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Topographer: His Instruments and Methods

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THE HEART OF THE ALLEGHANIES—CHEAT RIVER.

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THE

TOPOGRAPHER,

HIS INSTRUMENTS AND METHODS

DESIGNED FOR THE USE OF

STUDENTS, AMATEUR TOPOGRAPHERS, SURVEYORS, ENGINEERS, AND ALL PERSONS INTERESTED IN THE LOCATION AND CONSTRUCTION OF WORKS BASED UPON TOPOGRAPHY,

ILLUSTRATED

WITH NUMEROUS PLATES, MAPS, AND ENGRAVINGS.

BY

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PREFACE.

THE recent large and growing demand for topographers, reveals a void in this department of engineering believed to arise from inefficient instruction in this direction. In fact, there is found to exist, strange as it may appear, no publication laying special stress upon the practical duties and requirements, as well as the theoretical qualifications of the topographical engineer. Success has, heretofore, only been attainable from the study of standard works on surveying, in connection with others treating of the drawings, and a third series on military reconnaissances, supplemented largely by actual experience in the field.

It has been the author's aim, therefore, to prepare a compact manual of practical value to the embryo topographer, freed from all information so readily obtainable from ordinary sources, and containing in condensed form, a complete course for the guidance of the amateur.

The latest improvements in instruments are mentioned, with their numerous time and labor-saving devices; the practical limits of error are given for the various instruments in use, as determined by the scale of the map and character of the survey; the forms of record are clearly shown for all classes of work; the corrections and reductions given with a résumé of the computations and formulæ, all followed by a general outline of some of the numerous applications that may be made of this important study.

Among the special features of the work may be mentioned the section (23) on barometric hypsometry, in chapter II, prepared by Mr. Ashburner, Geologist in Charge of the Anthracite Regions, Pa., which the author desires gratefully to acknowledge.

PREFACE TO SECOND EDITION.

In revising this work the author has made such changes and additions as have been suggested by subsequent experience to keep it fully up to the requirements of recent American practice. The azimuth tables have been extended to A. D. 1905; the tables of map equivalents and for stadia reduction have been printed separately as well as in the body of the book, for convenient reference in the field, and a chapter on Submarine has been substituted for that on Underground Topography. This is a new and, it is believed, valuable addition, and, as an important adjunct to the topographer, enabling him to discover the relation existing between physical forms and the forces producing them, an appendix has been added, chiefly from the classic writings of Mr. Grove K. Gilbert, Geologist-in-Chief of the United States Geological Survey.

As many inquiries have been made concerning the application of Photography to Surveying, an abstract relative to this subject has also been added stating the fundamental principles, with reference to more extended works, written by Charles Herman Haupt, Instructor in Civil Engineering.

Aside from the above references, and others in the text, the author desires to make his personal acknowledgments to the Chief of Engineers, U. S. A.; the Superintendent of the U. S. Coast and Geodetic Survey, as well as the Assistant in Charge; Prof. J. P. Lesley, State Geologist; Edw. V. d'Invilliers, Assistant Second Geological Survey, Pennsylvania, and all others who have contributed to the material embraced within this work.

L. M. H.

University of Pennsylvania, Phila.
June, 1891.

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INTRODUCTION.

THE TOPOGRAPHER must be a man capable of correctly interpreting the face of nature, and of giving such intelligent graphical expression to his impressions, that a person unfamiliar with the ground may obtain, for all practical purposes, a sufficiently accurate knowledge of its features to enable him to decide the questions at issue.

This involves a careful training of the eye and hand in the estimation of distances and angles, the exercise of judgment in laying out and prosecuting the work, a knowledge of the conventional methods of representing surface or underground features, physical alacrity and endurance in the collection of the data, courage in making a reconnaissance in an enemy's country, skill as a draughtsman in free-hand and mechanical drawing and in colors, and a good mathematical training, as a basis for the solution of the many interesting and novel problems continually arising in practice. In short, the requirements are such that only a person of good judgment, temperate habits, active temperament, and scholarly attainments, can hope to excel in this profession ; and hence it is that the query is so often asked, "*Can you recommend a good topographer?*"—a question of great importance to the projectors of any work of magnitude, whether it be the establishment of a line of communication, the founding of a city, the supplying of a community with the necessaries of life, the removal of sewage, the laying out of parks and grounds, the opening and working of mines, or the impounding of water for power or for irrigation.

From this general review of the field, it would appear that the qualifications of the topographer are of a high order, and of such a nature as to be acquired only by patient and persistent efforts in the direction of his goal.

It is not within the province of this work to treat of the accessories which are requisite to success—as mathematics, physical training, etc.—but to deal directly with the technicalities of the service, and the most direct methods of obtaining good results. With this end in view we will take up the subject in its natural order, and treat first of the methods of acquiring a correct impression of the surface to be represented—or more briefly, HOW TO OBSERVE; second, the method of giving expression to the observations thus made by records and drawings, or GRAPHICAL REPRESENTATION; third, the determination of results by analytical, graphical or mechanical methods, or COMPUTATIONS; and fourth, the APPLICATIONS, which may be made directly from the data thus furnished.

TO THE STUDENT.

To intensify and render personal the suggestions to be given in this manual, let the student assume, wherever practicable, that he is in search of some definite information or data to be embodied in a report to be made to a party who is unable to make a personal inspection for himself, or that he may at any time be called upon to answer such questions as, How wide was the river? How deep the ford? How steep were the approaches? Was the country broken, rolling, or level? What were its resources? etc. Briefly, he is to regard himself as the eyes, ears, and hands of the company or party he represents, to absorb all the information possible in the time allotted him, and convey it to others in an intelligible report.

---

*As an instance of the wonderful perfection that may be attained in this direction, the reader is referred to the very interesting life of John Metcalfe, the *blind* road maker of England, as narrated in Smiles' Lives of Engineers, Vol. I. This pioneer of road making was a man of vigorous physique, who had rambled extensively over England and parts of Scotland and Wales, with no other companions than his cane and fiddle; but in so doing he became so thoroughly impressed with the need of better roads, and so well acquainted with the topography of the country, that he unhesitatingly took and successfully executed contracts for many miles of roads, some of which crossed deep marshes, and also built many bridges, remarkable for their strength and durability.

CHAPTER I.

HOW AND WHAT TO OBSERVE.

1. One of the first requirements in preparing for the duties of active field operations is to be able to read the face of nature quickly and intelligently. This involves a rapid analysis of the characteristics of the field and a fair memory, strengthened by a well-trained judgment in respect to the size and position of objects. But this maturity of judgment can only be acquired after considerable practice, of such a nature as to reveal and correct the errors of the untrained eye and hand by comparison with some standard. By a series of such comparisons and corrections it becomes cultivated to so high a degree of accuracy as to enable the topographer to dispense, to a great extent, with any other instruments than those with which he has been divinely endowed.

2. Amongst these may be mentioned *the range of vision*, or the distance at which objects of known dimensions may be distinctly seen in a clear atmosphere; the *length of a step* in ordinary walking, or of a *pace* in "stepping off" distances; the *height of the eye* above the ground; the *length of the reach*, or distance from end of fingers of right hand to those of left when the arms are outstretched; (this in a well proportioned man should equal his height) the *reach of the hand* or distance from end of thumb to that of second or fourth finger when extended; the *breadth of hand* as used by timber men in getting out rails, ties, etc., being the distance from the outer edge of the palm to the tip of the thumb when extended as in grasping a stick or handle; (The two hands thus placed with thumbs in contact will generally equal one foot), and the distance from the eye to a pencil held vertically at arms length, (*a*) laterally, with head turned to one side; (*b*) held immediately in front. To these, which may be designated the *personal units*, should be added the rate at which the

individual usually passes over various kinds of ground whether walking or riding, and at different seasons of the year.*

3. To test his judgment and remove any possible doubt he may have as to the necessity for the elementary discipline which follows, the tyro may endeavor to determine the difference in length between a horse's head or a flour barrel—or the actual height of a silk hat, or the slope of a road, nearly level. In all cases his first results will probably be wide of the mark. Hence he should subject himself to a course of training similar to the following, by selecting some familiar object and determining—

1. What the object is, that is, its name or names, common, technical or local.
2. The form of the object.
3. The general proportions of its dimensions.
4. The proportions of its parts.
5. Its colors, shades and shadows.
6. Its apparent dimensions as determined by estimation (eye).
7. Its approximate dimensions, as determined by pacing or the application of any other personal unit.
8. Its actual dimensions as found by measurements with a standard rule.
9. Comparison of above results and correction of 7 and 8.
10. Distance to the object.
11. Sketch of it with plan, section, and elevation, to scale.
12. A general written description.

The above system, if faithfully applied, will go far to correct the general laxity of judgment and expression as to observed facts. In applying it to topography the pupil must include in his list of objects such items as grades of roads, degrees of slopes, directions of "contours" and streams, outlines of distant horizons, and similar relevant features.

4. In filling in the actual values in the above outline, the novice will find some difficulty in eliminating the effect of perspective in reading slopes, and in selecting a suitable point of sight; thus, a road over the spur of a hill will appear almost vertical when viewed from an opposite elevation, and will seem less steep when seen from the bottom than if the observer stood at the summit.

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* The student should fill up the accompanying card.

A perfectly level road will appear to rise, and a descending grade will seem to be level to an untrained eye. A platform appears higher to an observer standing on it than if he were on the ground, for there is, in fact, a difference in the observed heights, due to the position of the point of sight, equal to twice the height of the observer's eye above ground. A straight rod seen "on end" looks like a mere point, but viewed broadside reveals its full length. These illusions can only be overcome by practice.

ANALYSIS OF SURFACE LINES.

5. The obstacles to the opening up of communications between two points are chiefly composed of surface inequalities (by whatever cause produced); hence the topographer must lay special stress upon these elements with the view of finding that line, on or near the surface, where the obstructions are a minimum. His first and main object will then be to study the drainage system of he district as revealed by its streams, then of the principal dividing idges or "water sheds," with their secondary spurs, and lastly, the relative inclinations of the surfaces connecting these two systems of lines.

