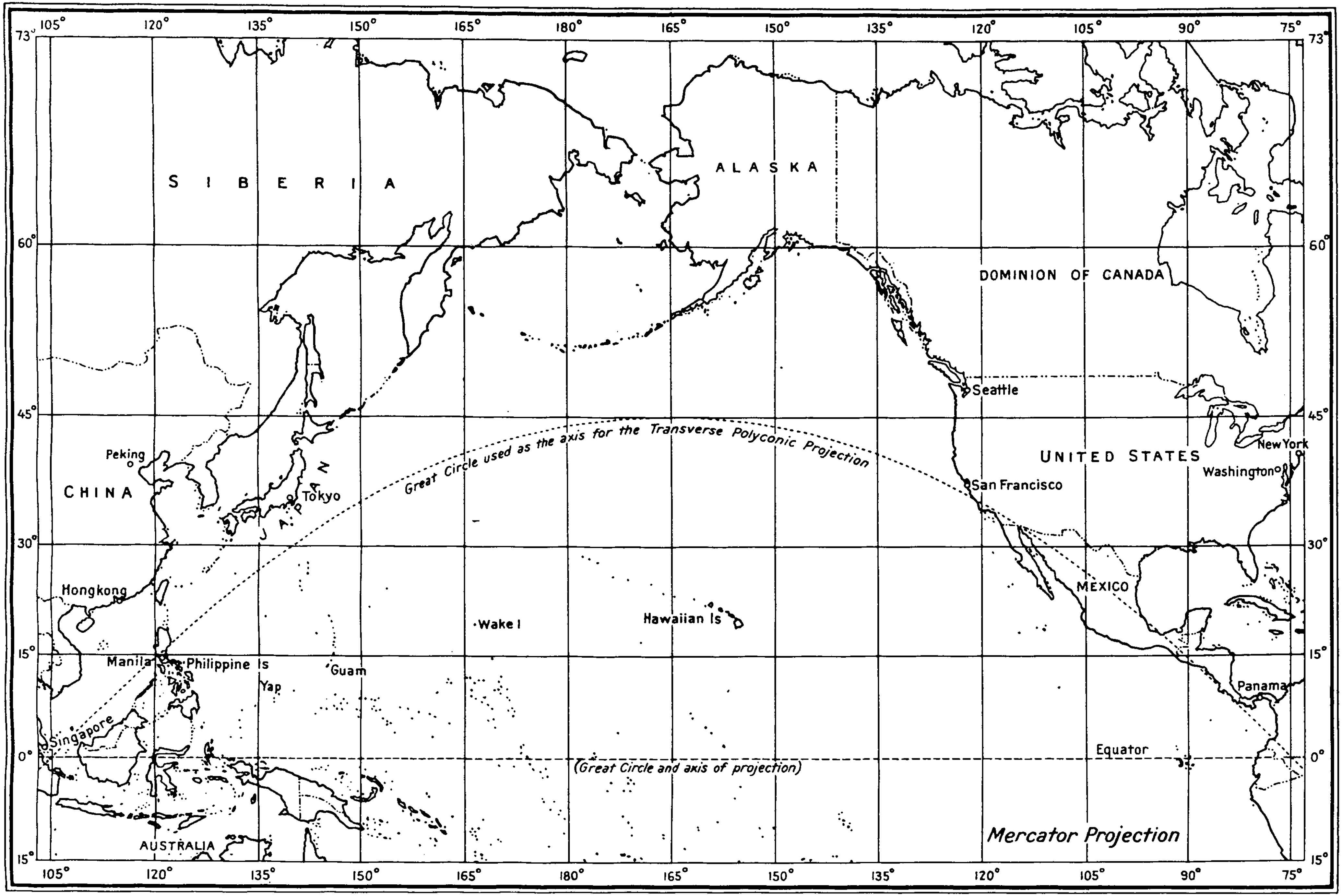


FIGURE 11. – MERCATOR PROJECTION – NORTH PACIFIC OCEAN.

For comparison with the Transverse Polyconic Projection, see note on the following illustration.

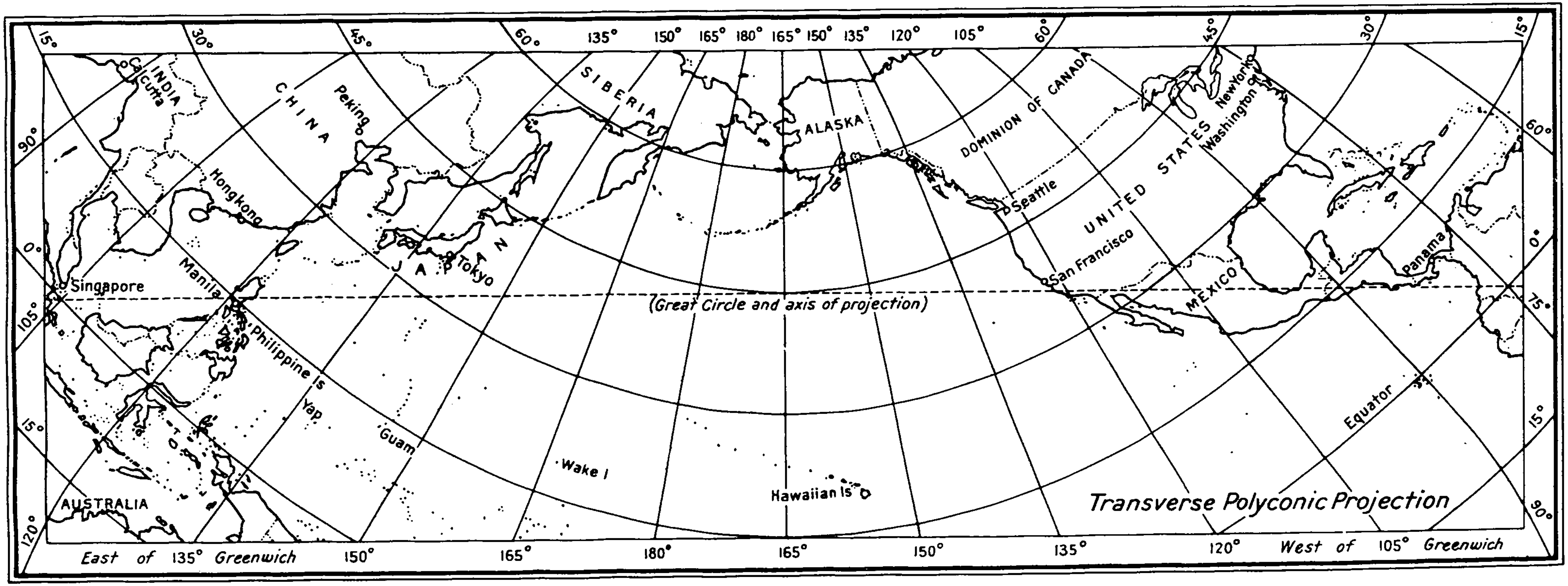


FIGURE 12. — TRANSVERSE POLYCONIC PROJECTION — NORTH PACIFIC OCEAN.

The transverse polyconic projection along its great-circle axis and central meridian reproduces conditions as they actually exist on the earth's surface. The map shows the relation of the United States to the Orient with unusual precision, as the main points of interest follow closely an axis of true scale.

The Mercator projection of the preceding illustration, although covering the same area, seriously fails to delineate the relative size of countries in different latitudes.

The comparison of the two systems is intended to illustrate the necessity of care in the selection of a projection in order to meet the requirements of any given cartographic problem.

From the preceding discussion of the various types of projections it will be seen that the selection for any problem should meet the purpose in mind; that the variations in any important section or from the center of the map, as the case may be, should generally be as slow as possible; and that the necessary deformations should be placed into parts of the map where they are least objectionable.

There is still room for theoretical study in the broad field of mathematical cartography which aims to improve the accepted central axis or central zone of a map, and to provide for least alteration from true representation.

THE GRID SYSTEM

In progressive military maps and frequently in maps of survey departments, a grid system of squares referred to one origin and determined by the rectangular coordinates of the projection, has come into use quite extensively since the World War.

For the ready use of the allied armies the grid system was extended over the whole area of the projected zone so that every point on the map could be coordinated both with respect to its position in a given square as well as to its position in latitude and longitude. In the military maps of the War Zone the orientation of all grid (or sectional) sheets of the general map, wherever located, and on any scale, were thus referred to the initial meridian of the origin of coordinates.

This system is adapted to the quick computation of distances between two points whose rectangular coordinates are given, as well as to the determination of the azimuth of a line joining any two points and, hence, is of great value in military operations.

The grid system being rectangular, its lines have a progressive deviation from the meridians and parallels, and become more and more oblique as the map is extended east and west from the point of origin. Caution must be exercised in classifying directions so as to avoid any confusion in true north, magnetic north, and "grid north," the latter term being here applied to the eastern and western borders of the grid squares.

As used by the United States Engineers, the zero of the grid system may be an assumed point which is not necessarily the origin of the system. The origin of the coordinates, or the point from which the computations should be based, is that point the meridian of which is parallel to the north-and-south grid lines. This can only be obtained by reference to the original survey notes.

In order to convert rectangular coordinates to geographic coordinates when the former are referred to a geographic position, the following method is employed in the Coast and Geodetic Survey in applying the local surveys of the United States Engineers. For cartographic purposes within the limits of our large scale charts this method is sufficiently close.

EXAMPLES

Examples are here given to serve as a guide in determining positions in any quadrant:

To find the geographic position of a point whose rectangular coordinates from a known geographic position are given.

By the use of the polyconic projection tables, United States Coast and Geodetic Survey Special Publication No. 5, the following are examples:

Example No. 1.—Find the geographic position of a point 40,000 feet south and 160,000 feet east of a point whose geographic coordinates are:

Latitude, 46°16′ 1,073 meters.
Longitue, 124°03′ 99 meters.

Latitude—south coordinates:

40,000 feet		=12, 192 meters.
		1, 073 meters.
South of	46°16′=	11, 119 meters.
From table	−7′=	12, 968 meters.
Latitude	46°09′	1, 849 uncorrected.
		−194 curvature.
Latitude	46°09′	1, 655 meters.

(Use in taking out longitude values.)

Longitude—east coordinates:

160,000 feet		=48, 768 meters.
		99 meters.
East of	124°03′	48, 669 meters.
	−30′=	38, 616 meters.
		10, 053 meters.
	−5′=	6, 436 meters.
		3, 617 meters.
	−3′=	3, 862 meters.
Longitude	123°25′	245 meters

Curvature correction:

$$\left(\frac{48,768}{10,000}\right)^2\times 8.14=4.88^2\times 8.14=194 \text{ meters.}$$

Example No. 2.—Find the geographic position of a point 30,000 feet north and 155,000 feet west of a point whose geographic coordinates are:

Latitude, 38°20′ 426 meters.
Longitude, 75°10′ 315 meters.

Latitude—north coordinates:

30,000 feet		=9, 144 meters.
		426 meters.
North of	38°20′=	9, 570 meters.
	+5′=	9, 250 meters.
Latitude	38°25′	320 uncorrected.
		−138 curvature.
Latitude	38°25′	182 meters.

(Use in taking out longitude values.)

Longitude—west coordinates:

155,000 feet		=47, 244 meters.
		315 meters.
West of	75°10′=	47, 559 meters.
	+30′=	43, 668 meters.
		3, 891 meters.
	+2′=	2, 911 meters.
	75°42′	980 meters.

Curvature correction:

$$\left(\frac{47,244}{10,000}\right)^2\times 6.21=4.72^2\times 6.21=138 \text{ meters.}$$

Table of curvature for X=10,000 meters

Latitude	Y in meters	Latitude	Y in meters	Latitude	Y in meters	Latitude	Y in meters
°		°		°		°	
25	3. 65	32	4. 89	38	6. 12	44	7. 56
26	3. 82	33	5. 09	39	6. 34	45	7. 83
27	3. 99	34	5. 28	40	6. 57	46	8. 10
28	4. 17	35	5. 48	41	6. 80	47	8. 39
29	4. 34	36	5. 69	42	7. 05	48	8. 69
30	4. 52	37	5. 90	43	7. 30	49	9. 00
31	4. 71						

RECTANGULAR COORDINATES FOR THE STATES OF THE UNITED STATES

An important aid to practical cartography has been supplied by the establishment of plane coordinate systems for all the States of the United States. In response to the demand for coordinate systems that may be applied to extensive areas, the control data are now put into such form as to be most readily available to the engineers in cadastral and public-works surveys. Each system is referred to one origin and extended over the whole area of the original projection so that every point on the map is coordinated both with respect to its position in a given square as well as to its position in latitude and longitude.

The trigonometric computations and refinements of a geodetic survey which takes into account the spheroidal shape of the earth need no longer concern the local surveyor who, with the simpler rectangular coordinates, automatically fits his local operations on the plane into the general geodetic control of a State-wide unit.

When the coordinate system is based on a definite system of projection, the scale distortion becomes known for all parts of the region and a relationship with the meridians and parallels is established. Definite scale factors for different parts of the map can be furnished and readily applied so as to bring the computations practically within geodetic accuracy.

With local surveys fitted into such a rectangular control, they can serve as a basis for further work in the same region, and will be coordinated with the work in any other region of the State. The triangulation stations are furnished for latitude and longitude by the Coast and Geodetic Survey, and in most cases now have an azimuth mark. The same stations are also furnished with their plane coordinates which, when plotted on the rectangular grid, will provide the control for a traverse from a station by turning off an angle from the azimuth mark to the next station. The work can then be continued on the plane and checked with other control points as the survey proceeds. Discrepancies can be distributed throughout the traverse and the survey coordinated with the general control.

As the subject of rectangular coordinates is directly related to the subject of map projections, a careful study is necessary in the choice of projection suited to the configuration of any locality or State. The properties and advantages of conformal projections have already been noted under their subject chapters of this publication. An added superiority is obvious in the use of two standard parallels, or, as in the case of transverse projections, the reduction of the scale along the central meridian so as to give a balance of scale within the limits of the projection. States and localities of predominating east-and-west dimension, such as North Carolina, Tennessee, and Long Island, N. Y., naturally call for a Lambert conformal projection with two standard parallels. New Jersey with its greater dimension in a north-and-south direction is better served with a Transverse Mercator projection with coordinates related to a central meridian. To give balance to the scale in the latter system, the scale is reduced along the central meridian so as to provide for exact scale along two circles formed by plans parallel to the plane of the central meridian. The process is similar to what we should have in the ordinary

Mercator projection if the scale were held exact at certain parallels north and south of the Equator. For some of the States, owing to their size and shape, two or more systems have been employed in order to avoid the large scale errors which might arise in the use of a single system.

The quadrillage or system of kilometric squares based on the Lambert projection, so successfully used by the Army in France, has thus gradually come into more general use in the United States.

Successfully employed in this country in small units by the United States Engineers, the extension of such a system to units of larger dimensions will serve a most useful purpose in the coordination of the work of State, city, county and public-works surveys.

The following manuals of plane coordinate computations have been issued by the United States Coast and Geodetic Survey:

Special Publication No. 193, Manual of Plane-Coordinate Computation.

Special Publication No. 194, Manual of Traverse Computation on the Lambert Grid.

Special Publication No. 195, Manual of Traverse Computation on the Mercator Grid.

Serial No. 584, Azimuths from Plane Coordinates.