The drawing based upon the data thus obtained will be more or less accurate, depending upon the frequency and accuracy of the lines as run; but if the topographer be also a geologist, and capable of connecting and portraying cause and effect, his representation will be a much more faithful delineation of the slopes as they are found to exist in nature

Aside from the slopes thus determined with the streams flowing over them; the vegetation, and other surface features, whether natural or artificial, should be clearly shown. As these are numerous and varied in character, a code of conventional signs has been generally adopted, which will be found in sheet No. 2 accompanying this work.

THE THALWEGS OR WATER COURSES.

6. Since water always seeks the lowest points of the surface, the bed of a stream or *thalweg* will invariably be found in the trough of a valley or ravine, and hence the presence of a stream, lake or pond, indicates at once the lowest line, as well as the direction in which the ground slopes in its vicinity. It does not, how-

ever, give the degree of slope further than to distinguish between an alluvial deposit and a mountainous declivity. In the former case the bed will be found to be tortuous, full of bends, loops and islands, whilst in the latter its local curvature will be greatly reduced.

A fair knowledge of the topography may, therefore, be obtained by inspecting a correct map containing only the water courses; thus,

7 a. Should it appear that all the streams crossed the surface in the same general direction, it would indicate a descending slope in that direction; but as the thalwegs are nearly parallel, there must be higher ground between, separating them. The same remarks will apply to their tributaries. This feature may be clearly seen by inspecting any map of the United States where the drainage from the Appalachian chain to the Atlantic is shown in nearly parallel lines, with the single exception of the New river of Virginia, which, rising far to the east, in North Carolina, and breaking through the mountainous barriers, flows into the Ohio and thence to the Gulf.

b. It may be found that a number of rivers all "head" at or near the same point, and flow off in different directions to their respective reservoirs. This will at once indicate conspicuously high ground, as seen in Northwestern Wyoming (Sheet 1) at Washakie Needle between the Shoshone Range, Owl Creek and Wind River Mountains, at the base of whose several slopes flow the Upper Yellowstone, Big Horn, and Wind rivers, tributaries of the Missouri; and the Buffalo Fork and Snake, tributaries of the Columbia river.

c. On the contrary, when two or more rivers or their tributaries approach or meet, it will indicate a gap, pass or col between them or at their junction. Thus, just north-west of Washakie Needle, in the Rocky mountains, will be found the tributaries of the Upper Yellowstone and of Buffalo Fork, known as Atlantic and Pacific creeks, heading at "Two Ocean Pass," forming a "divide" between their respective oceans.

This feature is well illustrated in the perspective view of Harper's Ferry (Plate I), showing the junction of the Shenandoah on the right or south, with the Potomac river on the north, and

HARPER'S FERRY—LOOKING EAST.

their united waters flowing eastwardly through the famous gap in the Blue Ridge.

Here are seen also, a number of topographical features, as mountain and valley crests, brows, slopes, cliffs and ravines—subsequently defined—as well as the artificial details of roads, railroads, canals, bridges, and buildings.

d. Two streams having parallel beds, but flowing in opposite directions, indicate a non-conformity in the general slope of the valleys, when it is difficult to determine the highest point on the dividing ridge without the aid of other streams in the vicinity. The gaps will be indicated by the approach of the bed of the streams or their tributaries, as above in *c.*

e. When two streams, after flowing parallel, rapidly diverge, it is due to an elevated knob rising between their banks; and in general, the distance between the streams, or breadth of base, and the frequency of the branches in a mountainous country, will give some idea of the heights and ruggedness of the ridges.

8. THE WATER-SHED OR RIDGE LINES, as the name indicates, are those lines lying on the crests of the ridges, which separate the various drainage areas or basins of a system and hence they will always be found on the highest ground. They are of necessity curves of double curvature bending in and out, up and down, and compose the "*backbone*" of the system to which they belong. They are not always continuous or connected lines, but may be broken off short as at the passage of a river through a gorge. The various spurs and secondary ridges will have their water sheds connected with the main stem and running out to nothing or merging away into slopes.

These two systems of lines, the thalwegs and water sheds, must be connected by a third series known as the slope lines or simply the *slopes*, which should be run wherever the *irregularities* of the descent or differences in the degree of the slope are greatest; thus at the end of a spur or ridge, and at the head of a ravine or valley, the slope will generally be less steep whilst down the side it will be more abrupt, as the base becomes less for a given height. Some of the numerous variations in direction and intensity which occur in nature and which must not be overlooked, will be found in the following

ANALYSIS OF SLOPES.

9 *a.* The ground may be *level in all directions* for some distance from the observer, forming a plain, plateau, steppe, table-land or llano and may be represented by the symbol zero ° indicating no angle with the horizon as at M., Sheet 4.

b. It may *fall from him in all directions* forming a peak, crater, cone, knob, hill, knoll, mound, dune, promontory or headland, all of which represent the same formation, but in various degrees of altitude and curvature. This general form may be represented by divergent arrows as indicating the direction of flowing water. Sheet 4. See Mt. Pisgah, and at K, south of Nesquehoning.

c. Again the ground may *fall toward him* forming a basin, pit, quarry, well or hole indicated in like manner by convergent arrows as at B.

d. Another combination is exemplified in ground *falling from the observer in three directions but towards him in the fourth*, as at the end of a *spur* or *offset*, sometimes called a *nose* (as at Anthony's Nose in the Highlands on the Hudson) or in some promontories, as at S.

e. The complement of this is to be found in or at the head of a valley, ravine, or hollow, gorge, cañon, barranca or coolie, where *the slopes descend towards the observer on three sides and from him on the fourth*, as shown by the arrows at R.

f. The next combination that occurs is that in which the slopes are taken in pairs, or two and two, thus, the declivities may be *away from the observer in two directions taken alternately, and towards him in two*, forming two cases first where the point is on a ridge between two knobs or knolls when it is called a *gap* as at G., and

g. Second, where it is between two ranges and on a low connecting ridge when it forms a *divide*, as D.

h. Or the formation may be one in which the ground is *level on two sides but falls towards the observer on a third and away from him on the fourth*, as at F, giving the "side-hill," usually terminatingin a plane or "bottom" at the foot and a plateau, flat or terrace at the top. As the edges of the slopes are worn down by time, the form of section will, when the material admits, be an ogee. When the material is rock and the slope nearly or quite vertical it becomes a palisade, precipice or cliff, as at C.

RAWLEY.

Or the ground may be *level in two directions and fall towards or from the observer in two others* forming the defile or valley V or the crest or ridge X, as shown on the narrow anticlinal of Sharp Mt.

Various combinations of these forms may occur as a hill in a basin, instanced by an island in a lake; a knob on the end of a spur, a basin on a side-hill, knolls on ridges and many others which may become objects of special study.

DEFINITIONS.

10. Aside from the mere directions of the slopes, there are certain technical features of detail which the topographer should clearly distinguish. These are best described by their definitions and a reference to Plate 2. Thus by

a. A plane is meant not merely a perfect level, but any slope up to 2°; or, in military language, any inclination upon which troops would be exposed to fire as a *glacis* or *terreplein.*

It is *open* when the view is unobstructed, *covered* or *a covert* when clothed with timber, buildings, etc. When traversed by running water, ditches or marshes, it is an *intersected plane.*

b. The term *hills* is limited generally to elevations of a few hundred feet, but the use of the word is relative and local.

c. The various parts of the slope in any elevation are known as the *summit*, or highest point; the *brow* or *crest*, being the dividing line between summit and slope; the *slope* or *declivity*, the main portion of the descent, and the *foot*, or *base*, which connects the hill and its plane or valley.

d. Under the combinations of two or more slopes may be found the *sharp corner* or *nose.* When of rocks dipping downwards they form the *anticlinal*, *ridge* or *razor-back.*

Two planes meeting at a re-entrant angle form a *water rift*, a *trough*, a *funnel*, or a *synclinal*, according to the inclination.

A *ravine* is an indentation formed in steep declivities. When it is so steep and wide that it cannot be crossed without bridging, it is called an *abyss*, and if very narrow and of great depth, a *chasm*, *gorge*, *gulch*, or *cañon.*

e. Avalanches, *hill-slides*, and *land-slips*, are formed by the action of water on steep slopes, and usually where porous soils overlie impermeable strata with a considerable dip. They are most apt to occur in the spring after a thaw or heavy rain.

f. Depressions or *sink-holes* are formed by vertical settling of the ground, and are generally found in limestone regions. *Caves* and *grottos* owe their existence to the same cause.

g. Valleys are the low stretches of country separating hills and mountains. They usually contain a stream, and form the most available part of the topography for communications and settlements.

11. With these preliminaries the topographer will understand about what to observe; but before taking the field he should roughly map out a plan of operations based upon the objects to be attained by the survey, and select appropriate instruments for the prosecution of his work.

Such an outline may be determined from an inspection of the best local maps, if any exist, from which he will be enabled to select one or more possible routes for a line of communication, or the most suitable points from which to project a system of lines or of triangles for surface work.

To determine the feasibility of the projected outline, a rapid examination must be made of the field of operations, known as the reconnaissance.

12. This should be conducted with reference to the object of the survey, whether for establishing communications, determining areas, or for topography, constituting the three classes of reconnaissance known as *linear*, *chorographical*, and *orographical*.

But, in any case, the topographer should equip himself with such portable hand instruments and note-books as may best assist him in collecting and recording the required data rapidly and accurately, which leads us to the consideration of the instrumental outfit.

CHAPTER II.

THE INSTRUMENTAL OUTFIT.

13. UNDER this head may be mentioned a prismatic compass, chronometer, barometer, odometer or perambulator, pedometer, clinometer, sextant, hand-level, heliotrope, reflector, range-finder, etc., from which a selection may be made according to circumstances.