WORLD MAPS

Regardless of the frequent criticism of the use of a Mercator projection for a map of the world, the defects are, after all, greatest in the polar regions. Generally our interests are centered between 65° north latitude and 55° south latitude, and it is in this belt that other projections present even greater difficulties when the world is mapped in one continuous sheet. When continuity and orientation as to cardinal directions are desired in this wide expanse of the earth's surface, the Mercator projection provides these special properties and avoids the discontinuities or breach of orderly arrangement seen in other world maps. The projection will undoubtedly remain a fixture within its own province. Nevertheless it is true that for geographic studies and for distribution purposes the projection is entirely unsuited, and it becomes necessary to find a representation in which the property of *equal area* is preserved. In respect to finding an equal-area projection adapted to a strictly continuous map of the world, no satisfactory solution has as yet been offered, and resort to a division of the earth's surface into hemispheres is preferable.

This method of representation has been successfully employed by the use of the Lambert meridional equal-area projection in the following atlases: Atlante Internazionale del Touring Club Italiano, Milano, 1929, and Nordisk Världs Atlas, Stockholm, 1926.

In respect to arrangements into smaller divisions than hemispheres, the difficulties are not solely due to the attempt to depict the spheroidal surface of the earth upon a plane. It is the great land masses of the Eastern Hemisphere, with their political considerations, that operate against evenly balanced alignments in tripartite or quadripartite units. In Elements of Map Projection, Special Publication No. 68, United States Coast and Geodetic Survey, figure 75 shows a Sinusoidal projection of the world in a tripartite arrangement which is probably as good as any, unless the Parabolic equal-area projection is preferred. The parabolas of the meridians in the latter projection are perhaps more pleasing to the eye than sine

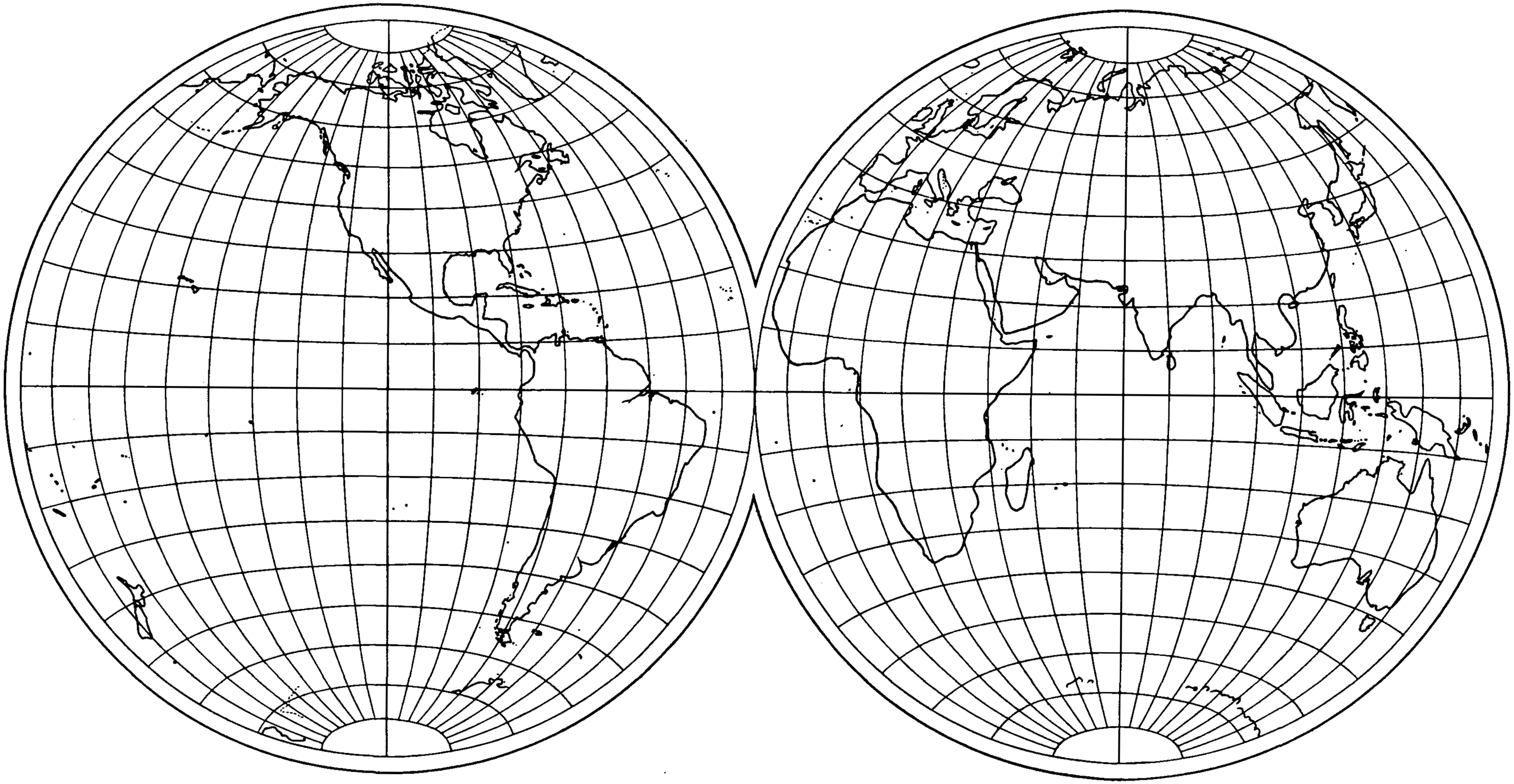


FIGURE 13. – LAMBERT MERIDIONAL EQUAL-AREA PROJECTION OF THE TANGENT HEMISPHERES.

curves, and the symmetry of the whole is a matter of personal taste. The Parabolic equal-area projection is shown as Plate IX in the same publication which includes a number of other studies in equal-area world projections.

In regard to the projection for the International Map, scale 1:1,000,000, it is unfortunate that an equal-area projection was not adopted. In view of the many criticisms of the projection, and without attempting any discussion, it is only fair to quote the following:

> In the writer's opinion, however, it would have been better to take as a reducing factor $\frac{1}{6}\lambda^2 \cos^2 \varphi_m$, [where φ_m is the mean latitude of a sheet and λ the longitude, reckoned from the central meridian in radians, of a point on the map], thus following Airy's criterion of making the average error a minimum and the total area true. But as a matter of fact the correction is on these sheets so small as to be within the errors caused by hygrometric changes in the paper.—A. E. Young, Some Investigations in the Theory of Map Projections, p. 67, 1920.

The knowledge that a projection provides an equal-area representation is of no small importance where the question naturally arises and a great number of sheets are involved.

Two projections of the sphere that are found in some atlases, as giving a fair representation of the world, are the Van der Grinten projection and Gall's projection. These two are neither conformal nor equal area, and may be classed as intermediates having no properties of definite scientific value. They present a fair uniformity in the configuration of the world, avoiding the excessive scale increments of the Mercator in the higher latitudes and lessening the distortions of equal-area projections. Their utility nevertheless is pictorial and their practical importance is limited. The two projections are described by J. A. Steers: An Introduction to the Study of Map Projection, London, 1929.

In regard to interrupted projections considerable attention has been given to their use for equal-area world maps. They generally present an unnatural picture of the world as a whole, and are seen in their worst form when, for the sake of better orientation, the meridians assume reverse curves or when they are mathematically discontinuous at other parallels than the Equator. However, in the case of the Western Hemisphere alone, two alignments of meridians—a central one for North America and a central one for South America—have given interesting results for the land masses of the two continents. Such an outline map of North America and South America on a Parabolic equal-area projection, scale 1:10,000,000, has been prepared for the Department of Genetics of the Carnegie Institution.

For purposes of acquiring better scaling properties at the expense either of conformality or equal area, it should be remembered that such scaling properties in other types of projection cannot ordinarily be formulated to a sufficient degree of advantage to admit their introduction. Although much study has been given to compromised properties as in "balance of error" and "minimum error" projections, these have not generally been well received by cartographers. Among this class of compromised properties the Van der Grinten projection has been employed by the National Geographic Society for a map of the world and offers an interesting study in the problem of world mapping. Its use, however, is limited. Continuity is only presented pictorially in a middleground between conformality and equal area, and difficulties arise in expressing any desired properties in analytic terms. Variations of scale or errors of scale are ever present in all maps covering a considerable extent of the earth's surface, and these errors can generally be better accounted for in projections where their properties are clearly defined and where spherical relations are more readily applied.

The Mercator conformal projection, so useful in nautical charts, has undoubtedly given an erroneous impression in the relative size of land masses, and for this reason there has been an increasing demand for equal-area projections in atlas maps.

The term *orthomorphic* which is sometimes used as synonymous with *conformal* signifies *right shape;* but this term is somewhat misleading, since, in conformal projections the scale in certain directions necessarily changes from point to point, and if the area mapped is large, the shape of any large country or continent may not be preserved. The term orthomorphic must therefore be used in a limited sense.

It is thus important, especially in extensive areas of the earth, to give careful consideration to the selection of a projection. Conformality meets the requirements of the navigator and the engineer, and equal area meets the requirements of geography.

GENERAL OBSERVATIONS ON PROJECTIONS

When the general shape of an area is known, and the problem of choice between conformality and equal area is under consideration, the projections generally involved are:

1. The Transverse Mercator for *conformality* and the Bonne projection for *equal area*, when the locality has a predominating north-and-south extent.
2. The Lambert *conformal* projection and the Albers *equal-area* projection, when the locality has a predominating east-and-west extent.
3. The Stereographic projection for *conformality* and the Lambert azimuthal projection for *equal area*, when the locality is approximately of equal magnitude in all directions.

A GUIDE FOR THE IDENTIFICATION OF PROJECTIONS, WITH A BRIEF OUTLINE OF THEIR PROPERTIES

In this chapter certain characteristics of the different projections are emphasized in order that the system of projection of a map or chart may be more easily recognized. In maps approaching continental proportions, precise measurements are available but in those of limited extent the properties peculiar to different projections are frequently not sufficiently in evidence to serve for identification purposes. Distortion of the paper under certain methods of printing or due to changes in the humidity of the air must be taken into account as resulting differences in maps of limited extent are often as large as the differences in systems of projection.

The following methods of identification are not infallible because of the possibility of meeting unusual projections that may be modified or transversed to serve special requirements or purposes of expediency. It is possible, however, for one having a slight knowledge of properties or formulas of the several projections used in atlas maps to identify the systems. The following outlines will serve as a guide for the majority of cases.

1. WHERE MERIDIANS AND PARALLELS ARE STRAIGHT LINES INTERSECTING AT RIGHT ANGLES

Mercator projection.—This projection is the only one here included as coming under this class. It has a world-wide use especially for nautical charts. In a general map of the world on a Mercator projection it is readily seen that the projection graticules become increasingly too large as their distances from the equator increase, and it follows that areas of considerable latitudinal extent are not correctly represented relatively.

The noticeable characteristics in the framework are:

(*a*) Meridians and parallels are straight lines intersecting at right angles.
(*b*) The interval between the meridians is a constant throughout the map.
(*c*) The rate of increase in latitude is the same as the rate of increase in longitude.

2. WHERE MEREDIANS ARE STRAIGHT LINES AND THE PARALLELS ARE CONCENTRIC CIRCLES, EQUIDISTANT OR OTHERWISE

Conic projection.—The simple conic projection sometimes appears in atlas maps for countries of small extent.

(*a*) The meridians are straight lines along which the parallels may be equidistant, truly spaced, or arranged in such a way as to give some other desired property, as conformality or equal area.

(*b*) The parallels are concentric circles and the scale is held true along one parallel only, the standard parallel or parallel of tangency of the developed cone, this parallel being usually the central parallel of the map.

(*c*) When the distance between the parallels becomes increasingly greater in opposite directions from the standard parallel, the projection is the conical *conformal* projection.

(*d*) When the distance between the parallels becomes increasingly less in opposite directions from the standard parallel, the projection is the conical *equal-area* projection.

Lambert conformal conic projection with two standard parallels of true scale.—This projection is used for a *conformal representation* in maps generally covering large areas and preferably where there is a predominating east-and-west extent as in the case of the United States.

(*a*) The meridians are straight lines and the parallels are concentric circles cutting the former at right angles. The angles formed by any two lines on the earth's surface are correctly represented on this projection.

(*b*) Between the standard parallels the intervals of latitude along the meridians are *too small* and beyond the standard parallels the intervals are increasingly *too large* as we approach the top or bottom of the map. East and west from the central meridian, on every parallel the intervals of longitude are equal but, excepting the standard parallels, they are *too small* or *two large*, because the longitude scale varies as the latitude, being always of the *same sign*, minus or plus, as its corresponding latitude scale in every grid.

Albers conical equal-area projection with two standard parallels of true scale.—This projection is used in atlases for purposes of *equal-area representation* in maps generally covering large areas and preferably where there is a predominating east-and-west extent as in the case of the United States.

(*a*) The meridians are straight lines and the parallels are concentric circles cutting the former at right angles.

(*b*) Between the standard parallels the distances between the intermediate parallels are *too large* and beyond the standard parallels the distances between the parallels are increasingly *too small* as we approach the top or bottom of the map. East and west of the central meridian on every parallel, the intervals of longitude are equal but compensatingly *too small* or *too large*, being always of *opposite sign* to the corresponding latitude intervals in every grid, because the projection is equal area; or, it may be stated that the product of the meridional scale by the scale at right angles to it at any given point must be unity.

3. WHERE PARALLELS ARE STRAIGHT LINES AND MERIDIANS ARE CURVED LINES

Sinusoidal projection.—This projection is a special case of the Bonne projection in which the equator is chosen for the standard parallel.

The projection is used rather extensively in atlases for maps which embrace the equatorial regions and which are generally of continental proportions, as in the case of Africa and South America.

(*a*) The curved parallels of the Bonne projection become straight lines on this projection and their intervals along the meridians are truly spaced.

(*b*) The meridians except the central meridian are curved lines and the intersections of parallels and meridians depart increasingly from right angles as the distance from the central meridian increases.

(*c*) In a map of the world all the meridians converge to a common point at the pole.

Parabolic equal-area projection.—This projection resembles the Sinusoidal projection in its properties and general appearance. Instead of sine curves, the meridians are parabolic curves which are perhaps more graceful. The distances between the parallels instead of being true to scale decrease towards the pole and, in a map of the world, all the meridians converge to a common point at the pole.

Mollweide projection.—The bounding line of a Mollweide projection of the world is an ellipse. The projection may be identified by the closer parallels towards the pole and the very noticeable meridional excess between the parallels near the Equator.

4. CHARACTERISTICS OF PROJECTIONS NOT INCLUDED IN 1, 2, AND 3

Modified polyconic or polyconic projection with two standard meridians.—This projection is used in the sheets of the International Map, scale 1:1,000,000. It is not easily distinguished from the simple conic projection.

(*a*) The meridians are straight lines and the parallels are curved lines on which the meridional intervals in the single sheets are practically equally spaced.

(*b*) The error appearing along the outer meridians in the ordinary polyconic projection is lessened in this projection by distribution of scale error in having two standard meridians instead of one central meridian.

Bonne projection.—The Bonne projection is an equal-area projection which is extensively used in atlases for maps of continental or lesser proportions.

(*a*) Distances along the central meridian are true to scale and all parallels are divided truly.

(*b*) The parallels are concentric circles and all the meridians except the central meridian are curved lines.

(*c*) The lengths of the intervals of latitude along the meridians gradually increase as we depart from the central meridian, and the intersections of parallels and meridians depart increasingly from right angles as the distance from the central meridian increases.

(*d*) To distinguish this projection from the polyconic, see paragraph *d* under *Polyconic projection* which follows.

Gnomonic projection.—The description of this projection is given in detail on page 43.