14. Probably the neatest and most accurate, as well as the cheapest and most satisfactory *prismatic compasses* now manufactured, are those known as "Casella's," Fig. 1, for sale by Fauth & Co., of Washington, D. C. They are graduated from 0° to 360° on a silvered ring, with a "least count" of half a degree. The box has a diameter of 2¾ inches. Since the degrees are numbered consecutively throughout the full circle in the direction of the hands of a clock, zero being North, 90° East, etc., it is only necessary to record the degrees to give at once, and in the simplest possible manner the bearing of a line.

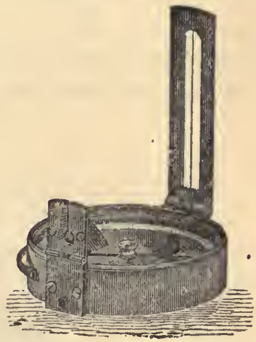


FIG. 1.

15. The equivalent compass bearing is readily obtained, if desired, by the following rules: In the first quadrant annex the letters N. E.; in the second, subtract the reading from 180°, and annex the letters S. E.—thus, 159½° would be S. 20½° E.; in the third, subtract 180° from the reading and annex the letters S. W., and in the fourth, subtract from 360° and annex N. W.

16. The necessity for such reductions will be removed, however, in plotting, by graduating a paper or metal protractor to correspond with that of the compass.

17. The *chronometer*, unless for a portable observatory, may be simply a good pocket time-piece, running with a uniform rate.

18. The *barometer* to be recommended for reconnaisance is the *aneroid*, of which a great variety exists. Its range should exceed the greatest altitude in the country to be examined. The aneroids, (3¾ inch dial) with a thermometer attached, range from 3,000 to 20,000 feet in altitude, and in price from $33 to $40. See Fig. 2.

FIG. 2.*

19. These instruments weigh the atmosphere by means of a vacuous, corrugated metal box, connected by a series of springs and levers with an index moving over a dial plate containing graduations reading to ten feet, and occasionally with a vernier, to single feet. By this

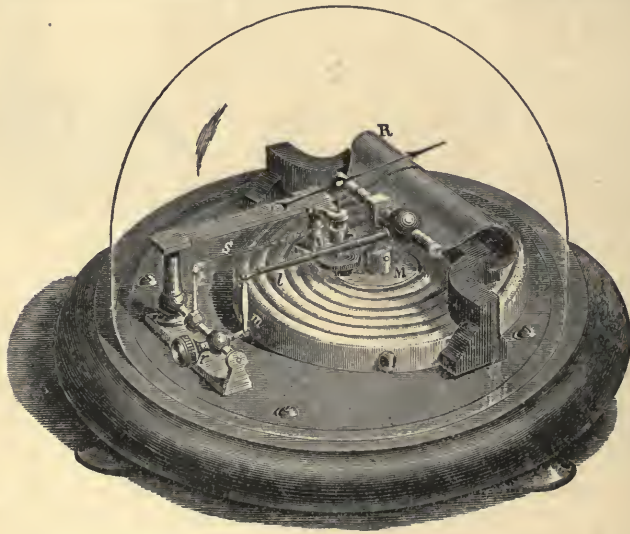


FIG. 3.*

combination the movements of the box are multiplied about 657 times, so that a movement of $\frac{1}{657}$th of an inch in the box will pro duce a motion of one inch in the index.

* For sale by J. W. Queen & Co., Philadelphia, Pa.

20. Many barometers are graduated in inches and decimals, in which case the equivalent heights may be taken from Airy's Tables page 26. Their difference will give the relative levels.

Should the mean temperature differ much from 50° F., add the temperatures of the two stations together, and if the sum is greater than 100° increase the height by its $\frac{1}{1000}$ part for every degree in excess; if less diminish in the same ratio.

Thus let the readings be:

inches.	*elevation at* 50°.	*temperature.*
30.25	667	75°
29.16	1669	82°
	1002	157—100=57°.

and $1002 \times \frac{57}{1000} = 57.114$, which added to 1002 gives for the corrected difference of level 1059.114.

The formula for the correction may be written $C=(H-h)\left(\frac{900+T+t}{1000}\right)$ in which H and h are the altitudes taken from the table, and T and t the corresponding observed temperatures.

The previous example applied to the formula gives $1002 \times 1.057 = 1059.114$. When the sum of the temperatures is less than 100 the second factor must be subtracted from unity before multiplying.

It is sometimes convenient to have a formula giving approximate heights without the use of a table, in which case the following may be applied:

$C' = 55032 \frac{H-h}{H+h}$ in feet at a mean temperature of 55° F. and $\pm\frac{1}{418}$ for each degree of mean temperature above or below 55°.

This is only applicable, however, to altitudes under 3000 feet. *H* and *h* are the barometric readings in inches.

In ordinary work it is sufficient to take 92 feet as equivalent to 0.1 of an inch change on the barometer—subject to a slight correction due to mean temperature above or below 55, as heretofore stated.

AIRY'S TABLE.

Arranged for temperature of 50° F.

Height in Feet. . .	Aneroid, or Corrected Barometer.	Height in Feet. . .	Aneroid, or Corrected Barometer.	Height in Feet. . .	Aneroid, or Corrected Barometer.	Height in Feet. . .	Aneroid, or Corrected Barometer.	Height in Feet. . .	Aneroid, or Corrected Barometer.
ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.
0	31·000	2,400	28·387	4,800	25·994	7,200	23·803	9,600	21·797
50	30·943	2,450	28·335	4,850	25·947	7,250	23·760	9,650	21·757
100	30·886	2,500	28·283	4,900	25·899	7,300	23·716	9,700	21·717
150	30·830	2,550	28·231	4,950	25·852	7,350	23·673	9,750	21·677
200	30·773	2,600	28·180	5,000	25·804	7,400	23·629	9,800	21·638
250	30·717	2,650	28·128	5,050	25·757	7,450	23·586	9,850	21·598
300	30·661	2,700	28·076	5,100	25·710	7,500	23·543	9,900	21·558
350	30·604	2,750	28·025	5,150	25·663	7,550	23·500	9,950	21·519
400	30·548	2,800	27·973	5,200	25·616	7,600	23·457	10,000	21·479
450	30·492	2,850	27·922	5,250	25·569	7,650	23·414	10,050	21·440
500	30·436	2,900	27·871	5,300	25·522	7,700	23·371	10,100	21·401
550	30·381	2,950	27·820	5,350	25·475	7,750	23·328	10,150	21·361
600	30·325	3,000	27·769	5,400	25·428	7,800	23·285	10,200	21·322
650	30·269	3,050	27·718	5,450	25·382	7,850	23·242	10,250	21·283
700	30·214	3,100	27·667	5,500	25·335	7,900	23·200	10,300	21·244
750	30·159	3,150	27·616	5,550	25·289	7,950	23·157	10,350	21·205
800	30·103	3,200	27·566	5,600	25·242	8,000	23·115	10,400	21·166
850	30·048	3,250	27·515	5,650	25·196	8,050	23·072	10,450	21.128
900	29·993	3,300	27·465	5,700	25·150	8,100	23·030	10,500	21·089
950	29·938	3,350	27·415	5,750	25·104	8,150	22·988	10,550	21·050
1,000	29·883	3,400	27·364	5,800	25·058	8,200	22·946	10,600	21·012
1,050	29·828	3,450	27·314	5,850	25·012	8,250	22·904	10,650	20·973
1,100	29·774	3,500	27·264	5,900	24·966	8,300	22·862	10,700	20·935
1,150	29·719	3,550	27·214	5,950	24·920	8,350	22·820	10,750	20·896
1,200	29·665	3,600	27·164	6,000	24·875	8,400	22·778	10,800	20·858
1,250	29·610	3,650	27·115	6,050	24·829	8,450	22·736	10,850	20·820
1,300	29·556	3,700	27·065	6,100	24·784	8,500	22·695	10,900	20·782
1,350	29·502	3,750	27·015	6,150	24·738	8,550	22·653	10,950	20·744
1,400	29·448	3.800	26·966	6,200	24·693	8,600	22·611	11,000	20·706
1,450	29·394	3,850	26·916	6,250	24·648	8,650	22·570	11,050	20·668
1,500	29·340	3,900	26·867	6,300	24·602	8,700	22·529	11,100	20·630
1,550	29·286	3,950	26·818	6,350	24·557	8,750	22·487	11,150	20·592
1,600	29·233	4,000	26·769	6,400	24·512	8,800	22·446	11,200	20·554
1,650	29·179	4,050	26·720	6,450	24·467	8,850	22·405	11,250	20·517
1,700	29·126	4,100	26·671	6,500	24·423	8,900	22·364	11,300	20·479
1,750	29·072	4,150	26·622	6,550	24·378	8,950	22·323	11,350	20·441
1,800	29·019	4,200	26·573	6,600	24·333	9,000	22·282	11,400	20·404
1,850	28·966	4,250	26·524	6,650	24·288	9,050	22·241	11,450	20·367
1,900	28·913	4,300	26·476	6,700	24·244	9,100	22·200	11,500	20·329
1,950	28·860	4,350	26·427	6,750	24·200	9,150	22·160	11,550	20·292
2,000	28·807	4,400	26·379	6,800	24·155	9,200	22·119	11,600	20·255
2,050	28·754	4,450	26·330	6,850	24·111	9,250	22·079	11,650	20·218
2,100	28·701	4,500	26·282	6,900	24·067	9,300	22·038	11,700	20·181
2,150	28·649	4,550	26·234	6,950	24·023	9,350	21·998	11,750	20·144
2,200	28·596	4,600	26·186	7,000	23·979	9,400	21·957	11,800	20·107
2,250	28·544	4,650	26·138	7,050	23·935	9,450	21·917	11,850	20·070
2,300	28·491	4,700	26·090	7,100	23·891	9,500	21·877	11,900	20·033
2,350	28·439	4,750	26·042	7,150	23·847	9,550	21·837	11,950	19·996
2,400	28·387	4,800	25·994	7,200	23·803	9,600	21·797	12,000	19·959

21. In reading an aneroid, it should be held at a constant height from the ground, which height may be assumed to represent the surface elevation. The dial may be either vertical or horizontal, but this latter is generally preferred, and the glass cover should also be gently tapped before observing.