(*a*) The meridians are straight lines which generally do not intersect the parallels at right angles, the exceptions being the crossings of the meridian passing through the point of tangency.
(*b*) The parallels are curved lines which are conic sections and therefore nonconcentric except in the gnomonic polar projection where the circles of the parallels are concentric.
(*c*) The projection may also be recognized by its rapidly increasing distance between the parallels, and its increasing scale and distortion toward all the borders. A complete hemisphere can not be constructed as the projecting lines become parallel to the plane of projection for points 90 degrees distant from the center of the map.

Polyconic projection.—This projection, largely on account of facility of construction because of the availability of general tables covering the whole spheroid, is used extensively for field sheets and for maps of limited extent. The projection is neither conformal nor equal area.

(*a*) The parallels are arcs of circles which are not concentric, and the meridians, except the central meridian, are curved lines.
(*b*) Along the central meridian the distances between parallels are truly spaced. The arcs of the developed parallels are also truly spaced.
(*c*) The lengths of the spacings of latitude along the meridians gradually increase as we depart from the central meridian, and the intersections of meridians and parallels depart increasingly from right angles as the distance from the central meridian increases.
(*d*) The projection in maps covering considerable extent, can be distinguished from the Bonne by the fact that in the latter the circles of the parallels are concentric and therefore remain the same distance apart between any given latitudes.

Lambert meridional equal-area projection and the Lambert horizon equal-area projection.—These two projections are admirably suited for extensive areas having approximately equal magnitudes in all directions, as for example, the continent of Asia or Africa. They embody the properties of true azimuths from a central point and equal-area representation, the former projection being useful when the center of the map is on the equator, and the latter when the center of the map is on another parallel.

(*a*) Both the meridians and parallels are curved lines which do not intersect at right angles excepting the crossings of the central meridian and equator of the first-mentioned projection, and the crossings of the central meridian only of the second. When the pole is the center of the map, the meridians become straight lines and the parallels concentric circles.
(*b*) If we conceive of a system of concentric circles about the center of the map, these two projections have the property of decreasing scale along the radii with a compensating increase along the circumferences of the circles. This is most easily tested by noting that the spacing of the parallels along the central meridian *decreases* as we depart *from the center of the map.*
(*c*) When the Lambert azimuthal equal-area projection has its center on the Equator, it is generally known as the Lambert meridional equal-area projection which is frequently employed for the mapping of a hemisphere.

Azimuthal equidistant projection.—This projection is sometimes employed in maps of continents, and, in a few instances, in world maps. It has the property that all straight lines radiating from the center represent great circles in their true azimuths from the center, and the distances along these lines are true to scale.

(*a*) Both the meridians and parallels are curved lines which generally do not intersect at right angles, except along the central meridian, or when the center of the projection is the pole. In the latter case the meridians are straight lines and the parallels concentric circles.

(b) The central meridian is divided truly and this fact may serve as a partial test to identification of the projection.

The projection is becoming more frequent and, in areas of limited extent, resembles several other projections. Certainty of identification may require measurements from tables or the use of formulas where tables are not available. In maps on this projection where the boundary line is a circle supplied with an evenly divided periphery scale for the measurement of bearings from a central point, identification is simplified.

Stereographic meridional projection and the Stereographic horizon projection.—The stereographic-meridional projection is sometimes seen in atlases where the conformal representation of a hemisphere is desired. It has of late fallen more or less into disuse, being superseded by the Lambert meridional equal-area projection.

(a) Except the central meridian and the Equator which are straight lines, all other meridians and parallels are curved lines, and all meridians and parallels cut one another at right angles.

(b) The scale increases conformally in all directions from the center of the map. While this feature gives true shapes for small or limited areas, on the other hand it gives a false impression of size in countries of large extent. Scale and area are correct only in any restricted locality when referred to the scale of that locality, but as the scale varies, large areas are not relatively correctly represented.

In the Stereographic meridional projection the center is located on the Equator; in the Stereographic horizon projection the center is located on any selected parallel, and the Equator becomes a curved line.

Hammer-Aitoff projection.—The bounding line of this projection when used for a map of the world is an ellipse. It can be identified by the fact that both systems of reference lines are curved.

USE AND NAME OF PROJECTIONS

The particular purpose for which the map is constructed usually determines the type of projection upon which it is based. The cartographer becomes readily acquainted with those universally used, as:

(a) Mercator, for nautical charts and continuous world maps.

(b) Equal-area (including the Bonne, Sinusoidal, and Lambert), for geography and purposes of classification of distribution and concentration topics.

(c) Gnomonic, for great-circle routes.

(d) Equidistant, for distances and azimuths from a central point and for transmission and commercial purposes.

(e) Lambert meridional projection, for maps of hemispheres.

(f) Mollweide, for equal-area world maps.

(g) Lambert conformal for areas of predominating east-and-west extent.

The intelligent use of any map or chart requires identification of the projection upon which it is constructed. This is almost as important as the scale, but unfortunately in too many instances maps and charts do not indicate the system employed. Cartographers in supplying information as to the name of the projection and its center of construction would not only assist in a more complete understanding of the map or chart, but would also increase the familiarity of map users with the various systems and their special properties.

Chapter V.—ELEMENTS OF DIRECTION AND ITS RELATED TERMS—DIFFERENT WAYS OF DEFINING DIRECTION

DIRECTION

The direction of an object is the line of vision toward it, or the line in which anything is lying or pointing, or the line in which an object is moving; thus, Pittsburgh is situated in an approximately northwesterly direction from Washington; the ship sailed in a southeasterly direction.

It is important, however, to distinguish between two kinds of direction, viz.—bearings or azimuths which are great circles and measure the shortest distance between two points; and, on the other hand, courses which are rhumb line directions.

Meridians are great circles and are at right angles to the equator which is also a great circle. Parallels of latitude are rhumb lines, at right angles to the meridians, and are true east-west lines, thus,—a direction, defined as *due east*, follows the parallel and not the great circle. See following pages for further description of terms relating to direction.

Winds and currents.—A north wind blows in a southerly direction but a southerly current flows toward the south.

Seemingly at variance with the definition of direction, winds derive their names from their source or the cardinal points *from which* they blow. This sense of direction has its origin with the ancients among whom winds were regarded as personalities, or rather deities; thus, in Greek, Boreas was the north wind, Eurus the east wind, Notus the south wind, and Zephyrus the west wind.

It is from this same idea that the four principal cardinal points of the compass are sometimes referred to as *the four winds.* The winds were confined in a cave of which Aeolus had the management and without this necessary precaution, they would have overturned the earth and reduced everything to its original chaos. On the Tower of the Winds at Athens, still standing in excellent preservation, eight winds are represented.

In works of art, the winds were represented with winged heads and shoulders, open mouths, and inflated cheeks. Likewise on medieval and even later charts, the points of the compass are symbolized by heads shooting forth air currents from the mouth. In some of the Ptolemy maps, the meridians issue from the mouth of a symbolic head representing the north pole.

Although some later commentators have assumed these symbols to be purely a part of the decorative feature of the map, they are, in fact, illustrative of points of the compass.

Direction is usually considered from our general mental standpoint rather than as a definitely determined relation. We speak of an object as being north of us when its accurate direction may be several degrees to the right or left of north.

CARDINAL POINTS AND THE MARINER'S COMPASS

The four principal points are called *cardinal points* and are named North, South, East, and West, as determined by the four intersections of the horizon with the meridian and the prime vertical. Midway between the cardinal points are the *intercardinal* points, named according to their position, Northeast, Southeast, etc.

In the mariner's compass the circle is divided into 32 parts or *points*, also called *rhumbs*, all of which are named from their respective directions (magnetic), as N. by E., SSW, etc. For lesser divisions, points of the compass are further divided into halves, quarters, and eighths.

The names of whole points, together with fractional points of the compass, are given on page 28, Bowditch: American Practical Navigator, 1938. The list also shows the degrees, minutes, and seconds from north or south to which each division corresponds.

True and magnetic bearings are usually expressed from zero (north) clockwise to 360°; in some instances bearings are expressed from zero (south), or by quadrants each separately from north or south.

ORIENTATION

Orientation is a process of determining direction in maps relative to the earth's surface itself. The original meaning implies looking to the eastward, from the fact that early medieval maps were drawn with the east on top, in veneration of the sacred places.

It is essential to have some such indication of direction on every map, not necessarily a turning to the east, but to a point which is serviceable from an astronomic viewpoint and in conformity with the system of reference lines of latitude and longitude of the map. At the present day, maps are drawn almost universally with true north at the top. In cases where maps or plans are not so arranged the indication of direction is generally given by compass or arrow.

Although a map may be oriented to the north, it should be remembered, especially where a considerable extent of the earth's surface is shown, that true north is indicated by the direction of the meridians and not by the top of the map except at its central meridian.

BEARING

A bearing is an azimuthal direction measured from the meridian at origin. It is the direction of a line which is a great circle. Although the direction changes at every point along the great circle, the line (or curve) of the great circle represents the shortest distance line between any two points.

A bearing may be expressed in a number of ways, of which the following are most frequent:

1. By points (magnetic), as NNW.
2. By degrees of a quadrant (magnetic), as N. 22° W. (mag.).
3. By degrees clockwise from N. (true), as 338°.
4. By degrees of a quadrant (true), as N. 22° W.

Although all bearings are azimuths, and the use of either term is correct, *bearing* is more often used in navigation, land surveys, and descriptions, and is expressed in one of the above ways. In celestial navigation, the term azimuth is commonly used and is reckoned from the north. *Azimuth*, as used in the United States in geodetic computations, is always measured clockwise from the south.

COURSE

A course is a rhumb line direction, or the direction of a line which makes a constant angle in crossing successive meridians. It does not represent the shortest distance between any two points; thus, a ship's course is 304° (true), or NW. ¼ N. (magnetic), approximately, when the variation is 14° W.

VARIATION OF THE COMPASS

Magnetic variation, also called the declination, at any place is the angle between the geographic or true meridian and the magnetic meridian. The magnetic meridian is fixed by the direction taken by the magnetic needle when free from any deviation error inherent in itself. The compass needle will not, in general, indicate true north, but each compass pointing will differ from the true north by an amount equal to the algebraic sum of the variation and the deviation of the particular compass used.

Besides the error thus produced in the indications of the compass, a further one, due to local attraction, may arise from extraneous influences in certain places in which the distribution of the earth's magnetism is very irregular. Due to the proximity of magnetic masses, either natural or industrial, the variation at two places only a short distance apart may be materially different.

DEVIATION OF THE COMPASS

Deviation is the angular difference between a compass direction and a magnetic direction of any given heading. This is caused by the influence of permanent and induced magnetism of the ship itself; the effect is that the compass needle does not lie in the magnetic meridian, but generally to one side or the other. It differs for each heading of the ship, and the values determined at one place cannot be used in determining courses at a distant place. In order to meet navigational requirements, special deviation cards or tables are prepared which will give the amount of the corrections for the various headings of the ship.

By applying deviation to a compass course, we obtain the magnetic course; by applying variation to a magnetic course, we obtain a true course. In order, therefore, to obtain true courses, compass courses require correction both for deviation and variation.

The process for applying corrections of variation and deviation is given on pp 59–61, Bowditch: American Practical Navigator, 1938, and in Civil Aeronautics Bulletin No. 24, pages 70 to 75 and 80–83.

RADIO BEARINGS AND MERCATORIAL BEARINGS

Inasmuch as the meridians of a Mercator chart are represented by parallel lines, it follows that the *true bearing* of a ship from a point as a station, or vice versa, cannot be represented by a straight line joining the two positions. The straight line joining them on the chart being the *mercatorial* bearing, differs from the true bearing by ±½ the convergency of the meridians.

CONVERSION OF RADIO BEARINGS TO MERCATORIAL BEARINGS

The increasing use of radio directional bearings for locations of ships' position at sea, especially during foggy weather, has made it particularly desirable to be able to apply these radio bearings taken on shipboard or sent out by the shore stations directly to the nautical chart. These radio bearings are the bearings of the great circles passing through the radio stations and the ship, and unless in the plane of the equator or of a meridian, would be represented on a Mercator chart as curved lines. Obviously it is impracticable for a navigator to plot such lines on his chart, so it is necessary to apply a correction to a radio bearing to convert it into a mercatorial bearing; that is, the bearing of a straight line on a Mercator chart laid off from the transmitting station and passing through the receiving station.

In the United States Coast Pilots, published by the United States Coast and Geodetic Survey, there is given a table of corrections for the conversion of a radio bearing into a mercatorial bearing. It is sufficiently accurate for practical purposes for distances up to 1,000 miles.

The only data required are the latitudes and longitudes of the radiobeacons or direction-finder stations and of the ship by dead reckoning. The latter is scaled from the chart, and the former either scaled from the chart or taken from the published list of radiobeacon and radio direction-finder stations found in the Light List, United States Department of Commerce, or in Radio Aids to Navigation, Publication No. 205, Hydrographic Office, United States Navy Department.

A more complete table and method of applying the corrections, including a formula for more accurate determinations is given in Association of Field Engineers Bulletin, United States Coast and Geodetic Survey, June 1932, pages 101–108.

The method as described is equally applicable to aeronautical charts published on a Mercator projection.

AZIMUTH

The azimuth of a line from a point *A* to a point *B* is the angle between the vertical plane containing the line *AB* and the meridional plane at *A*. In the United States, as has already been stated, azimuth in geodetic computations is measured clockwise from the south.

In modern times, and in accordance with the practice of geodetic surveying and astronomy in favoring the south point, exploratory and general surveying are more or less following the same method. The practice of reckoning azimuth from the south, however, is not universal and some scientists refer azimuths to the north point in preference.

Most azimuths at sea are referred to the north point. In Hydrographic Office, United States Navy, Publication No. 71, Azimuths of

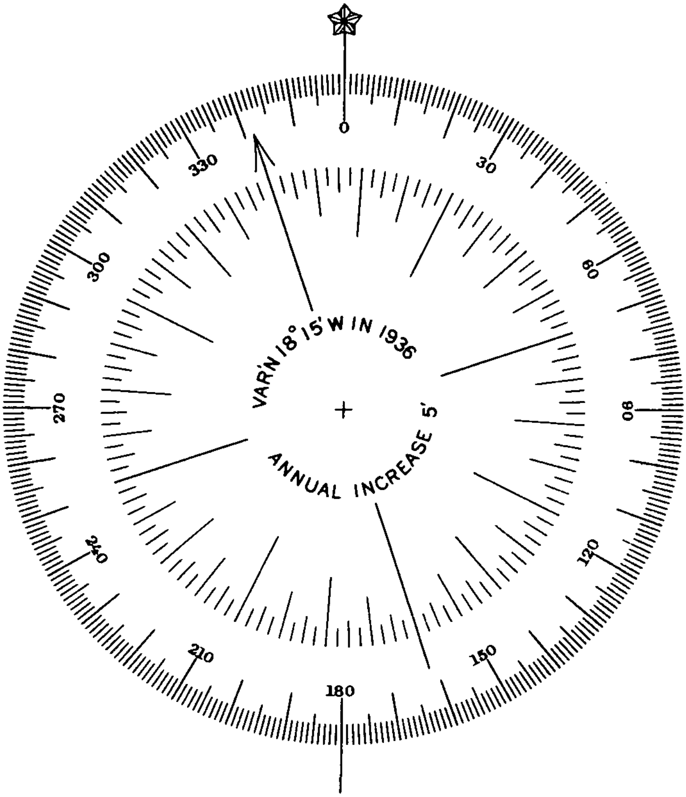


FIGURE 14. — COMPASS ROSE.

As used in various sizes on U. S. Coast and Geodetic Survey charts.

the Sun, certain special rules are observed in the tables for the reckoning of azimuths in north latitude and in south latitude.

FORWARD AND BACK AZIMUTHS

In any line other than a north-and-south line, the two ends will lie on a different meridian. It follows then, that the azimuth of a line reckoned from one end will not be exactly 180 degrees different from the azimuth of the line computed from the other end, due to the convergence of the two meridians. From this condition, therefore, the line defined by the forward azimuth and the line defined by the back azimuth are not coincident.

The back azimuth equals the forward azimuth, $+180^\circ+\Delta\alpha$, in which $\Delta\alpha$ represents the convergence of the meridians.

$\Delta\alpha=-\Delta\lambda \sin \frac{1}{2}(\phi_2+\phi_1)$ in which $\Delta\alpha$ is expressed in seconds.

$\Delta\lambda(=\lambda_2-\lambda_1)$ is the difference between the longitudes of the ends of the line, expressed in seconds.

ϕ_2 and ϕ_1 are the latitudes of the ends of the line.

With the azimuths reckoned clockwise from the south, in the northern hemisphere, it results that $\Delta\alpha$ is subtracted numerically when the forward azimuth lies between 0° and 180°, and added numerically when it lies between 180° and 360°. In the southern hemisphere the signs are reversed.

For long lines a more precise formula is given on page 8, Formulas and Tables for the Computation of Geodetic Positions, Special Publication No. 8, U. S. Coast and Geodetic Survey.

Azimuthal properties in map projections have been discussed under the subjects, Lambert azimuthal equal-area projection, azimuthal equidistant projection, and Gnomonic projection.

GEODETIC LINES, GREAT CIRCLES, AND RHUMB LINES

A geodetic line, sometimes termed a *geodesic*, is the shortest or minimum line that can be drawn between any two given points on the ellipsoidal surface of the earth. More generally, a *geodesic* may be the shortest line btween any two points on any surface.

A great circle is the line of intersection of the surface of a *sphere* by a plane passing through the center; and a shortest distance line is thus represented by an *arc* of a great circle.

In computing the shortest distance between two points on the earth's surface it is customary to regard the earth as a sphere of equal surface in which 1 minute of arc of a great circle is equal in length to a nautical mile, or 1,853.248 meters. (For a discussion of the length of a nautical mile, see U. S. Coast and Geodetic Survey Report, 1881, Appendix No. 12).

For ordinary purposes the great-circle distance is sufficiently accurate, but for greater precision corrections are necessary in order to reduce to the distance on the spheroid. Under certain azimuthal conditions, a difference of as much as 11 statute miles has been noted in the computed distance of sphere and of spheroid, in a total distance of 6,800 miles.

The solution by spherical triangle is given in Bowditch: American Practical Navigator, pages 87–89.

A rigid computation of a long distance is so laborious that it is employed only when extreme accuracy is required in geodetic problems. Special long-distance formulas have been devised to approximate the true distance, one of which is given in Manual of Triangulation and Adjustment, pages 207–208, Special Publication No. 138, United States Coast and Geodetic Survey.

A formula which is even better but involves more work was devised by Henri Andoyer, and is given in the following publications: Bulletin géodésique, no. 34, 1932; and in Annuaire, publié par le Bureau des Longitudes, 1935.

Still greater refinement in the length of a geodetic line may be obtained in Effect of Variations in the Assumed Figure of the Earth on the Mapping of a Large Area, Special Publication No. 100, U. S. Coast and Geodetic Survey.

A rhumb line, or loxodromic curve, is a line which crosses the successive meridians at a constant angle. Its use in nautical charts is due to the fact that a ship's track under a constant course is a straight line on the Mercator chart. Except on a meridian and the Equator, the rhumb line is longer than the great circle. Between a great circle and a rhumb line, the actual distance is frequently immaterial, being but one-fourth mile in 500 statute miles along parallel 40°. In longer distances, depending upon latitude and azimuth, the difference may increase very rapidly; and from New York to San Francisco the rhumb-line distance exceeds the true distance by 37 statute miles. At a central point between these two cities, the departure of the rhumb line from the great circle is as much as 181 statute miles.

General observations on the Mercator projection, the rhumb line and its use in navigation are given on pages 101–103 and 170–178 in Elements of Map Projection, Special Publication No. 68, U. S. Coast and Geodetic Survey.

GNOMONIC CHART

In this chapter, which deals with the subject of direction, it may be well to mention again the Gnomonic projection in regard to the compass rose. It should be noted that in this system of projection, a uniformly divided compass can only be placed at the point of tangency on which the projection is constructed. However, the rose can be held circular in any other part of the chart by making its graduations unequal in such a way as to meet Gnomonic requirements. With a compass rose so constructed at each radio station, directions, i. e., true azimuths, may be plotted as straight lines by means of a protractor. In other words, the true azimuths thus indicated are the traces on the plane of the projection of the planes of corresponding true directions at the station.

Instead of a special compass rose at a given radio station, a table of corrections from true azimuths to Gnomonic azimuths may be computed for each station on that particular Gnomonic chart in question. Such tables are given for a number of stations in Radio-Compass Bearings, Special Publication No. 75, U. S. Coast and Geodetic Survey.

Chapter VI.—TECHNIQUE OF CONSTRUCTION

SCALE AND THE SELECTION OF SCALE

The selection of the scale to be employed depends *first* upon the character of the country to be mapped, and *second* upon the uses which the map is intended to serve. These two factors determine the amount of detail to be included in the map, which in turn is the principal element to be considered in slecting the scale. To illustrate the application of these factors, the intricately developed terrain of New York State demands, for adequate presentation of detail, a larger scale than would be necessary for a comparatively featureless region. Likewise, the mariner, who must read his chart in the dim night light of his pilothouse, or the aviator, who must pick from his map at one brief glance the relationship of the salient features upon which his attention has centered, both demand a boldness of treatment of detail, with its intimate bearing upon scale selection, not necessary to the map which can be studied at leisure in daylight.

Considerations of convenience in handling, and of economy in cost usually exert their influence in favor of selecting small scales. On the other hand, minuteness of detail detracts from the clearness of the map and becomes a tax upon the reader. The cartographer must also have in mind limitations imposed by the mechanical processes used in printing the map, which may result in an unsatisfactory product if detail be too minutely drawn.

In selecting the scale the cartographer must arrive at a compromise between these opposing considerations. The basic consideration must be: How much will a given scale carry, and how much can we generalize?

Generalization is the art of distinguishing between the essential and the nonessential, and of utilizing the first and discarding the second. Its importance justifies separate consideration in another part of this publication, but because of its relation to scale it may be mentioned briefly here. Effective generalization is not the product of the mediocre mind. It is rather the product of the trained cartographer and affords the principal test of his efficiency. Good generalization is the most effective method of securing simplicity in the map, yet in no instance should accuracy in essentials be subordinated to simplicity. Generalization does not imply loose work or a haphazard selection of material; otherwise the finished map may present a satisfactory appearance and still be defective.

From the foregoing the relation of generalization to the selection of scale will be obvious. The cartographer who can generalize efficiently is justified in selecting a smaller scale than the one who, lacking that ability, tends usually to show too much detail for fear of omitting some which is essential. (See fig. 24.)

FRACTIONAL SCALE

The terms fractional, numerical, natural, and linear are used more or less interchangeably by cartographers. In this article the term fractional is employed when the scale is expressed, thus, $\frac{1}{100,000}$, 1—100 000, 1-100,000, or 1/100,000. Of these, the first one has the advantage of legibility and has a wide use on published maps and charts.

The scale determines the size of the map relative to the portion of the earth's surface represented. It is a system of proportion by which definite selected magnitudes on the chart represent definite given magnitudes on the earth, and it is therefore essential to the accuracy of a map that all linear dimensions bear the same relation to one another as they do in nature. This relation may be represented by what is termed the linear scale expressed as a fraction or a proportion; thus the fraction $\frac{1}{63,360}$ means that every dimension on the map is 1-63,360th of its actual dimension in nature. In general parlance such a map would be spoken of as 1 inch to the mile, there being 63,360 inches in a mile.

In the metric system the denominator of the fractional scale is naturally a round number and all units are related decimally. It therefore becomes more convenient to speak of $\frac{1}{100,000}$ or 1/100,000 than to say that the scale is 1 centimeter to 1 kilometer, especially when we are not fully accustomed to the use of the decimal system.

The determination of the fractional scale of a map is illustrated by the following example: Let us assume a map in which the intervals of latitude are given for every degree. Taking preferably a unit of 1° in the center of a given map, we find its meridional length in latitude 40°00′ to 41°00′ to measure 0.2776 meter. The actual length of 1° of the meridian on the corresponding portion of the earth's surface is 111,042.4 meters, as taken from the column "Lengths of Degrees of the Meridian," page 7, Special Publication No. 5, United States Coast and Geodetic Survey. The fractional scale of the map in question will therefore be expressed by the fraction $\frac{0.2776}{111,042.4}=\frac{1}{400,000}$ (approximately, or as closely as can be determined).

If it is desired to express the relation in miles to the inch, we measure the same meridional length on the map and find it to be 10.93 inches. The length of 1° of the meridian on the corresponding portion of the earth's surface is found from the same table to be 68.998 statute miles. Therefore, if 68.998 statute miles are represented by 10.93 inches, the scale of the map in terms of miles to the inch will be $\frac{68.998}{10.93}$ or 6.3 statute miles to the inch.

In the expression "miles to the inch" or "inches to the mile," it is customary to employ the one that avoids, in the statement, the fractional use of an inch as the representative term of the map in its relation to the ground, thus: The expression *10 miles to the inch* is preferred to its equivalent expression, *1 mile to one-tenth of an* *inch;* likewise, the expression *10 inches to the mile* is preferred to the expression, *1 inch to one-tenth of a mile.*

A scale expressing proportions in this way is not truly fractional, and when the relation is expressed as *inches to the mile*, or vice versa, it is better to use the name *proportional* scale rather than *fractional* scale.

In the contention as to choice between scales based upon the complicated British system of measures of length, and scales which are rounded off decimally as based upon the metric system, the former system leading to awkward fractions, as $\frac{1}{63,360}$, and the latter leading to scientifically convenient figures, as $\frac{1}{1,000,000}$, the tendency in modern times rather favors the latter system. However, until we become more accustomed to metrical units, the scale of the so-called "Millionth" map (1 kilometer=1 millimeter) does not establish itself in our mind quite so clearly as its equivalent expression, 15.78 miles to the inch. This inconvenience does not exist in continental Europe where people are accustomed to the metric system. By international agreement in adopting a decimal scale for the world map, English speaking people must remain content with the ill-adapted expression 15.78 miles to the inch if they wish to translate the expression "International Map 1/M." Moreover, the use of the expression "miles to the inch" or "inches to the mile," has a tendency to encourage the use of a foot-rule for scaling distances from the map, instead of using the graphic scale.

Further consideration on the subject of distortion and the use of scales in measuring distances are given under the heading, *Graphic Scale—Its Construction*, page 66.

PRINCIPAL SCALE, AND LOCAL OR PARTICULAR SCALE

Another property inherent in the scale of maps, has led to the use of such terms as "principal scale" and "local or particular scale." As the scale of a map varies in certain directions from point to point, the *principal scale* is generally based upon some meridian, parallel, or certain other line that is uniformly the same as the scale used for decreasing the spheroidal surface to the plane of the projection. In other directions where the scale may be larger or smaller than the principal scale, the name *local or particular scale* is generally applied. Thus, we have instances where the principal scale of a polyconic projection, as based upon a central meridian, may be 1:500,000; along the outer meridians the local or particular scale may be as large as 1:498,000.

The expression 1:1,000,000, which is proportional rather than fractional, is considerably used, especially in publications and correspondence.

SCALE AS A DETERMINING FACTOR IN THE DESCRIPTIVE NAMING OF A MAP

As the amount of detail required to be shown determines the scale, it will be found that maps or surveys of the same type or purpose in general follow the same limits of scale division. Thus the descriptive terms cadastral, topographic, atlas, or the simple word map, may generally be applied in accordance with the variation of scale from large to small.

In a general way the term *cadastral map* or *plan* is used for maps showing buildings, cultural features, boundaries, and extensive detail frequently of a registral character, the scales usually employed being 1 : 10,000 and larger.

The word *topographic* is employed in maps showing roads, railroads, towns, contour lines, and other detail, including maps for military purposes, ranging in scale from 1: 10,000 to 1: 1,000,000. Topographic maps generally exhibit an exact and scientific delineation and description of the place or region covered.

Maps of a scale smaller than 1: 1,000,000 are generally termed *maps or atlas maps*. They serve to delineate a more general configuration of the earth's surface, including its relief, boundaries, cities, railroads, stream courses, and similar data.

GRAPHIC SCALE—ITS CONSTRUCTION

As the fractional scale represents the ratio of a distance on the map to its corresponding distance on the earth, a graphic representation of this relation is rather simple. In thus translating map scale-distances to ground-distances in any desired units, our map units should be chosen for convenience in dividing and subdividing the total length of the scale, as well as for convenience in stepping off these distances with dividers.

The total length of graphic scales varies considerably in maps published by different organizations and in maps used for different purposes. The lengths also vary more or less with the size of the map and the unit that is employed. Graphic scales are usually from 3 to 7 inches in length.

What, for example, would be a convenient unit of division of miles, and the graphic length of such a scale on a 1: 1,000,000 map, size 18 by 22 inches? By trial, we find that intervals of 10 statute miles measure each about five-eighths of an inch, which is an easy step of the dividers. The length representing 80 miles (or eight such units) would be about 5 inches. In exact figures this length is obtained as follows: $\frac{63{,}360 \times 80}{1{,}000{,}000} = 5.07$ inches, in which the first term of the numerator is *inches to a mile*, the second term is the *number of miles*, and the denominator is the *scale of the map*.

It is found convenient to graduate this scale so as to have seven major divisions to the right of zero and one major division to the left of zero. The division to the left may be subdivided for convenience into 10 units of 1 mile each, the graduations to the left of zero serving as a subsidiary scale. By this arrangement single miles can be attached to multiples of 10 miles and minor distances read off at once with one step of the dividers. To measure distances greater than the length of the graphic scale, first, measure from the scale its total length and then, with this as a unit, step off distances between two given points until a part of this larger unit remains. This remaining part measured on the scale itself can be added to the sum of the larger units already obtained.

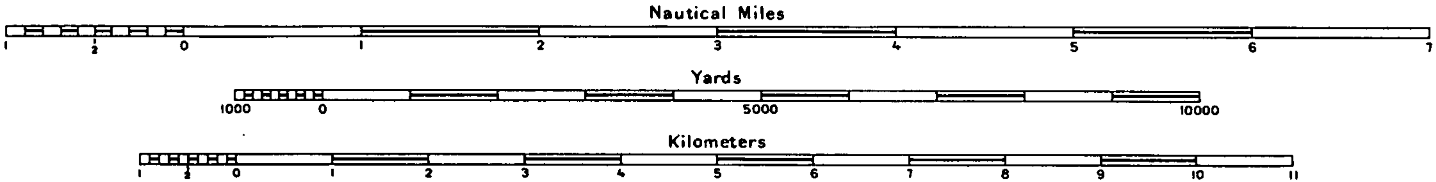


FIGURE 15. — GRAPHIC SCALE OF A CHART 1:80,000.

It is good practice to show on a map both a fractional scale and a graphic scale, but if the fractional scale has been omitted, and it is desired to determine a graphic scale, the length of the latter may be obtained directly from the projection intervals or grid system of the map.