22. As the aneroid is so readily affected by irregular changes in the atmosphere, care must be taken to eliminate these so far as possible by making simultaneous observations on two barometers, one of which is kept by a recorder at a station whose altitude is known or assumed.* The chronometers, barometers and thermometers should be compared before starting and on the return, to determine the rate of change, and the record of the stationary instrument should be made at least every fifteen minutes, and plotted on profile paper, or a continuous record may be obtained by attaching a chronograph. From these data the topographer's barometer may be corrected, provided both instruments have been subjected to the same disturbing causes at the same time. This limitation restricts the range to comparatively short distances. To keep the instruments close together on an extended line it would be better to have two or more recorders, that one may be moved up to the last station for the day, whilst another is traveling to a new point ahead.

23. When there is but one instrument the best method of determining its thermal and other disturbing variations is the graphical one suggested and used by Mr. Chas. A. Ashburner, of the Second Geological Survey of Pennsylvania. By this means the rate of change may be found with considerable accuracy, and the observations thus corrected will agree closely with those determined by the more reliable method of spirit levelling.

The following form of record is that used by Mr. Ashburner, in his work in McKean and other counties:

---

* On the selection of this station much depends. It should be so situated as not to be abnormally affected by ordinary atmospheric changes.

"BAROMETRIC OBSERVATIONS over line between station 0 at 7 a. m. and station 13 at 1.15 p. m., made by Chas. A. Ashburner, M. S., Geologist in Charge, Survey Anthracite Region of Pennsylvania.

Station	Time	Barometer reading in feet	Correction to be made for change due to the atmosphere	Altitude above ocean level	*Remarks.*
0	7 a. m.	1,800		800	
1	8 "	1,850	15	835	Elevation station 0 above tide 800 feet, equivalent to reading on aneroid of 1,800 feet. Barometer rises at station 1, 15 feet, from 8 a. m. to 8:30 a. m.
1	8:30 "	1,865			
2	8:45 "	1,910	41	869	
3	8:50 "	2,050	44	1,006	
4	9:05 "	2,015	55	960	Barometer rises at station 4, 20 feet in 25 minutes, from 9:05 a. m. to 9:30 a. m.
4	9:30 "	2,035			
5	10:00 "	2,100	102	998	
6	10:15 "	2,110	114	996	
7	10:35 "	2,170	133	1,037	
8	10:45 "	2,140	144	996	
9	11:00 "	2,250	160	1,090	
10	11:15 "	2,300	174	1,126	Barometer rises at station 10, 30 feet in 30 minutes, from 11:15 a. m. to 11:45 a. m.
10	11:45 "	2,330			
11	12:15 p.m	2,600	226	1,374	
12	12:45 "	2,900	237	1,663	
13	1:15 "	2,970	242	1,728	

BAROMETRIC OBSERVATIONS over above line between station 12 at 1.45 p. m. and station 0 at 7 p. m.

Station	Time	Barometer reading in feet	Correction to be made for change due to the atmosphere	Altitude above ocean level	*Remarks.*
12	1:45 p.m.	2,900	237	1,663	Barometer reads the same at station 12 at 12:45 p. m. and 1:45 p. m. In consequence it probably rises during the early part of the hour and falls during the latter part.
10	2:20 "	2,355	228	1,127	Barometer falls at station 10, 10 feet in 25 minutes, from 2:20 p. m. to 2:45 p. m.
10	2.45 "	2,345			
4	3:50 "	2,175	217	958	Barometer rises at station 4, 10 feet in 30 minutes, from 3:50 p. m. to 4:20 p. m.
4	4:20 "	2,185			
1	5:30 "	2,075	240	855	Barometer reads the same at station 1 at 5:30 p. m. and 5:55 p. m.
1	5:55 "	2,075			
0	6:30 "	2,030	231	799	Barometer falls at station 0, 15 feet in 30 minutes, from 6:30 p. m. to 7 p. m.
0	7 "	2,015			

The corrections in the fourth column are obtained by scale from a profile of probable atmospheric changes, constructed as follows:

PLATE 3.

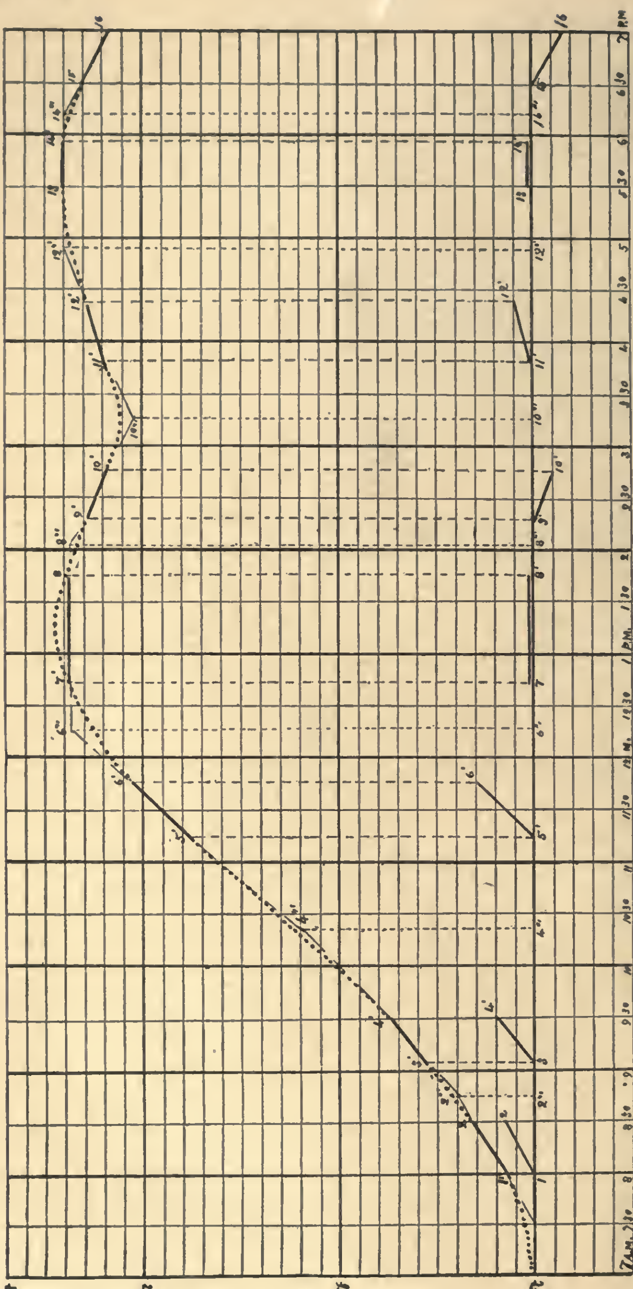


DIAGRAM OF A CORRECTION CURVE FOR A SINGLE ANEROID.

24. *To reduce the observations* profile paper is taken of convenient scales, the scale of hours heing horizontal, and the scale of feet vertical. The reduction is made on the assumption that the change of the barometer in the intervals between the stations where stops are made is a regular one. (Plate 3.)

The change at the stop-stations are first recorded along the horizontal line of hours as in figure at 1, 2; 3, 4; 5, 6; etc. The hour distances between the last observation of one stop-station and the first observation of the next stop-station are then bisected and perpendiculars erected, as 2″ 2‴, 4″ 4‴, etc. A line is then drawn from a point on the base line between the first station and the time of the first stop, parallel to the profile of the first recorded change, to the bisecting perpendicular between the first and second stop-stations (line 1′ 2′ 2‴), thence from 2‴ a line is similarly drawn parallel to the profile of the second recorded change, and this method is repeated throughout to the end of the observations. The profiles of the changes at the stop-stations are then projected perpendicularly into the broken line profile obtained, and the extremities of these projections thus obtained, are connected by a curve line which is the profile of the change of the barometer due to changes in the atmosphere. The correction to be made of the barometric observation at any station may be directly obtained from the profile thus constructed."

This is believed to be the best method of eliminating many of the disturbing variations of observation made by a single observer with but one instrument, and it is due to Mr. Ashburner to say that so far as he is aware, the method originated with him.*

* Valuable and exhaustive contributions to the subject of Barometric Hypsometry have recently been published by Prof. Wm. Ferrel in the U. S. Coast Survey Reports, and by G. K. Gilbert on Barometrical Reductions, in the U. S. Geological Survey Reports.

NOTE.—25. Concerning instruments, Mr. Ashburner further remarks: "The Short & Mason aneroid, of London, is used in all the barometric work of this region, and I do not hesitate to say that they are the best of the many different makes which I have used. They are frequently called the Hick's barometers, from the fact that he sells them. See Fig. 2.

I never read the barometer to less than five feet, although a change of position of one foot in height is readily shown by the barometer of 3¾ inch dial, graduated to 3,000 feet. This accounts for a different elevation of the stations in going out over the line and returning.

26. The *odometer* (road measurer), also called the *perambu lator*, is a small apparatus for registering the number of revolu tions of a wheel which may be rolled over the surface. It consists generally of toothed wheels with graduated faces gearing into a worm, the shank of which is connected with the revolving wheel of some vehicle. In the Roman chariots (in use 50 B. C.), the wheels were nearly four feet in diameter, so that 400 relutions made a Roman mile of 5000 feet, but the wheels may be of any convenient size. Those of the U. S. Coast Survey are 8¼ feet or one-half a rod in circumference. A convenient size would be one ten feet in circumference.