Thus, in the preceding example, the length of a line representing 80 miles is found to be 5.07 inches. This length may be found without the use of the fractional scale, as follows:

Two degrees of latitude measured on the map=8.74 inches.

Two degrees of corresponding latitude from the tables=137.94 miles, assuming in this example the degrees of latitude to be 37° to 39°, and their corresponding values in statute miles as taken from *Lengths of Degrees of the Meridian*, page 7, Special Publication No. 5, U. S. Coast and Geodetic Survey.

The assumed total distance to be represented by the scale=80 miles. Therefore, we have the proportion, 137.94: 8.74: :80: (5.07), the last term being the same as obtained by the use of the fractional scale.

A scale, either, fractional or graphic, can also be obtained, in the absence of a projection or grid system, from the relation of a known distance between any two points on the ground to the corresponding distance on the map.

In finding the scale of a map and, in order to overcome distortion, i. e., unequal shrinkage or expansion of the paper in different directions, it is generally desirable to take our units from the projection-center of the map and to obtain a mean scale by computing it both for latitude and longitude.

For precise measurements, two graphic scales should be drawn across the paper at right angles to each other, in order to provide a means for eliminating the effect of unequal shrinkage or expansion in the two directions of the paper. Another method of providing for this consists in supplying a distance scale along the borders of the map.

In the sheets of the International map, however, the meridians of true scale are 2° each side of the center. Likewise in the Lambert conformal projection and the Albers equal-area projection, true scale is found only on the standard parallels. Inasmuch as the best average scale cannot always be determined from the center of the map, a knowledge of the properties of a given projection is often necessary to obtain the best results. A brief review of these properties is given under *A Guide for the Identification of Projections*, pages 52–56.

Furthermore, in the measurement of distances, great caution should be exercised in not assuming a principal scale to be applicable throughout the map, especially in maps of continental proportions that are made on the Bonne, the Sinusoidal, and more or less so on all projections. In several of these projections, distances measured in certain parts of the map are greatly in error when derived from the scale of the center of the map. Thus, as an extreme case, a map of Eurasia on the Bonne projection indicates meridional distances near the margin of the map which are in excess of true distances by as much as 14 percent. In some instances, too, sufficient care has not been exercised in the selection and compilation of projections, and in the plotting of cities to provide for an accuracy in measurements within a half of 1 percent, more or less.

A further discussion of errors of distance measurements, including certain useful means for applying corrections to the polyconic, the Lambert conformal, the Albers, and the Mercator projections, is given on pages 179–182, Special Publication No. 68, United States Coast and Geodetic Survey.

It is safer in long distances, especially in distances of continental proportions where reasonable accuracy is desired, to make the computations in accordance with formulas devised for such purposes; as, for example, the solution for a long distance already noted on page 61.

If extreme accuracy is desired, the computation will have to be made by means of the formula for the length of the geodesic. The method for such a computation and an example are given, page 16 *et seq.*, in Special Publication No. 100, United States Coast and Geodetic Survey. Other formulas which are closely approximate have already been mentioned on page 61.

MARGINAL SCALE OF THE MERCATOR CHART

In the Mercator projection, the latitude intervals increase progressively with the distance from the equator, so that in the higher latitudes the meridional increments are quite noticeable. For the convenience of measuring distances, the eastern and western neat lines of the chart provide a scale in which the computed intervals are shown and subdivided with sufficient closeness to furnish distance units for any latitude on the chart.

Distances between points bearing north and south of each other may be ascertained by referring them to the subdivisions between their latitudes. Distances represented by lines (rhumb or loxodromic) at an angle to the meridians may be measured by taking between the dividers a small number of the subdivisions on the border scale near the middle latitude of the line to be measured, and stepping them off on that line. If, for instance, the terrestrial length of a line running at an angle to the meridians, between the parallels of latitude 24°00′ and 29°00′, be required, the distance shown on the neat space between 26°15′ and 26°45′ (=30 minutes or nautical miles approximately) may be taken between the dividers as a measuring unit and stepped off on the line. In thus taking for a unit a mean spacing of the dividers, there will be approximately as many miles shorter than the mean as there are miles longer than the mean; but, as the scale of a Mercator projection increases with the latitude, a meridional or oblique line of considerable length may best be divided into parts and each part referred to its middle latitude for a unit of measurement.

Strictly speaking, a minute of latitude is equal to a nautical mile in latitude 48°15′ only. The length of a minute of latitude on the ellipsoid increases from 1,842.8 meters at the Equator to 1,861.7 meters at the pole. Therefore, instead of assuming a minute as equal to a nautical mile, better results can be obtained by taking the value for unit minutes from Special Publication No. 5, United States Coast and Geodetic Survey.

In small-scale charts covering a considerable extent of the earth's surface, it may be desirable, in the measurement of a long distance, to transfer the great circle from a Gnomonic chart to the Mercator chart, or to plot it from computation.

Although the shortest measured distance is obtained from the apparently longer of the two lines (the great circle being a curve, and the rhumb line being a straight line between two points), the distance units of measurement as obtained from the middle latitude of a great circle are in a higher latitude and therefore longer than the middle latitude units of the rhumb line. It thus follows that the distance along the great circle on the Mercator chart measures the shortest distance between two points.

RELIEF REPRESENTED BY CONTOURS

Relief should be shown in some readily interpreted graphic manner, whatever the medium chosen for its expression. Contours have been in common use for over a century and are still employed either as the sole medium of showing relief or as the basis of other combined methods. A contour is a line every point of which is at the same height above mean high water, mean sea level, or whatever datum has been chosen for a reference plane; thus, a rise in sea level of 10 feet would decrease the contour heights by a corresponding amount.

The interval between contours should be based upon several considerations among which are scale, general slope, character of details which constitute the relief of the area under consideration, and the use for which the map is intended. Contours of 50-foot intervals cannot give a satisfactory representation of a very broken country where maximum elevations are only 200 feet. On nautical charts contours should convey to the navigator a general idea of the configuration of the land areas; and their difference, or the interval they represent, may be larger than where they serve engineering, military, or scientific purposes.

For engineering purposes where relief is represented by contours alone, the latter are usually based upon instrumental determination of elevations, and are given at definite intervals with a maximum precision. Where contours so determined run close they have a true effect of hill shading. Contours in dotted lines are useful to bring out a summit or important features intermediate between the intervals employed.

The introduction of relief on maps in general involves the usual difficulty of representing a third dimension on a flat surface. This must be done in a way that will not obscure otherwise important features. For this reason the contour system on topographic maps is generally shown in brown or some color other than black.

LAYER SYSTEM OF COLORS

Color by means of a layer system is one of the most effective means in supplying relief in a way such as contours alone cannot give. In this method a scale of graded color tints, or a system of different colors based on contour intervals, is chosen to show a progressive increase of height. In its most effective form considerable care is necessary in a selection of colors that will denote progress from one shade to another without obscuring details under the heavier tints.

APPROXIMATE CONTOURS AND FORM LINES

Contours which are approximate only are usually represented by broken lines. Form lines, which are less accurate than contour lines, have no definite interval and are usually shown more or less by full lines interspersed by broken lines of unequal length, the general treatment being of a sketchy character.

HACHURES

Hachures are short lines drawn from the direction of steepest slope and are heavier as the slope becomes steeper. Under certain conditions they are very expressive but are of little use in supplying degree of slope or actual height of ground above high-water or sea-level. In themselves, hachures with their shaded effects frequently do not distinguish readily that which is hill from valley, and interpretation must be based on other details such as rivers and heights at different places. A combination of contours and hachures has occasionally been employed on certain maps where artistic effect has been sought.

Hill-shading, as another medium, produces an effect similar to that of hachures. In this method the slopes are colored by brush or stump in proportion to their degree, and the hill-shading plate is produced in half tone.

As the possibilities afforded in the representation of relief determine in many instances the success in the use of maps, special attention should also be given in supplying heights of prominent objects. In any method of relief that may be employed, actual elevations and contours accentuated at selected intervals play an important part in visualizing or constructing a panoramic sketch of the broad features of a map.

RELIEF MODELS AND RELIEF GLOBES

In the representation of relief either by models or on globes, it is always found necessary to exaggerate the vertical scale in order to bring out the third dimension on land or its undersea extension. This practice necessarily creates an erroneous picture of the lithosphere. For example, the Mindanao Deep, which is the greatest vertical departure from mean sea level and reported to be 35,410 feet, would, when truly represented on an 18-inch globe, show a depression of only $\frac{1}{67}$ of an inch, an indentation almost imperceptible. It is quite evident then that the intensified model or relief globe, while valuable, is not adapted to a comprehensive study of the lithosphere, and that the indispensable basic document necessary to such a study exists only in the bathymetric chart prepared from accurate surveys.

CULTURE

Culture and development should be indicated in their characteristic form and extent. There should be uniformity of treatment of similar subjects and avoidance of that individuality so frequently seen in chart series as the work of different compilers. Complex expression through different modes or media should be avoided. Uniformity and simplicity must be obtained to insure economic and improved production. Mixed types of symbolism as the degenerate

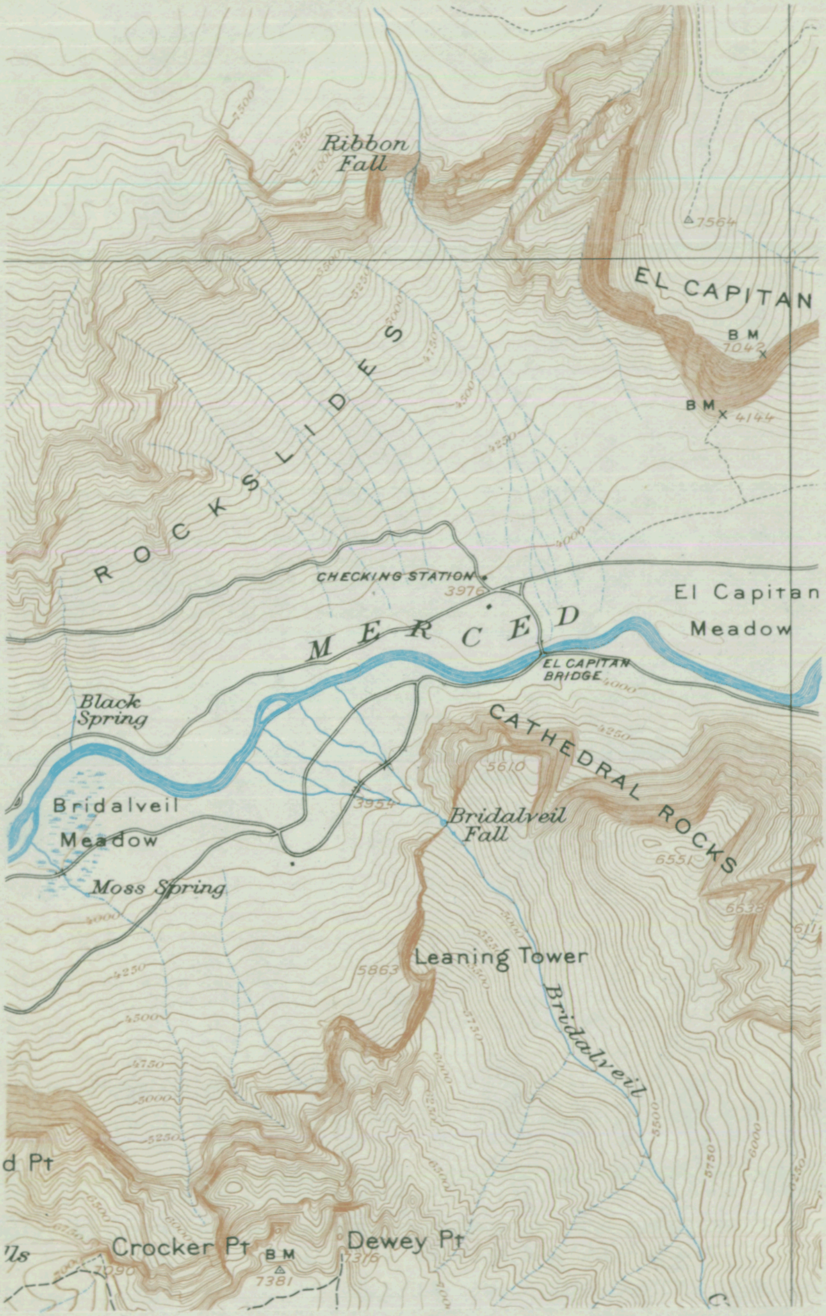


FIGURE 16. — YOSEMITE VALLEY, CALIF.

From U. S. Geological Survey map, scale 1:24,000.

FIGURE 17. – HACHURES FOR SCALES 1:10,000 TO 1:20,000.

Designed by A. Aguirre, Spanish artist.

FIGURE 18. — HACHURES FOR SMALLER SCALES

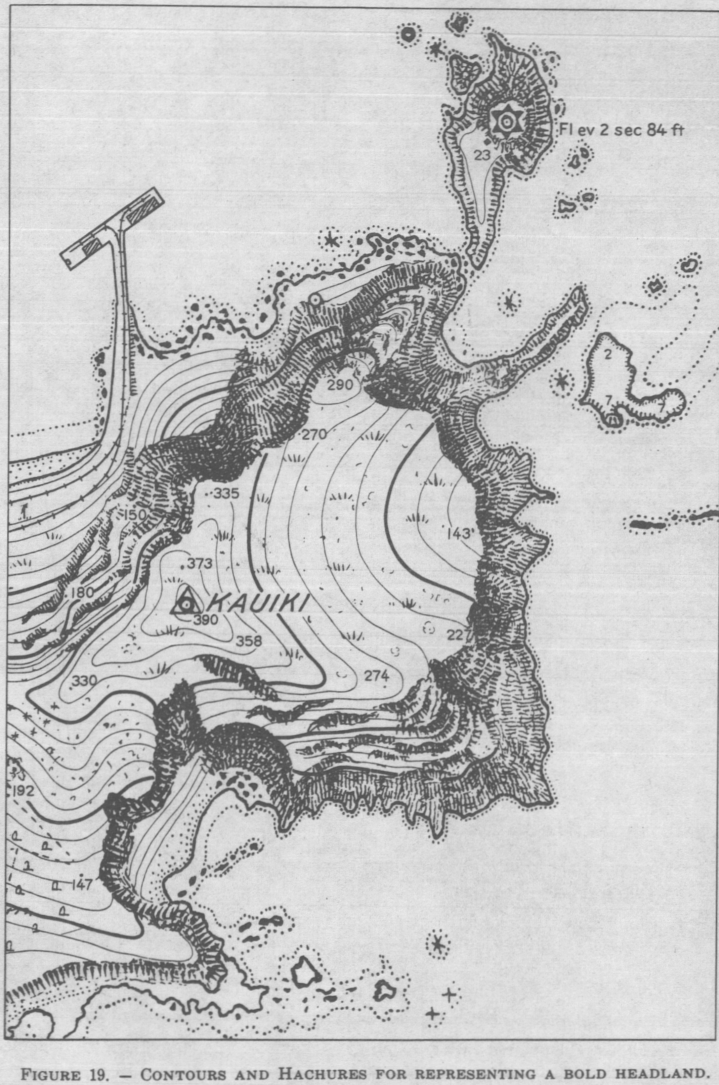


Figure 19. — Contours and Hachures for representing a bold headland.

From an original topographic sheet of the U. S. Coast and Geodetic Survey, scale 1:5,000.

FIGURE 20. — GLACIERS ON THE SOUTH COAST OF ICELAND.

From Danish chart No. 225, 1911, scale 1:250,000.

FIGURE 21. — GLACIERS ON THE SOUTH COAST OF ICELAND.