27. In Hunter's odometer (Fig. 4) there are two wheels on the same center, both gearing into the same worm. One has 100 teeth, the other 101. On the first is a graduation giving the single revolutions up to 100 on the second, the multiples of 100. The range of the instrument is therefore 100×101, when the zeros will again be together, if so started, and if the wheel be ten feet in circumference, the total distance traversed, as measured on the *surface* (not in horizontal projection) will be 101,000 feet, about 19¼ miles, or about a day's march. This instrument should be so attached to the carriage or wagon wheel as to register forward and not backward, as less conducive to error.

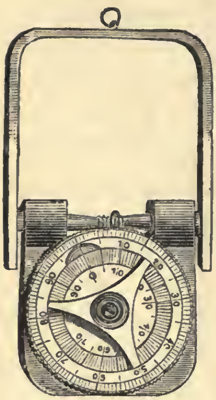


FIG. 4.*

28. A more convenient arrangement for the topographer would be something in the shape of a light hand-barrow as designed and used by Prof. Lesley on his earlier work in the Allegheny mountains in Pennsylvania. It was simply a large wheel driven by two handles which supported a light box for the barometer and other instruments and note books. By resting the handles in sockets on a belt, the operator will have his hands free for sketching or other purposes.

29. Another form used for itinerary journeys and conveniently attached to any vehicle, is that sold by W. & L. E. Gurley, of

* For sale by J. W. Queen & Co., Phila.

Troy, N. Y., and shown in (Fig. 5). Its range is 100,000 revolutions and price $10.

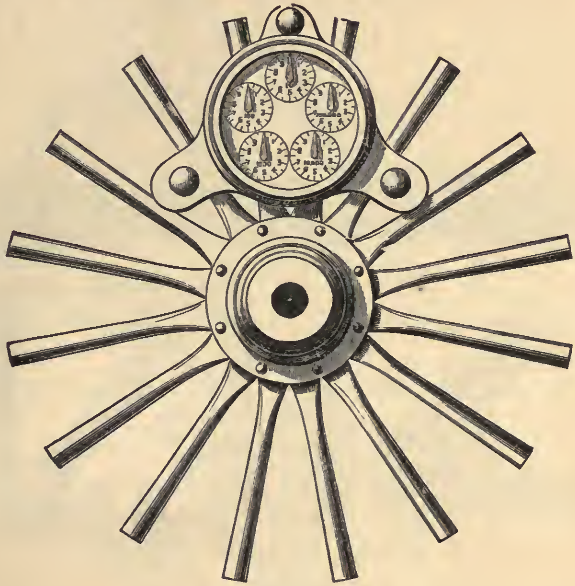


FIG. 5.

30. The *pedometer* is a small instrument resembling a watch, which may be carried in the vest pocket to register the number of steps or paces traveled over. One form is shown in (fig. 6).

31. *Clinometers* (angle measurers,) of various patterns are offered by different makers, and any of them may be used to advantage in steep slopes or for observing the dip of the strata. The angle may be obtained either by reference to the horizon as given by an attached spirit level or from the normal by reference to a plummet, as shown in the annexed forms, (Figs. 7, 8, 9). 32. Slopes may also be readily taken by a vertical and a horizontal rod or by a vertical rod, hand level and tape.

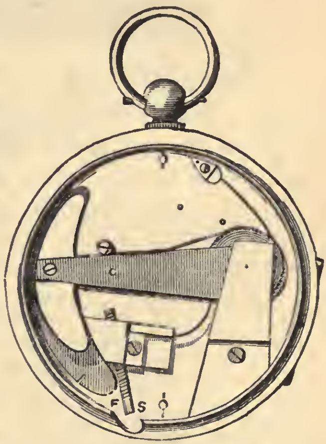


FIG. 6. (REAR VIEW.)*

* For sale by J. W. Queen & Co.

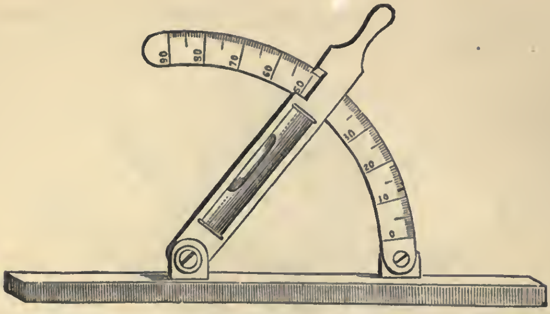


FIG 8.*

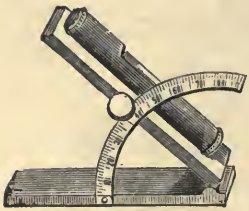


FIG 7.*

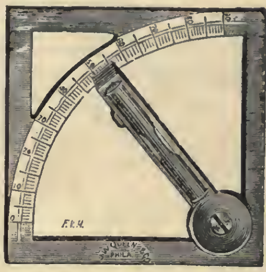


FIG 9.*

32. The ordinary *hand level*, as shown in Fig. 10, consists of an

FIG. 10.*

optical tube, in one-half of which is placed a prism, by which the bubble of the attached level is reflected to the eye lens, and appears to be bisected when the axis is horizontal. By sighting through the open portion at this instant, the observer notes the point on the ground, or on a rod, which is at the height of his eye, and thus obtains the difference of level or slope between himself and the foot of the rod.

33. A convenient combination of hand level and clinometer is seen in the Abney Instrument, manufactured by Messrs. W. & L. E. Gurley, of Troy, N. Y. (Fig. 11.)

* For sale by J. W. Queen & Co., Phila.

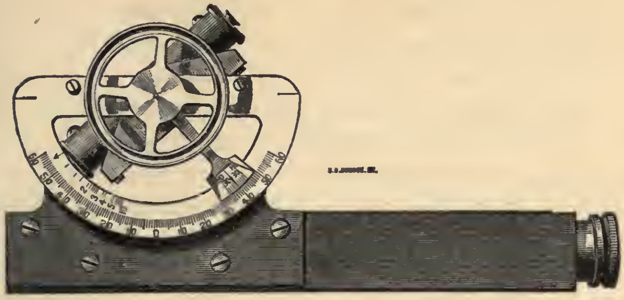


FIG. 11.—ABNEY LEVEL AND CLINOMETER.

34. The *sextant* (Fig. 12) is a useful instrument for reading

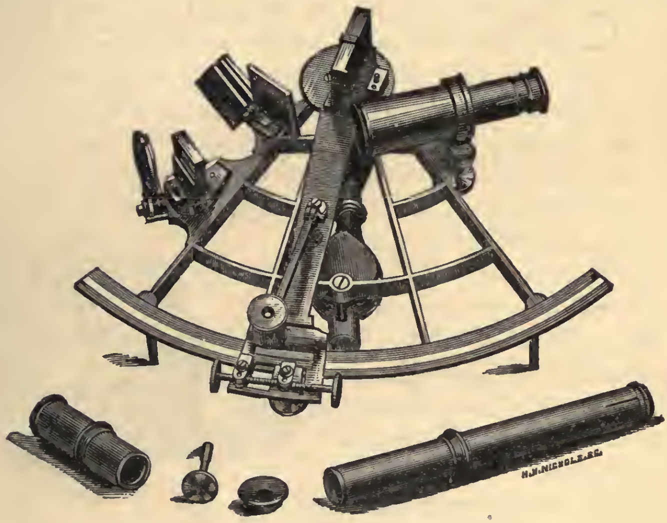


FIG. 12.—SEXTANT.*

angles or determining distances to inaccessible points. It does not, however, give the angle in a horizontal plane, but the oblique angle between the objects—neither does it give the magnetic bearing of lines.

For a minute description of this instrument the reader is referred to any standard work on surveying.

Briefly, it consists of two mirrors placed at right angles to the

* For sale by Messrs. W. Fauth & Co., Washington, D. C.

plane of a graduated arc, on which the half degrees are numbered as full degrees, since the angle between the incident and second reflected ray is double that between the planes of the mirrors. One of the mirrors, called the index glass, is attached to the upper end of the index arm, with which it moves. The other extremity of the index arm carries the vernier. The other, or horizon glass, is rigidly attached to the frame-work of the arc.

35. To make an observation, hold the instrument with the right hand in the plane of the two objects between which the angle is to be read. The beginner may then set the index at zero and sight to the right-hand object, when, by a slight motion of the sextant, he will see both the direct and reflected images. With the left hand move the index along the arc, keeping the reflected image in sight until the direct image of the second object becomes visible, when the vernier may be clamped and the coincidence be made by the tangent screw. After a little practice, the sight may be taken at once to the left-hand object, and the other will soon be found by a sweep of the index arm.

36. With the pocket sextant (Fig. 13), the method of observing is the same, but the instrument is held in the left hand while the right is used to turn the large milled-headed screw which moves the index-glass. The arm must be held so high as not to intercept the ray entering the box.

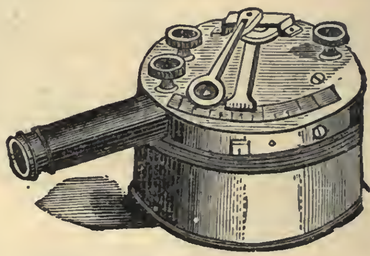


FIG. 13.*

37. The index error, if any, should always be determined and properly applied. It is constant for the same instrument. It is positive when the zero of the vernier is off the arc and negative when on, as it is from the position of this zero that the angle is read. The error may be detected by sighting to some well-defined distant object, as a star, and bringing the direct and reflected images into coincidence. If then the zeros of the arc and vernier coincide, there is no error. If not, the reading gives its amount, which must be applied as above, or the horizon glass may be turned slightly until the images coincide at zero.

* For sale by Fauth & Co., Washington, D. C.

When an artificial horizon is used in reading altitudes, the observer places himself so as to see the object by reflection from the surface of the mercury, and then looks directly into this horizon through the telescope or sight-hole, catching the reflected image by a movement of the index arm.

The altitude thus observed will be double the required angle, and must be divided by two.

38. To *determine the distance to an inaccessible point*, the index may be set at any angle whose natural tangent is known, and a point be found on a line, at right angles to the required line, from which the objects at the ends of the unknown line appear to be coincident. The measured distance from this point to the near end of the required line, multiplied by the natural tangent, will give the required distance. For convenience, the angle 45° is generally taken, as its tangent is unity.

A more general solution is to stake off a line making any angle with the required line, Fig. 14, then set the sextant at ½ of the deflection angle and find a point P. as before, along the line staked out. The distance from it to the starting point A will be equal to that required.

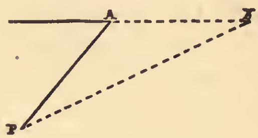


FIG. 14.

VERNIERS.

39. To read any vernier, the application of the following simple formula (a) will readily solve the most complicated cases, or will enable any one to make a vernier having a given graduated limb and "least count."

The *least count* is the difference in length between one division on the limb and one on the vernier. If the latter divisions are shorter than the former, the vernier is *direct;* if the reverse, *retrograde.*

40. Let L = the number of minutes in the smallest division of the limb; V, the same for the vernier—then L—V will be the "least count," to be determined. Let n represent the number of divisions of the vernier, counting from zero, then since n times L—V must equal L, there results

$$L-V=\frac{L}{n} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (a).$$

Thus if L be 20′, and n=40, the least count will be $\frac{20}{40}$=½ a minute=30 seconds.

41. Should it be desired to space a vernier so as to give a certain least count, say $\frac{1}{1000}$ of a foot on a scale graduated in feet, tenths and hundredths, the formula would become $n=\frac{L}{L-V}=\frac{\frac{1}{100}}{\frac{1}{1000}}$ $=10$ parts, covering $\frac{9}{100}$ of the scale.

EXERCISES ON VERNIERS.

42. 1. A scale is divided into feet and inches. The latter subdivided into 20 parts.

A vernier of 11 parts covers 10 subdivisions on the scale; what is the least count in terms of an inch?

2. What would it be if 9 parts of the limb were equal to 10 of the vernier?

3. What, if 10 parts of the limb were equal to 9 of the vernier, and how distinguished from the above?

4. What if 11 parts of the limb were equal to 10 of the vernier?

5. A circle is graduated into quarter degrees, and a vernier into 15 parts covering 14 on the limb; what is the least count?

6. Having a circle divided into 20 minutes, what must be the number of divisions of the vernier to give a least count of 10 seconds?

7. Construct a vernier scale to read to $\frac{1}{1000}$ of a foot.

RIGHT ANGLE REFLECTOR, OR OPTICAL SQUARE.

43. Another convenient reflecting instrument for turning oft right angles consists of a small frame (Fig. 15) containing two mirrors so placed as to make with each other an angle of 45° Immediately over the mirrors are two slots or "windows" through which the direct ray passes.

44. To use the instrument a plumb-bob should be attached to the hook at the end of the handle, and be allowed to hang over the point on the line at which it is desired to erect a perpendicular B., Fig. 16. The face of the reflector is then turned slowly around until the image of some other point on the line, as A., is seen in the mirror opposite the eye. By now glancing through the opening above this image, a rod may be placed at C. in the same vertical line with it, thus giving the required point.

By this reflector a point may readily be found on a given line at which, if a perpendicular be erected, it will pass through a given point.

45. THE PRATT RANGE FINDER* is an extension of this principle by a combination of two pairs of mirrors so arranged that

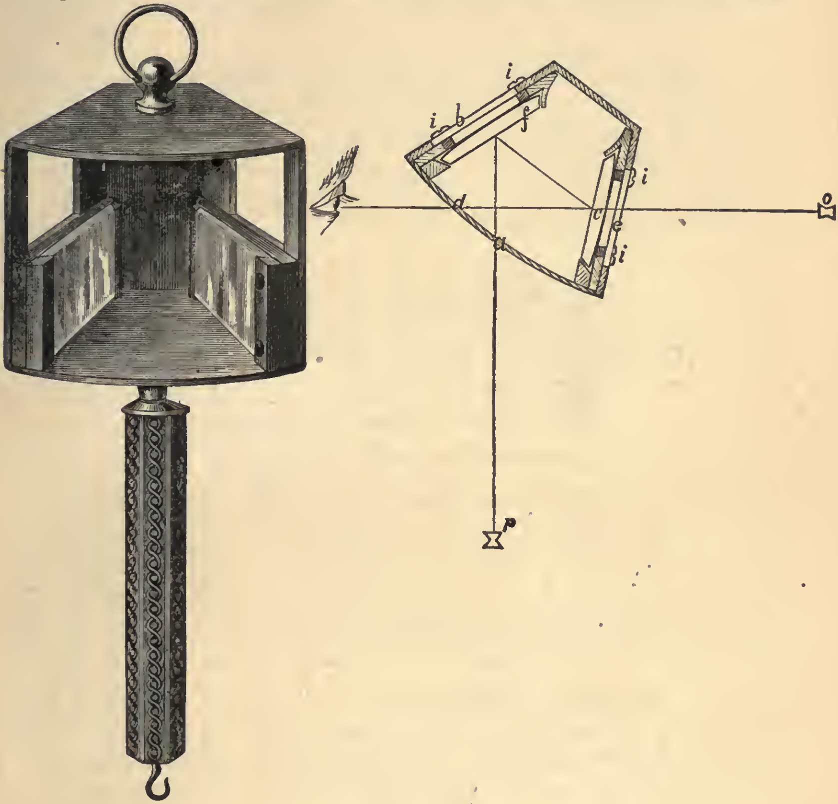


FIG. 15.†

while the upper set gives the right angle, the lower set will determine another angle differing from it by some small quantity, preferably 2° 51′ 45″. By this arrangement two points, B and D, Fig. 16, may be found on a line at which the images of the two objects (one A on, and the other C off the line) appear to coin-

FIG. 16.

*NOTE.—Numerous applications may be made of this covenient instrument, for a complete description of which the author is referred to its inventor, Lieut. Sedgwick Pratt, U. S. A, Artillery School, Fortress Monroe, Va.

† For sale by Queen & Co.

cide or cover one another. For the value of the angle given above, the sides BD and BC are to each other, as 1 : 20; hence it is only necessary to measure the short base BD to determine the distance to the inaccessible point C.

As in this case, the required quantity is a *multiple* of the base, the latter should be measured with sufficient accuracy, since its errors will be increased twenty fold by the operation.

46. Another instrument of extreme portability and remarkable accuracy, is that known as the *Gautier's Telemetrical Telescope.**

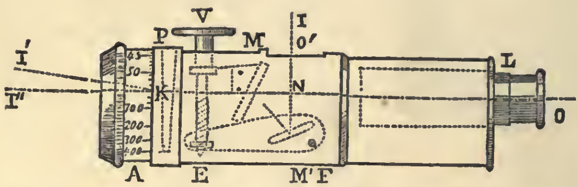


Fig. 17.—Gautier's Telemetrical Telescope (in plan.)

It consists, as shown in the figure (17), of a tube about five inches long, having a short telescopic eye-piece, L, of low magnifying power, at one end, and two mirrors M and M′ making an angle of 45° with each other, and occupying half the width of the tube, leaving the remaining half open to rays coming in the direction I″O.

P is a glass prism, having an angle of about 6°, which is attached to a graduated ring rotating on the end of the tube. O′ is an aperture to admit rays in the direction IO′, which reach the eye after a double reflection, as in the sextant. M′ is fixed to the lever EF, which is moved about the pivot F by the screw E. This lever carries an index on the under side to indicate the exact angle made by the mirrors. The prism causes the rays entering the tube to deviate by half the angle between its faces, or I″KI′ equal to 3°. By turning the ring A with the attached prism P, the ray I′K will describe a conical surface, and its *lateral* deviation will vary from 3° on the right to 3° on the left, passing through zero at top and bottom.

To set the instrument for use, turn the ring A until the mark

* More fully described in "Report on Industrial Arts," by F. A. P. Barnard, published by D. Van Nostrand, of New York.

∽ is under the index, which much also be brought to read zero. The edge of prism is now vertical, and objects seen through it are displaced to the right. The mirrors are at 45° and the angle N is 90°.

Let the observer be stationed at D (Fig. 16), and let it be required to ascertain the distance to C. Sight through the telescope in the direction of AD produced, and select some object E a little to the right of the image of C, seen by reflection. Then by means of the screw-head V bring the selected object E into coincidence with the image of C, upon a line traced on the centre of the mirror M. This done, move to some convenient point B, more remote from E, and observe again, making the coincidence by turning the ring A. When this is accomplished, the graduation under the index of A will give a factor which multiplied into the distance DB will give the distance BC.

The accuracy of this instrument is extraordinary. With a base of 20 meters (65.6 feet), the error for distances below a kilometer (3280.9 feet) is almost imperceptible. Distances from three to six kilometers, and even more, have been measured by it, with bases of from 20 to 50 meters, with a maximum error not exceeding one-fourth of one per cent.

47. Many forms of instruments have been invented for determining inaccessible distances by sights taken upon some object of known or estimated height, but a slight error of height vitiates the result.

Professor Piazzi Smith, Otto Struve, and others, invented an instrument upon a directly opposite principle, viz., one that should carry its own base. This base is placed at right angles to the line of collimation, and carries two mirrors or prisms M and M′ at its extremities, one of which is in line with the axis of the telescope T, so that a direct sight may be made through the unsilvered portion of the mirror upon the object O. The same object is seen by reflection from the other mirror (as in the sextant), and the coincidence or the amount of separation of the two images furnishes

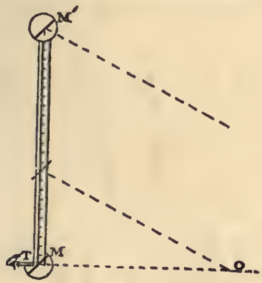


FIG. 18. (PLAN.)