From Danish chart No. 225, 1911, scale 1:250,000.

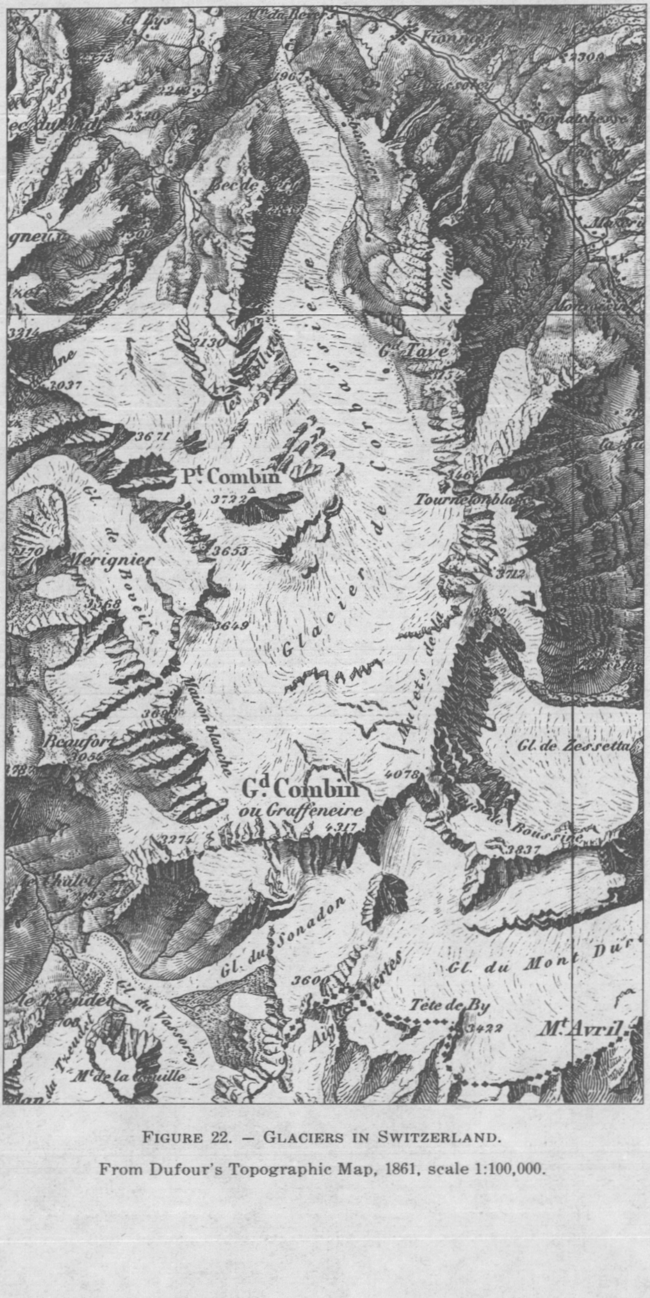


FIGURE 22. — GLACIERS IN SWITZERLAND.

From Dufour's Topographic Map, 1861, scale 1:100,000.

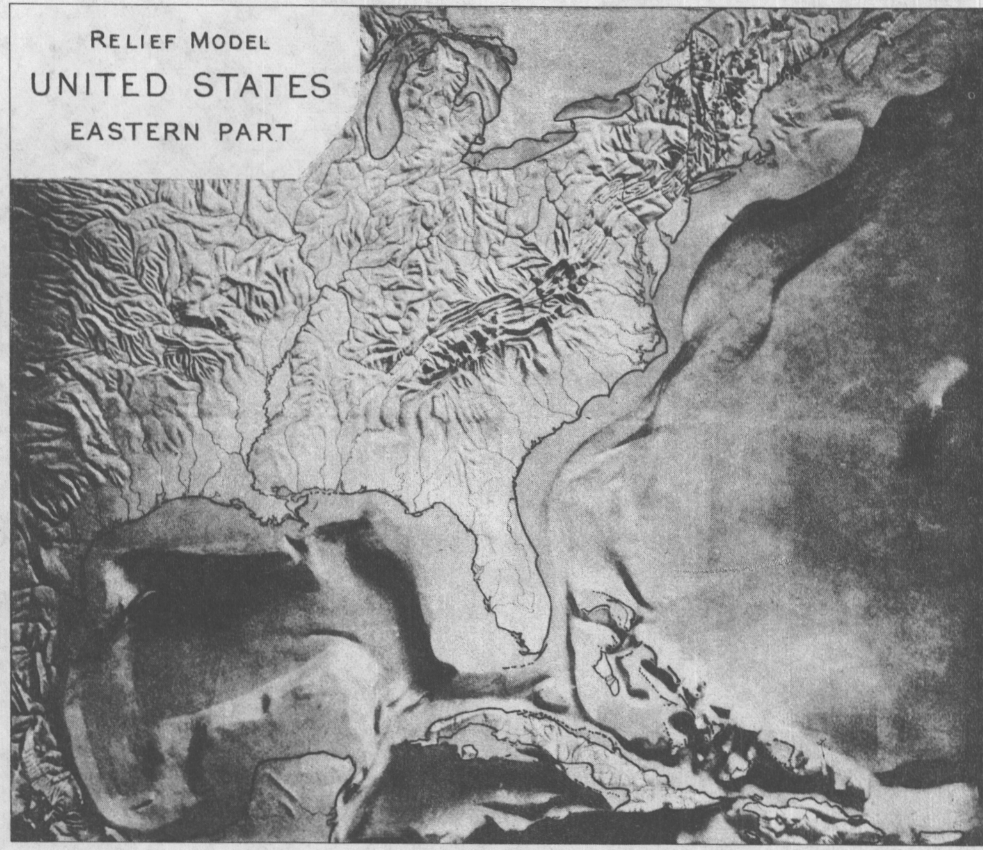


FIGURE 23. – PHOTOGRAPH OF RELIEF MODEL, UNITED STATES--EASTERN PART, SHOWING CONTINENTAL SHELF.

Constructed by the U. S. Coast and Geodetic Survey in 1884.

offspring of types already abandoned for good cause frequently have no *raison d'être*. Methods should ever be the result of matured plans adopted after due consideration of all the factors of field and office work which constitute the problems of map and chart making. As these same problems doubtless have presented themselves to various chart-producing establishments for solution, the creditable results happily attained by others cannot always be ignored or excelled by adopting independent procedure.

THE HYDROGRAPHIC SHEET AS SOURCE MATERIAL IN THE SELECTION OF SOUNDINGS

Upon the receipt of a hydrographic survey in the Office of the United States Coast and Geodetic Survey, an examination of all the records pertaining to the survey is made, including a review of all previous surveys of the locality. All other contributing material is also collected and appraised at the same time. Any pertinent and additional information is then brought forward and the new survey becomes the basic survey of the locality.

In the application of this material, the largest-scale chart should be compiled first, after which the next smaller scale should follow and should be based as much as possible on the larger-scale chart. Elimination and generalization proceed in the order of scale reduction.

SELECTION OF SOUNDINGS

It should be borne in mind that no feature of the chart is of more importance than the selection of soundings which will represent the hydrographic features properly and clearly. As the survey sheets are generally of a much larger scale than the chart, and each sounding line contains as many of the soundings as can be plotted thereon, it is obvious that the chart can show only a small percentage of the soundings. Moreover, it is objectionable to crowd the chart with unnecessary soundings which detract from its clearness and show only a lack of skill on the part of the cartographer.

Before selecting the soundings, the charting material should be studied thoroughly until the control, the plane of reference, the unit of soundings, and the dates of the surveys are clearly established, and a mental picture of the general characteristics of the locality has been acquired; otherwise an intelligible selection is impossible.

The soundings on shoals or rocks discovered with the wire-drag should be charted first in the compilation of a chart, and after such charting, previous surveys of the same area should be examined for less depths than the drag depths. A careful study should be made as to the source of such information, whether from a survey sheet or not, and its probable value for retention purposes. Then should follow the soundings that will bring out clearly all other shoals by their least depth. Subject to the foregoing, the soundings over areas completely developed should be shown fairly uniformly and without crowding.

The selection of channel soundings should be based on the line of maximum depths running with the channel. A hydrographic curve on the original sheet will generally serve this purpose. No pencil notations, lines, or marks should be made on the original survey sheets, and all preliminary studies should be made on tracing paper for transfer to the chart compilation.

If there are channel ranges, a line of soundings on the range should be selected, or suitable legend employed. After this is done, an intermediate temporary curve, if necessary, may be obtained from the original survey sheet which will serve to define the navigational limits for a vessel whose draft approximates the controlling channel depth, and which will be an aid in filling in soundings within those limits. In general, the soundings should be more closely spaced in such areas than elsewhere, and it follows that any unnecessary sounding is more objectionable than it would be in other areas. Beyond these limits, after the channels have been developed and the shoals plotted, the selection for the rest of the chart depends on the physical characteristics of the bottom, so no hard-and-fast rules can be stated. If the slopes are gentle, it is simply a matter of as uniform a spacing as the surveys will permit.

If the bottom is undulating, consisting of a series of ridges and valleys, as on the New Jersey coast, a uniform selection, using the soundings of least depth will result in an erroneous representation In such a case some of the deeper soundings should be shown, even if it necessitates a somewhat closer selection. If the bottom is rocky and broken, a uniformly spaced selection is impossible. The minimum depths must be shown and then filled in with the deeper soundings between them, care being taken not to place a deep sounding so close to a danger as to tend to obscure it.

Soundings of the same depth as a curve, and placed close to or on the curve are of doubtful value and should be omitted.

Where larger-scale charts exist and the scale of a chart under construction is so small that channel depths cannot clearly be shown with standard-gage soundings, the soundings should be omitted, and the smaller the scale the more should the details be generalized. A legend, preferably printed in red, giving the chart number of local charts of the next larger scale should be supplied on the smaller scale series. This will encourage the use of larger scale charts where the smaller scales are inadequate in supplying necessary details.

If a recent survey shows greatly changed conditions where it joins an older survey, a junction should not be forced, but a blank space should be left with a suitable note beyond the limits of the more recent survey. In any case an "office survey" is to be avoided.

SHOALS AND DANGERS

Shoal spots should be clearly shown and nothing permitted to obscure the soundings.

Isolated shoal soundings, not definitely located by a survey should be accompanied by the abbreviations *PD* (*position doubtful*) or *ED* (*existence doubtful*), as indicated by the information.

The size of surrounding curves on the compilation should be exaggerated so that they will not touch the sounding figures, and, if it is a curve that is usually sanded, it should be drawn sufficiently distant from the sounding to allow for several rows of sand dots outside the sounding figure. This should be done on the compilation and not left to the draftsman making the smooth drawing nor to

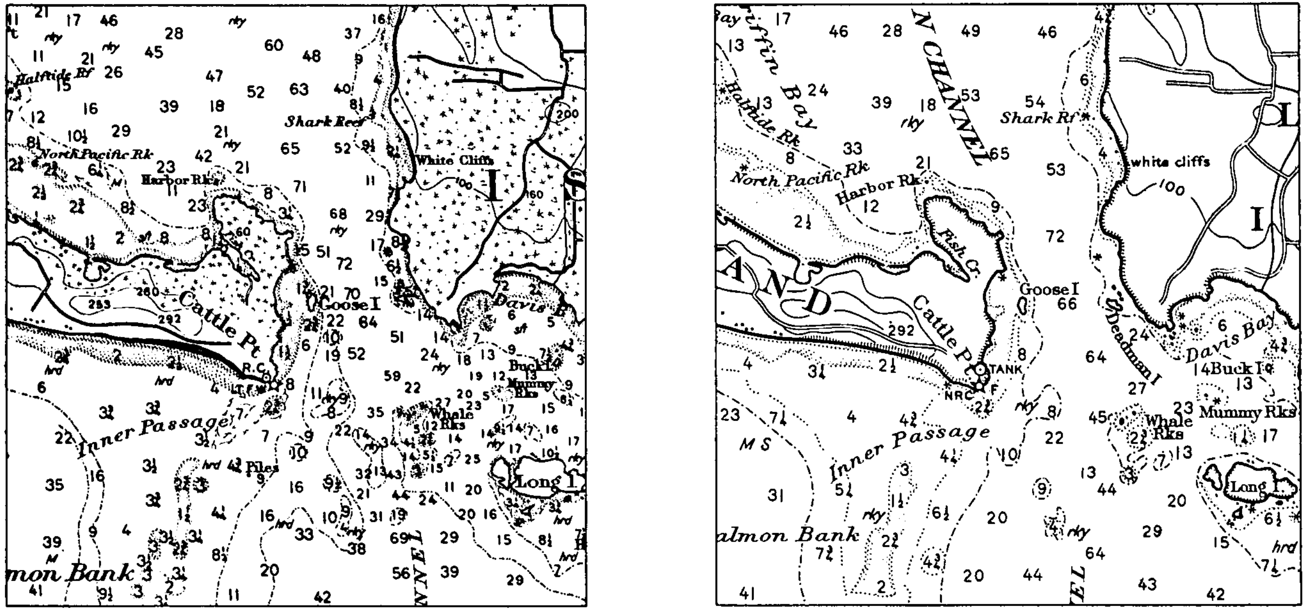


Figure 24. — Selection of Soundings.

Selection of soundings in fathoms prepared in 1907, scale 1:80,000.

Same area and same scale from a selection in 1927.
A clearer picture for navigational purposes is given by a selected lesser number of soundings.

the engraver. Sand dots should not be placed within the numerals nor nearer to the body of any numeral or letter than the average space between dots. When the curves around shoals join, they should be generalized into one shoal. In interpreting the above, care must be taken not to close or seriously decrease the width of navigable channels.

A shoal sounding on an isolated rock should have the abbreviation *Rk* placed near it in upright or slanting letters accordingly as the rock is bare at high water or otherwise.

Soundings should be omitted or less frequent within the space covered by groups of rocks or coral heads through which there is no well-defined channel.

Islets, rocks, and rocks awash must never be confused by placing soundings close to them; the symbols, as they represent the greater dangers, are of much more importance than adjacent soundings.

The elevations of islets or rocks bare at high water should be shown *parenthetically* in slanting figures when they appear in water areas in order to distinguish them from nearby soundings.

When of sufficient importance and the information is available, the height of rocks which are bare at low water and covered at high water should be indicated as follows: *bares 7 ft LW*, or *bares 7 ft LLW*. As indicated in these legends, the use of periods after abbreviations within water areas, is not permitted on nautical charts.

CURVES OF EQUAL DEPTH

Curves of equal depth are the means by which submarine relief is expressed in generalized terms. They enable the mariner to interpret readily the charted hydrography and to grasp at a glance the full significance of the area in which he is interested; but a system of curves to meet the requirements should be adapted to local conditions of both the character of the relief and the needs of navigation.

The widely varying relief of different regions, local variations in general depths over considerable areas, and the character and form of the bottom have an important bearing upon the curves to be adopted. The draft of vessels using the chart and the increases in draft from time to time are important factors. As no system will serve universally, the final charted curves should result from the study of conditions of each locality so that the hydrography may be clearly represented and prove of greatest value to the navigator. The use of tinted surfaces and gradations of color by layer system offer advantages.

NAVIGATION BY MEANS OF ECHO SOUNDING

With the rapidly extending use of echo sounding, the navigator will rely more and more upon the accuracy and completeness of depth curves and charted soundings in ascertaining his position and in holding his ship on her course. Astronomic observations may be uncertain and frequently impossible due to weather conditions, while dead-reckoning positions are likely to be unsatisfactory on account of current conditions or other causes. An instrument with which soundings can be obtained with little effort and with no delay, therefore, provides the mariner with a most valuable means of supplementing other methods of position finding.

Early nautical charts depicted the channels and dangerous shoals with a few scattered soundings and a limited number of prominent landmarks for fixing positions. This was principally due to lack of facilities in making surveys, the necessity for covering large unexplored areas, and the inability of the navigator to obtain soundings except to limited depths.

The trend of modern navgation to the wider use of echo sounding apparatus in position determination undoubtedly will have important effect on future charts as to the number of depth curves to be used. The ease with which depths can be obtained may make it desirable to change the present methods of charting water areas. If depth curves are used for the delineation of the ocean bottom they should be labeled at such frequent intervals that the depths may be read from them quickly and without the use of additional soundings to identify the individual curves. In this case isolated soundings would be limited to maximum or minimum depths on depressions or shoals.

A sudden transtion from the present-day method to one so radically different is not readily accomplished, mainly due to the conservative nature of most navigators. However, modern surveys are made under such regulations as to permit the collection of sufficient data to show complete contours. Merchant and passenger ships are now equipped to take continuous soundings, and, since the navigator may obtain exact profiles of the ocean bottom, the next step will be to prepare the chart so that these profiles may easily be coordinated with it. The extension of the depth curves will enable the navigator to utilize this knowledge more fully.

NEW INSTRUMENTS AS CONTRIBUTING DEVICES TO CARTOGRAPHY

Accuracy in the construction of projections for the chart or the field sheet and the reproduction of previous surveys for reexamination in the field has ever been a prerequisite to good cartography. To maintain this accuracy and to speed production there have recently been developed in the Bureau two instruments of precision; viz, the projection ruling machine and the 50-inch precision camera.

PROJECTION RULING MACHINE

By means of the projection ruling machine the projection network of any chart published by the Coast and Geodetic Survey may be produced on paper, aluminum-mounted sheets, and copper plates in about one-fourth the time previously required. In the construction of any projection on paper it has been found convenient to rule in at the same time needed subdivisions in blue ink to facilitate compilation. Likewise the border and neat lines of the drawing are supplied in one operation. Rectilinearity, parallelism, and curvature requirements are obtained with ease and firmness.

The machine is not only adapted to the Mercator projection of straight lines but by means of a flexible straightedge made of saw steel the mathematically determined offsets (or curvature components) of a polyconic or Lambert projection, at least up to scale 1:500,000 can be provided for.

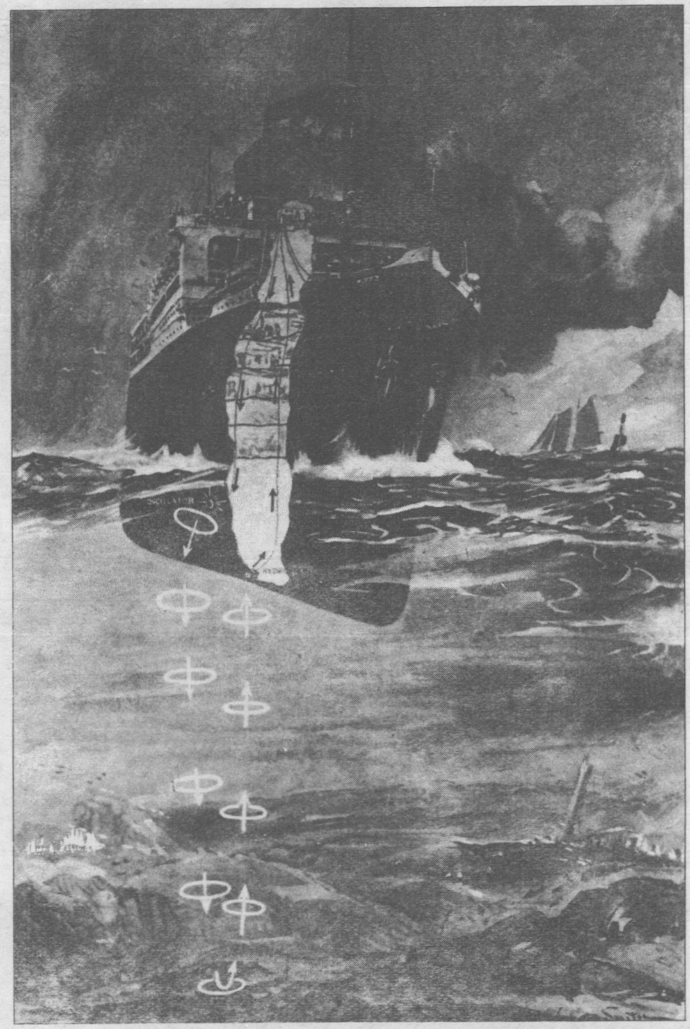


FIGURE 25. — THE FATHOMETER FOR DEPTH FINDING.

Black arrows show electrical impulses.
White rings and arrows show sound waves.

FIFTY-INCH PRECISION CAMERA

The new precision camera is capable of making negatives 50 by 50 inches in size, sufficient to reproduce the largest size chart on one negative if desired.

MECHANICAL STIPPLING

In the final preparation of plates for printing, certain mechanical shading devices are sometimes employed to aid the eye in distinguishing geographic areas one from another. Facilities of this type are utilized especially when the maps or charts are to be printed in black only. Since a one-color press that is inked for black printing cannot also simultaneously print gray, patterns of black dots or finely ruled black lines are made to produce a variety of tones, the white of the paper showing through the minute open spaces in the black screen, giving an appearance of grayness or half tones.

Several mechanical methods have been developed to supersede almost entirely the laborious method of stippling by hand. The Ben Day shading machine is widely used by engravers in preparing zinc line-cuts, the designated screens being applied to the metal plate which is then etched. The various tones resulting from a single printing are known throughout the graphic arts industry as Ben Day, the name of the inventor. Ben Day shades possess regularity of pattern and evenness of color-spread approaching perfection.

In recent years, a number of articles have appeared on the market designed for drafting-room use, making possible the application of mechanical stipples directly to the drawing. One type, for instance, is the transparent sheet of thin paper on which is printed a pattern of dots or lines. On the under side is a coating of wax which acts as an adhesive when the paper is rubbed down and attached to the drawing with the aid of a flat burnisher. Using a frisket knife, the cartographer cuts away all excess screen, and the drawing is ready for the photographer. The parts of the drawing underneath the screened paper are not lost to the camera, because the paper and the wax film are both transparent.

Other articles of this type are available, each with some advantage lacking in the others. Among the latest is drawing paper with all the stippling invisible until the paper is treated with a chemical. After the geographic outlines have been inked in, those areas to be stippled are brushed over with a chemical, and instantly the dots appear, each of uniform blackness. Presenting a disadvantage is the fact that the surface of the paper must not be bruised by erasures. Still other products of this type will probably appear on the market in the future, especially in view of the growing importance of reproduction by photolithography.

Individual methods have been improvised, indicating further that there are many approaches to the same problem. One such procedure consists of making separate drawings in solid black for each area which is to have its own tone character. These drawings are then separately photographed through engravers' half-tone screens—a darker screen for each successive drawing. By a process of superimposing one photographic result upon another, a composite plate is made from which the printed impressions are taken. Again the

509014—43——6

objective is served in that only a single printing is required to produce the entire range of tones meeting every distinction, even to the extent of showing the delicate crescendos in shade that occur when one or two shaded areas overlap still another.

LETTERING AS A CONTRIBUTING FACTOR TO THE GENERAL APPEARANCE OF A MAP, AND RULES FOR GUIDANCE

The necessary skill to obtain a high standard in the form and size of letters, and in the spacing and placing of names, can only be acquired as a matter of study. The lettering of maps is controlled largely by convention which imposes upon the cartographer the necessity of a knowledge of different approved alphabets.

Craftsmanship in this field, for unaccountable reasons, occasionally suffers from a lapse due to lack of individual taste. Since the early days of printing a revival of knowledge and interest in lettering has taken place periodically by the famous presses, interrupted again by intervals of deplorable decline. When four or five of the most conspicuous names on a map are artistically placed and lettered, the improved appearance makes itself felt and adds to the general effect of the whole, and conversely, the poor lettering of only a few prominent names may give an erroneous impression of an otherwise accurate map or chart. Things are frequently appraised from the general effect of first impression rather than from the inherent qualities of things more essential.

By careful use of roman, italic, and block letters, much information can be conveyed to serve a useful purpose in the differentiation of groups of unrelated material. A unity of style in each class of lettering should be maintained in order to secure the best results. Too much variation, however, is bad for the general appearance of a map and should be avoided. Heavy block letters, for instance, do not provide that artistic touch or grace which lends character to a map. It is generally safe to assume that type which does not look good in general printing, does not serve for map lettering.

Before any lettering is placed on the map, a study should be made of the relative importance of the leading features so that the names representing them may effectively indicate degree of prominence.

The main line of the title should have the maximum gage and all other names should be lettered in gages proportionate to their significance.

The lettering of the title and the names of topographic features should be in vertical letters. Names relating to hydrographic features should be in slanting letters. The lettering of the title and its accompanying notes should be placed parallel with the bottom of the map or chart.

Lettering should always be placed so that in facing the bottom of the map, names may be read from left to right.

Lettering in any diagonally straight line should be avoided except along boundary lines, railroads, channels, and artificial features which frequently permit no other better arrangement.

In order not to obliterate the street system and prominent features, the name of a city may be placed anywhere so long as it refers unmistakably to the correct locality. Preferably the name should be to the right, to the left, centrally below, or centrally above, in the

Department of Commerce

COAST AND GEODETIC SURVEY

Washington

ABCDEFGHIJKLMNOPQRSTUVWXYZ&

ABCDEFGHIJKLMNOPQRSTUVWXYZ&

1 2 3 4 5 6 7 8 9 0 *1 2 3 4 5 6 7 8 9 0*

abcdefghijklmnopqrstuvwxyz

abcdefghijklmnopqrstuvwxyzz

FIGURE 26. – PLATE OF LETTERS – ROMAN AND *ITALIC*.

Department of Commerce

COAST AND GEODETIC SURVEY

Washington

ABCDEFGHIJKLMNOPQRSTUVWXYZ&

ABCDEFGHIJKLMNOPQRSTUVWXYZ&

1 2 3 4 5 6 7 8 9 0 *1 2 3 4 5 6 7 8 9 0*

abcdefghijklmnopqrstuvwxyz

abcdefghijklmnopqrstuvwxyz

FIGURE 27. — PLATE OF LETTERS — BLOCK.

order here given, always bearing in mind that the selected position should be based on least interference with other data on the map.

Hydrographic features having special importance from the standpoint of navigation, as, for example, navigable channels should not be obscured by names running through them. Such names should likewise be placed so as to conform to a position of least interference.

Names of equal importance need not necessarily have quite the same gage, as it may be desirable to lessen or contract the longer ones to obtain an even degree of stress.

The same rule applies where some names of equal importance are in upright letters and others in slanting letters, in which case the slanting letters should be made a trifle smaller in order to overcome their excess and appear equally prominent with upright letters.

Where slanting letters are employed in names that are curved, the slant of every letter should be determined with reference to a normal to the curve where the letter is to be made.

In general, where the feature to be lettered is of considerable length, the name should not be spread out over the whole, but should be shortened and centered in a way so as to provide space at the beginning and end of the feature equal at least to twice the space between letters. It may be desirable in many cases to bring the letters fairly close together, approaching normal spacing. In the case of rivers, railroads, and features of unusual length, the letters of the name should be so spaced as to be read at a glance without searching individual letters, and the name repeated elsewhere if necessary.

Names should preferably be placed parallel to the lower neat line. However, in maps where the parallels of latitude are noticeably curved lines (for example, U. S. Geological Survey Map of the United States), the names in general should follow the trend of the parallels. Exceptions are frequent as there are many instances where it is necessary to employ a curve which follows the general trend of the feature.

On account of the formality of a circular curve, a more pleasing effect can be obtained if the curve is more pronounced at one end than at the other.

A curved name is more easily read if its beginning approximates the horizontal; but when the beginning cannot approximate the horizontal, it is desirable to have this effect at the end of the name. For this purpose, the celluloid curve known as the logarithmic spiral is useful in supplying a curve of rapidly increasing radius.

Lettering should not be too close to the margin of a stream or too close in parallelism with a feature. Its distance away should generally be about half the height of the lettering used, but increasing with the length of the name or legend.

The names of small towns, peaks, prominent objects, aids to navigation, etc., should be close to the feature but not touch or blend into it. The space of a lower-case letter is ordinarily required.

Reverse curves should be avoided.

When two or three words constitute a single name, they should ordinarily be separated by the amount of space necessary for the letter "I" (with its spacing), were it placed between the words. When the several parts of such a name cannot be placed in a straight line, they should be placed along a curve that is continuous between the parts, so no search will be required to pick up the whole of the name. No angular or zigzag arrangement can be tolerated.

Pointed letters such as A, V, and W, and curved letters like C, G, J, O, Q, and S should extend slightly above and below the lines limiting the height of other letters in order to correct an optical illusion. In providing for this correction, care must be taken not to exceed requirements.

The combination of free-hand with mechanical lettering tends to produce effects that are not pleasing. There is a limitation to the amount of the straight portions of letters that should be made with a ruling pen. In the pencil lay-out of map lettering, it is quite proper to secure uniformity in the vertical, horizontal, and slant lines, but for best results the final execution can be made more effective by the avoidance of mixed mechanical and free-hand forms.

Likewise in names set up from type, the latter should be carefully based upon, and specially designed to conform with the otherwise generally accepted style of the map-producing agency, and not from fonts that are only closely approximate.

The colorless effect of lettering on maps is frequently due to several causes, among which are a lack of knowledge of the anatomy of letters, insufficient or excess width in the shaded portions of letters, confusion with surrounding detail, and the use of gages which are too large. What may be achieved by art in the placement of names cannot readily be rationalized into a science. The letterer is a creative artist and must solve the problem optically, bearing in mind that paper itself is a part of the picture and that rhythm in relationship of space is a part of the study.

In its final test, the lettering which makes a map clear, harmonious, and beautiful can be achieved only by a certain distinction and uniformity of style and a personal taste of good proportions.

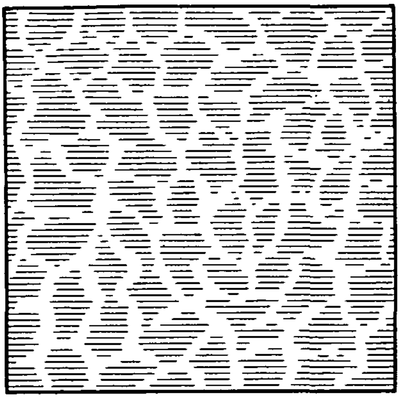
CONVENTIONAL SIGNS

In the use of conventional signs, the symbolism now generally employed in the United States is that of the Federal Board of Surveys and Maps. Acting in an advisory capacity this Board has prepared a set of standard symbols which is published by the United States Geological Survey. A more harmonious understanding in the use of symbols and in the general treatment of expression is thus made possible, and the reading and interpretation of maps and charts are thereby simplified.

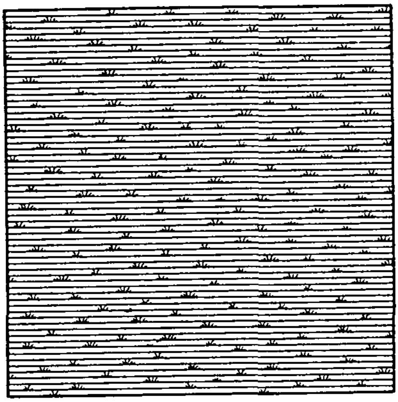
The International Hydrographic Bureau at Monaco aims to have uniform conventional symbols adopted by all countries producing nautical charts, and some progress has been made toward this ultimate object.