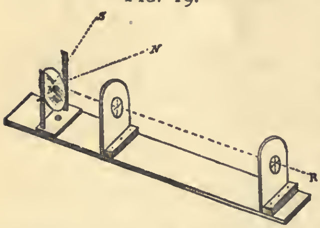
the means of ascertaining the required distance. The coincidence may be effected by turning the index mirror M′ in azimuth, or by moving it along the base, or the amount of separation may be read by a wire micrometer and finely divided scale, in which case both mirrors are fixed. This latter arrangement is found most convenient. Any distance may be measured with this instrument in about half a minute. The maximum error in distance for the 36-inch base is 3 inches at 300 feet, 7½ feet at 1,500 feet, and 30 feet at 3,000 feet.

The instrument of Lieut. Pratt is much more compact, and when adjusted, quite as accurate.

48. THE HELIOTROPE is an instrument used to reflect the sun's rays to distant points, and thus facilitate the operation of reading angles, either horizontal or vertical, on lines of from 15 to 100 miles in length. The name is derived from ἥλιος the sun, and τροπή turning—hence the instrument is one which turns or deflects the rays in any required direction. It differs from the heliostat in not being automatic.

Its construction is very simple, Fig. 19. Two opaque screens may be placed about 18 inches apart upon a strip of wood forming a base and be screwed or nailed fast. A hole about one inch in diameter should be cut through each screen, the one in rear being a little larger than the other, and across each there should be drawn two fine wires or threads so as to intersect each other.

FIG. 19.



SIMPLE FORM OF HELIOTROPE.
S=Sun.
M=Mirror.
S M=Incident Ray.
M N=Normal.
M R=Reflected Ray.

About six inches in rear of the screens there should be placed a small mirror—3 inches in diameter will be sufficient—so mounted as to have the two motions horizontal (or in azimuth) and vertical (or in altitude.) The crude instrument is then ready for operation. To throw the ray upon any given object visible to the unaided eye, turn the mirror down out of the way or remove it altogether, and sight across the wires, moving the base until the line joining the intersections of the cross wires passes through the object. Then replace the mirror carefully so as not to disturb the line of sight, and turn it in either or both directions until the shadow of the edge of the hole in the first screen is concentric with that in the second. The reflected ray will then be visible to an observer at the given point.

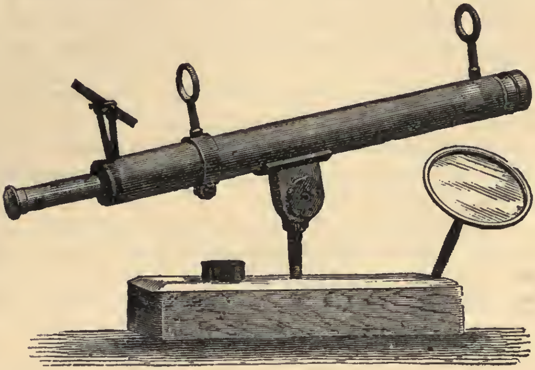


FIG. 18.—HELITROPE.*

When the observer is so distant that a telescope is necessary to determine the direction to him, the instrument is modified by attaching the rings and mirror to the telescope, care being taken that the axis of the rings is parallel to that of the instrument. (See fig. 20.) Should the sun be in the plane of the mirror or back of it, so that no reflection can be obtained along the telescope, an auxiliary mirror must must be used and placed in such a position as to reflect the ray upon the primary mirror, which, by a second reflection, sends it through the rings.

Although so simple and inexpensive, this little instrument serves to increase greatly the economy and accuracy of reading angles to very distant objects. The rays reflected from it are plainly visible to the naked eye at from 30 to 50 miles, and with telescopes these "day stars" have been seen at a distance of nearly 100 miles across Lake Superior, when no trace of land was visible.

It needs no second thought to perceive that they may be used as were the semaphores of Claude Chappé, introduced in 1794 as the first efficient *telegraph*, but with greater effect. By adopting

* For sale by Fauth & Co., Washington, D. C.

any convenient code of long and short flashes made by obscuring the ray, messages may be sent from point to point.*

The Morse code is as convenient as any other, but for simplicity a conventional code expressing certain sentences by a few flashes is found to answer the ordinary requirements of field work. That in use on the Geodesy of Pennsylvania will be found in the following letter of instruction to the heliotropers:

U. S. COAST AND GEODETIC SURVEY.—SEASON 1880.

49. *Instructions for Heliotropers.*

1. Always centre instrument carefully over point on the ground.

2. Keep the line of collimation carefully pointed on distant station, and make the shadow of first ring fall upon the second.

3. On receiving signal to move, do so as expeditiously as possible.

4. Always assume that observers are reading to your flash, and do not leave your post for any length of time except in emergencies.

5. The following *code* will be used in signalling:

Keep a copy in heliotrope box, or marked on lid.

Show brighter —— — — ——
Repeat signal —— ——
Stop for the day —— — —— — — — —
Invisible —— — —— — —— — —— — ——
Have finished angle — — —
Move to — — — ——
Flash to —— —— — ——
Show more constantly —— —— —— ——
Right or yes —— —— —— —— —— ——
Wait for signal —— —
I am reading to your flash — — — —
Wrong or no — —

6. The stations will be designated by the following numbers and indicated by the short flashes following the long one in the signal for moving. 1, "Big Rock" near Allentown. 3, "Topton." 5, "Black-spot at Reading," etc.

7. The signal for *attention* will be ten short quick flashes, which will always precede a message. It should be repeated by the receiver before the message is sent—and by the sender at a brief interval after message, to indicate its completion.

L. M. H.

In charge Geodesy of Penna.

A simpler form of heliotrope may be made by driving two nails into a short stick, tacking it to a rest and sighting over the nail heads in the desired direction. Having fixed the sights in this

* In one instance a vessel was saved by signalling to a party at Marquette, Lake Superior, that she had grounded on some rocks near the station "Vulcan" on Keweenaw Point.

position, reflect a sunbeam so that the shadow of the nearer nail head covers the farther one.

This simple device will be found of great value in determining the intervisibility of two or more points, or in sending messages. In fact the Indians of the northwest have been using mirrors for this purpose for some time; though without sights, and for comparatively short distances.

CHAPTER III.

SCALES OF MAPS.

50. Before proceeding to make a reconnaissance, even with the equipment just described and a knowledge of its use, the topographer must decide a few questions, ignorance of which may cost him his position, or cause him to fail entirely when success was almost within his grasp. Amongst them there may be mentioned:

1. The selection of the scales of his sketches, and their relation to the final drawings.

2. The use of some systematic method of taking and recording notes, which may be intelligible to one not familiar with the ground.

3. The exercise of considerable discretion as to what features should be introduced and what omitted without waste of time.

4. The marking of reference-points in the field so as to be readily found by others.

5. The method intended to be used in working up the data or the *form of computations*, whether graphical or analytical. It will only be necessary here to touch upon the first two of the above points before beginning with the field work. when the remaining ones will follow in proper sequence.

They should be well considered, however, before work is begun, as some of them will recur at every change of station and must be answered; but as they are all more or less contingent upon the scale of the map, the topographer should first select that with a view to show clearly all necessary details and no more, remembering that anything superfluous is a wasteful expenditure of time and money. The degree of accuracy to be observed in conducting the survey is also a function of the scale, as it is useless to attempt to avoid errors which are too small to appear on the map. See § 162 on Limits of Error.

51. *The Scale* may be defined to be the ratio of the field or

object to the plot or drawing—and may be expressed in the form of a fraction, obtained by dividing the second quantity by the first. Thus if F represent the field and P the plot, the ratio or scale would be $\frac{P}{F}$. The antecedent, the real tangible object to be represented, being the unit of comparison is made the divisor or first quantity, whilst the variable representation of that object, which may be made of any size sufficiently large to show the parts, is taken as the second quantity or consequent; as in a geometrical progression, where the ratio is the quotient of any consequent divided by its antecedent.

52. Thus if n represent the number of units of the Field corresponding to one unit of the Plot, the general formula becomes an equality of ratios, $\frac{P}{F} = \frac{1}{n}$ from which it follows that $F = Pn$ or $P = \frac{F}{n}$; in other words, *any length in the field is obtained by multiplying its homologous line of the plot by the denominator of the scale*, and *any line on the plot is obtained by dividing the corresponding field dimension by the denominator of the scale.*

The units must invariably be of the same denomination. By observing these suggestions no confusion can arise as to what is meant by the scale. Thus, 1 mile to the inch=63360 inches to 1 inch, or $\frac{1}{63360}$. Three miles to an inch would be $\frac{1}{190080}$—and of these two scales thus expressed there is no doubt as to which is the larger, since the first divided by the second gives a quotient of 3. In general if a scale (A) be represented by $\frac{1}{N}$ and another (B) by $\frac{1}{S}$ the ratio of A to B will be $\frac{B}{A} = \frac{1}{S} \div \frac{1}{N} = \frac{N}{S}$, which may be a whole number or fraction. If N=2s, then $\frac{B}{A} = 2$, or B is twice as large as A.

Again if we wish to make a new scale B any number of times a given scale A, as $p\,A$, we substitute this value for B in the above equation and obtain $s = \frac{N}{p}$, or in other words divide the denominator of the fraction expressing the given scale by the multiplier (whether whole or fractional) for the denominator of the new scale. Thus if N = 63360 and p be ⅓, s will be 190080, and the scale B will $= \frac{1}{190080}$.

It should be remembered also that a *larger scale always means* *a magnified representation of the surface* as compared with some other map, and not a greater number of linear units to the inch or a greater area of surface represented in a given square of the map. For instance, 6 miles to an inch is not greater but less than one mile to the inch, being but $\frac{1}{6}$ the size—that is, it would take a much smaller sheet of paper to represent a given area at 6 miles than at 1 mile to the inch.