GEOGRAPHIC NAMES

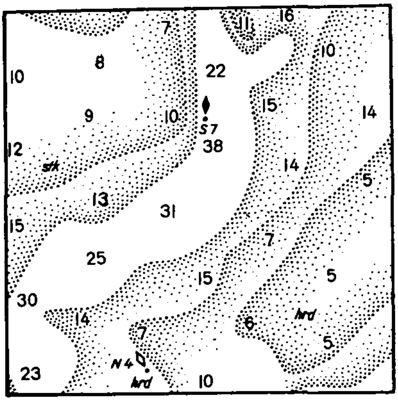
It is the duty of the field surveyor to determine those geographic names which have been well established by local use. In the case of conflict in names he gathers from the best available sources as com-



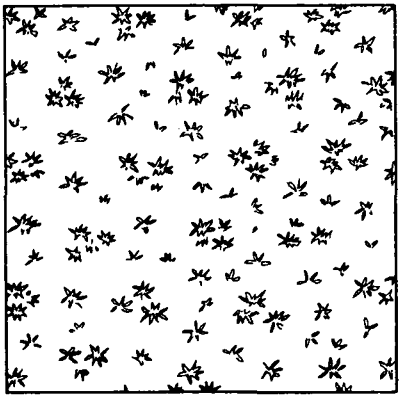
TIDAL FLATS OR MUD



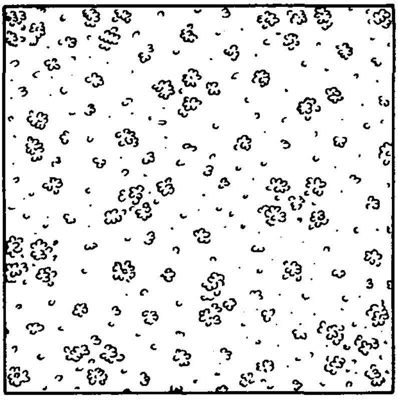
MARSH



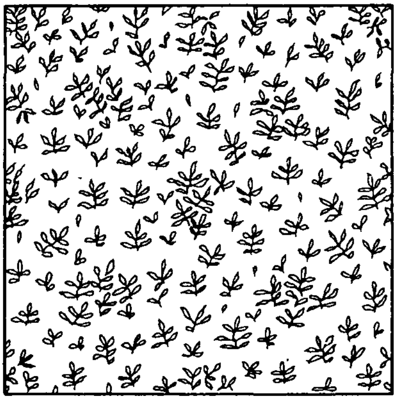
SHADED WATER AREAS (SAND)



PALMETTO



WOODS (BROAD LEAF)



MANGROVE

FIGURE 28. — SYMBOLS.

plete information or history of such names as is practicable. In some States local boards have considered and listed the correct spelling of many geographic names. When this local authority does not exist and in cases of disputed nomenclature a decision by the United States Board on Geographical Names is made for the benefit of those Departments of the Federal Government compiling maps and charts.

ARTISTRY OF THE MAP AND CHART

The compilation is generally completed in detail as a working drawing without special attention to artistic effect. Qualities of expression must still be added in a redrawing for which the original compilation provides the basis. The redrawing may be in the form of a finished drawing of the original penciled compilation, or it may be in the form of an engraving on copper. The method of recutting and finishing on glass negatives has recently been developed to such an extent in the United States Coast and Geodetic Survey that it is now one of the leading processes of this bureau.

The finished chart as an expression of natural conditions delineates geographic material partly in the form of reduced outline and partly in the form of symbols of various kinds. The symbolism to be employed is an approved conventionalism, and in this respect the cartographer must ever employ the symbols in use today in order to meet communities of opinion. Every map should present, as far as possible, legibility, clearness, unity of style, and harmony. A taste of good proportions and a certain distinction of style in the relative prominence of features makes itself felt in the improved appearance of the map.

Most of us are sensitive to our surroundings. It is beauty that cheers, and we want maps and charts around us that look like something worth while—maps that do not suggest the thought of commonness and cheapness.

The general appearance of a map is, to a certain degree, controlled by the treatment of its shore line, rivers, and creeks. Too frequently the same weight of line is applied throughout the map, instead of gradations in which the maximum weight or width of line should be assigned to the outer or general stretches of coast and important rivers. The lesser indentations of shore line should always be shown by thinner lines, approaching a minimum width for the smallest streams. Frequently, islands, lagoons, etc., adjacent to the coast line, unless they are treated lightly, will blend, when reproduced, with the general sweeps of shore line, producing clumsy or amateurish effects. Except for the special purpose of drainage, the dense treatment of river systems, due to the unlimited reduction of all tributaries, is useless and should be avoided.

In regard to the treatment of shore line, the main consideration consists in giving it an expression of character especially as to headlands and other prominent features useful to the mariner for identification of position. As prominent points of land also serve the useful purpose of control in applying aerial photographic surveys, the elements of character should not only convey a true geological picture but should also clearly distinguish and differentiate between natural and artificial features. Conspicuous wharves, for instance, can best be shown when drawn with a right-line pen. Freehand execution of piers and bulkheads often produces the effect of a *point of land* instead of an *artificial improvement;* all doubt in this respect should be removed by careful delineation.

In the absence of the beautiful views which embellish former coast charts, the useful information conveyed by them to the mariner may be supplied or recompensed to some extent by close attention to a characteristic treatment of all prominent shore features.

The generalization necessary in the transition from the large scale original survey to the smallest scale chart is analogous to James McNeill Whistler's thoughts expressed in his wonderful description of painting in the twilight:

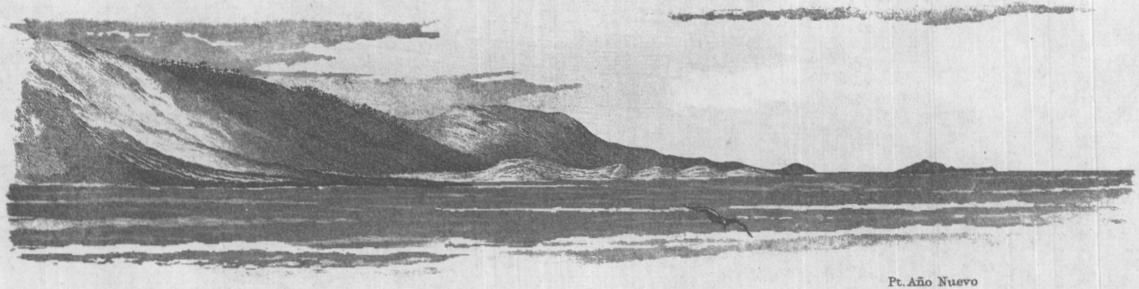
> As the light fades and the shadows deepen, all the petty and exacting details vanish; every triviality disappears, and I see things as they are, in great strong masses; the buttons are gone, but the garment remains; the garment is lost but the sitter remains, the sitter is lost but the shadow remains. And that, night cannot efface from the painter's imagination.

Figures 6, 7, 8, and 29 are included in this publication as specimens of the engraver's art which attained its highest point of development both technically and artistically during the latter half of the nineteenth century. Figure 29 is from engravers to whom Whistler owed his early inspiration, and from whose gentle touch of point and needle he acquired that technique which made him one of the world's most renowned etchers. Figure 30 is by Whistler himself whose brilliant career began in the Coast Survey in 1854. His stay in this Bureau will be memorable for the technical instruction he received in the etching of views of the coast, three of which are here reproduced, the upper two being made available by the courtesy of the Freer Art Gallery of Washington, D. C.

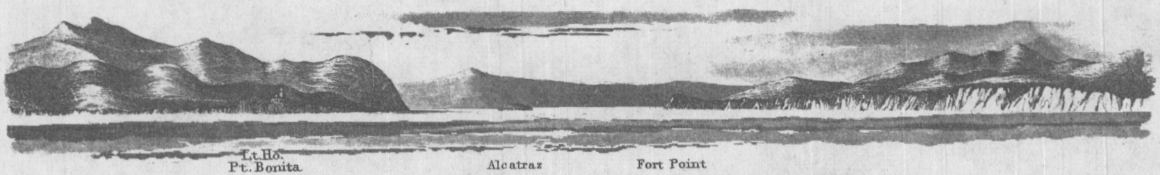
Although in more recent times new modes of expression have been introduced to meet the demands of expediency, it should not be forgotten that at a European exposition a gold medal was awarded the United States Coast Survey for superior excellence in the art of etching and engraving.

It is attention to details like lettering, balance of chart, amount of topography and hydrography, a proper use of conventional signs in their size, avoidance of crowded or open treatment in symbols for trees, sand, etc., avoidance of any pattern arrangement in the symbols employed, a critical study of the hydrography in order to secure a selection of soundings that is at once simple, characteristic, and practical—all these distinguish good work from amateurish efforts. The purchaser of the chart may not notice it at first, but when placed alongside an amateur's work, that indefinable something will be as evident in a good chart as in a fine painting. Attention to such details seldom involves much additional labor, only a sense of proportion and propriety being necessary to supply the artistic element without sacrificing any essential details.

While the artistic side of cartography is a heritage transmitted from the nineteenth century and should not be disdained, we should ever keep foremost in mind, and in an ordered fashion depict the scientific side of the product so as not to give out a dream of our imagination but a faithful portrayal of the area charted.



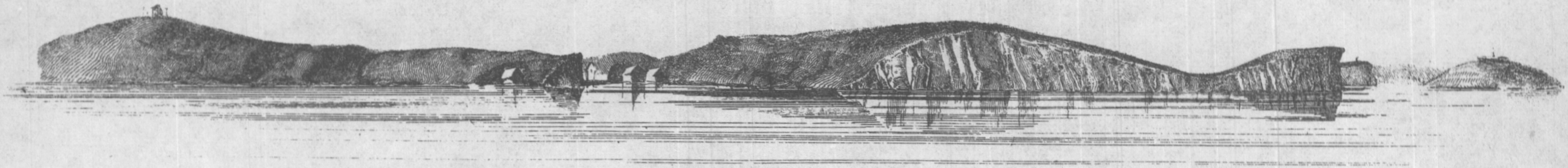
View Pt. Año Nuevo bearing S.E. by E. (Compass) 4½ miles



View of the Entrance to San Francisco Bay Alcatraz N.E.½E. (by Compass) 12 Miles

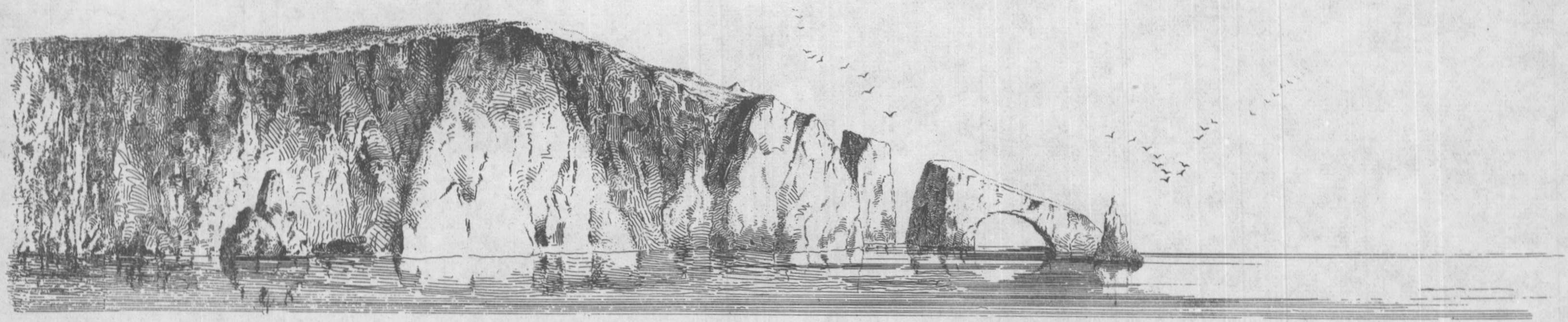
FIGURE 29. – VIEWS OF THE COAST, ENGRAVED IN 1853.

Passing of Nix's Mate - South Channel to Boston Harbor, Whistler, 1854



View for clearing Harding Ledge - Southeastern approach to Boston Harbor, Whistler, 1854

The above two views are reproduced by the courtesy of the Freer Art Gallery.



View of the Eastern extremity of Anacapa Island, Cal.- from the Southward, Whistler, 1855

Fig. 30 - Views of the coast, etched by James McNeill Whistler, U. S. Coast Survey, 1854-55

SIMPLICITY IN MAPS

Simplicity will scarcely be denied to be the best recommendation of a map or chart—but it should be kept in mind that *simplification* and *abridgment* are by no means convertible terms. Many maps have been published, professing to simplify the elements by reducing their exposition into a compass sufficiently generalized to dissipate the alarm which is reasonably felt where unlimited content and minute detail prevail.

The proper procedure is to bring out the essential characteristics in a clear light, without entering deeply into incidental features which have no reference to the professed purpose of instruction. If it is true, as Aristotle says, that the mere chalk outline of a simple figure is more interesting than a multitude of brilliant colors or details thrown carelessly together, without regard to significant design, it is no less true in maps and charts, that pertinent objects should be boldly outlined for the rapid comprehension of the mind's eye, even at the exclusion of parts of minor importance.

We find too often a sort of patchwork composition without intelligent design, and the user of a chart *is led to fix equal attention* on all its parts, though many are superfluous, and many defective. Even where an original survey may be quite satisfactory, the final compilation of its elements, after all, is the thing where honest thought and utmost skill are of vital significance.

Simplicity is the golden mean between *too little* and *too much.*

It has been the aim of the author to trace in a general way the evolution of map-structure and the technical details governing the art and science of cartography. It is hoped that the information may be useful in pointing out the conditions and restrictions under which this branch of science is operating, its magnitude and character, and its usefulness to national development.

INDEX

CUT ON THIS LINE

PUBLICATION NOTICES

To make immediately available the results of its various activities to those interested, the Coast and Geodetic Survey maintains mailing lists of persons and firms desiring to receive notice of the issuance of charts, Coast Pilots, maps, and other publications.

Should you desire to receive such notices, you may use the form given below, checking the lists covering the subjects in which you are interested.

(Date)------------------

DIRECTOR, U. S. COAST AND GEODETIC SURVEY,
Washington, D. C.

DEAR SIR: I desire that my name be placed on the mailing lists indicated by check below, to receive notification of the issuance of publications referring to the subjects indicated:

- ☐ 109. Astronomic Work
- ☐ 109–A. Base Lines
- ☐ 109–B. Coast Pilots
- ☐ 109–C. Currents
- ☐ 109–D. Geodesy
- ☐ 109–E. Gravity
- ☐ 109–F. Hydrography
- ☐ 109–G. Leveling
- ☐ 109–H. Nautical Charts
- ☐ 109–I. Oceanography
- ☐ 109–J. Traverse
- ☐ 109–K. Seismology
- ☐ 109–L. Terrestrial Magnetism
- ☐ 109–M. Tides
- ☐ 109–N. Topography
- ☐ 109–O. Triangulation
- ☐ 109–P. Cartography
- ☐ 109–R. Aeronautical Charts

(Name)------------------------------------

(Address)------------------------------------

A catalog of the publications issued by all Bureaus of the Department of Commerce may be had upon application to the Chief, Division of Publications, Department of Commerce, Washington, D. C. It also contains a list of libraries located in various cities throughout the United States, designated by Congress as public depositories, where all publications printed by the Government for public distribution may be consulted.

O