53. The scales of maps expressed decimally are to be avoided as unintelligible, as e. g., the number $.00020\frac{5}{6}$, a mixed vulgar and decimal fraction, means simply a scale of $\frac{1}{4800}$, or 4800 feet to 1 foot = 400 feet to 1 inch.

54. It is always desirable to use the largest scale for the field notes, and sub-multiples of these for the compiled sheets. So far as possible, the same scale should be used for all the parts of an extended survey, that the several sections may be united in a general map. Exceptions may be made in case of special features requiring more minute study.

55. In some foreign countries, as Prussia, Austria and Switzerland, the plane table sheets for topography are plotted on a scale of $\frac{1}{25000}$; in Italy, on a scale of $\frac{1}{50000}$, and in Sweden, $\frac{1}{100000}$. The older British charts and maps of kingdoms were made on a scale of 1 mile to 1 inch, or $\frac{1}{63360}$; the later maps of counties are 1 mile to 6 inches, or $\frac{1}{10560}$; but these latter, while not being large enough to show parish boundaries with sufficient accuracy, require about six times the amount of labor in their preparation, and are inconvenient, so that at present, populous, cultivated and mineral districts in Great Britain are plotted on a scale of $\frac{1}{2500} = 1^m$ to 25.344″, in which an English acre is represented by one square inch, while the thinly settled districts retain the scale of 1^m to 6″ $= \frac{1}{10560}$. For plans of cities of over 4,000 inhabitants, a scale of $\frac{1}{500}$, or 1^m to 10.56 feet is used, and for towns and villages $\frac{1}{1056}$, or 1^m to 5 feet, is general. Of their relative cost, the parish surveys are estimated at 25 cents per acre; the county, at $21\frac{1}{2}$ cents for cultivated, and $12\frac{1}{2}$ for uncultivated districts; and for kingdoms at $40 per square mile.

The scale used by Prussia and Switzerland for general maps is $\frac{1}{100000}$, or $\frac{1}{4}$ that of the detail sheets of the plane table surveys.

In France the topographical maps are made on scales of

1 : 10,000, 1 : 20,000, 1 : 40,000, and 1 : 80,000. The maps of the *Corps des Ponts et Chaussée* are on a scale of 1 : 5000 and of 1 : 500. The scales most in use for very exact details are 1 : 2,500 to 1 : 5,000.

56. On the Second Geological Survey of Pennsylvania, a system of scales ranging from 400 to 1600 feet to one inch is employed ($\frac{1}{4800}$ to $\frac{1}{19200}$)—the largest scale, 400 feet to 1″, being used in the note book, which is divided into quarter inch or 100 foot squares. Ten feet would then be represented by $\frac{1}{40}$ of an inch, sufficient to show a small building.

The district maps of the city of Philadelphia are made on a scale of 200 feet to 1 inch, or $\frac{1}{2400}$.

57. Cadastral maps of farms, parks, etc., may be conveniently plotted to a scale of 50 or 100 feet to an inch = $\frac{1}{600}$ or $\frac{1}{1200}$; but frequently, especially in old surveys, a certain number of poles or chains may be taken per unit.

58. To assist in determining rapidly the equivalent numbers of such variable standards of comparison as may be represented by a linear unit of the map, or the reciprocal extent of map covered by a unit of the standard, two tables have been prepared which will be found appended.—To these have been added the number of acres to the square inch of map for the various scales given in the list. These will prove valuable in rapidly estimating contents—by counting the number of square inches on the map, or by the use of the planimeter.

Should a scale be sought which is not included in the table, its multiple or sub-multiple may be found, and the quantities taken from the table multiplied by this factor will give the required amount, excepting in the area column.

To find the number of acres in the square inch, square the number of chains as given in that column and divide by one hundred.

Table of Map Equivalents giving for each

No.	Scale.	Miles.	Kilometers.	Chains.	Poles.
1.	$\frac{1}{7\,349\,760}$	116.	186.6821	9280.000	37120.00
2.	$\frac{1}{2\,090\,880}$	33.	53.1078	2640.000	10560.00
3.	$\frac{1}{1\,267\,206}$	20.	32.18663	1600.000	6400.00
4.	$\frac{1}{1\,200\,000}$	18.9393	30.4791	1515.151	6060.60
5.	$\frac{1}{1\,013\,760}$	16.	25.7492	1280.000	5120.00
6.	$\frac{1}{1\,000\,000}$	15.7828	25.3992	1262.624	5046.50
7.	$\frac{1}{823\,680}$	13.	20.9209	1040.00	4160.00
8.	$\frac{1}{811\,008}$	12.8000	20.5994	1024.000	4096.00
9.	$\frac{1}{760\,320}$	12.	19.3129	960.000	3840.00
10.	$\frac{1}{696\,960}$	11.	17.7023	880.00	3520.00
11.	$\frac{1}{635\,060}$	10.0221	16.1286	801.768	3207.07
12.	$\frac{1}{633\,600}$	10.	16.09320	800.000	3200.00
13.	$\frac{1}{600\,000}$	9.4696	15.2398	757.575	3030.30
14.	$\frac{1}{506\,880}$	8.	12.87456	640.000	2560.00
15.	$\frac{1}{500\,000}$	7.8914	12.6996	631.313	2525.25
16.	$\frac{1}{443\,520}$	7.	11.2651	560.00	2240.00
17.	$\frac{1}{400\,000}$	6.3131	10.1597	505.050	2020.20
18.	$\frac{1}{380\,160}$	6.	9.65587	480.000	1920.00
19.	$\frac{1}{375\,000}$	5.9185	9.5239	473.480	1893.92
20.	$\frac{1}{316\,800}$	5.	8.04664	400.000	1600.00
21.	$\frac{1}{300\,000}$	4.7348	7.61992	378.780	1515.15
22.	$\frac{1}{253\,440}$	4.	6.43732	320.00	1280.00
23.	$\frac{1}{240\,000}$	3.7878	6.09570	303.030	1212.12
24.	$\frac{1}{200\,000}$	3.15656	5.07985	252.525	1010.10
25.	$\frac{1}{190\,080}$	3.	4.82793	240.000	960.00
26.	$\frac{1}{160\,000}$	2.5252	4.0638	202.020	808.08
27.	$\frac{1}{150\,000}$	2.36742	3.80496	189.393	757.57
28.	$\frac{1}{126\,720}$	2.	3.21866	160.000	640.0
29.	$\frac{1}{120\,000}$	1.89393	3.05784	151.515	606.06
30.	$\frac{1}{100\,000}$	1.57828	2.53995	126.262	505.05
31.	$\frac{1}{80\,000}$	1.2626	2.0319	101.010	404.04
32.	$\frac{1}{79\,200}$	1.2500	2.01166	100.000	400.00
33.	$\frac{1}{76\,800}$	1.21212	1.9604	96.967	387.87
34.	$\frac{1}{63\,360}$	1.	1.6093	80.000	320.00
35.	$\frac{1}{60\,000}$	0.94696	1.52392	75.757	303.03
36.	$\frac{1}{59\,400}$	0.9375	1.50874	75.000	300.0
37.	$\frac{1}{50\,000}$	0.78914	1.26996	63.131	252.52
38.	$\frac{1}{47\,520}$	0.7500	1.20696	60.00	240.00
39.	$\frac{1}{40\,000}$	0.63131	1.0159	50.500	202.02
40.	$\frac{1}{39\,600}$	0.6250	1.0058	50.000	200.0
41.	$\frac{1}{39\,370}$	0.62138	1.	49.710	198.88
42.	$\frac{1}{38\,400}$	0.6060	0.9752	48.484	193.93
43.	$\frac{1}{38\,016}$	0.6000	0.9656	47.925	191.70
44.	$\frac{1}{31\,680}$	0.5000	0.80465	40.00	160.00
45.	$\frac{1}{30\,000}$	0.47348	0.7619	37.878	151.48
46.	$\frac{1}{25\,344}$	0.4	0.64373	32.000	128.00
47.	$\frac{1}{25\,000}$	0.39457	0.63967	31.565	126.26
48.	$\frac{1}{23\,760}$	0.37500	0.60349	30.000	120.00
49.	$\frac{1}{21\,120}$	0.33333	0.53589	26.666	106.66

lineal inch of Map, the following number of

Meters.	Yards and Feet { of Actual Distance.		No. of Acres to the sq. inch.	Where Used.	No.
186682.18	204160.0	612480.0	. . . . . .	Map of U. S. . .	1.
53107.86	58080.0	174240.0	. . . . . .	Map of Pa. . . .	2.
32186.635	35200.0	105600.0	. . . . . .	U. S. C. S. . . .	3.
30479.7	33333.3	100000.0	229567.	U. S. C. S. . . .	4.
25749.27	28160.0	84480.0	163840.	△ India	5.
25399.2	27755.7	83333.3	159420.	U. S. C. S. . . .	6.
20920.9	22880.0	70640.	114555.	. . . .	7.
20599.416	22528.0	67584.0	104845.	. . . .	8.
19312.95	21120.0	63360.0	92160.	R. R. Va. . . .	9.
17702.3	19360.0	57080.0	74796.	. . . .	10.
16128.6	17638.9	52916.6	64283.	U. S. C. S. . . .	11.
16093.29	17600.0	52800.0	64000.	U. S. Eng. . . .	12.
15239.8	16666.6	50000.0	57392.	U. S. C. S. . . .	13.
12874.65	14080.0	42240.0	40960.	Eng. Ord. Sur. .	14.
12699.6	13888.8	41666.6	39855.	U. S. C. S. . . .	15.
11265.1	12320.0	36960.	31360.	. . . .	16.
10159.7	11111.1	33333.3	25507.	U. S. C. S. . . .	17.
9655.87	10560.0	31680.0	23040.	Ludlow's Rep. .	18.
9523.9	10416.5	31250.0	22419.	U. S. C. S. . . .	19.
8046.64	8800.0	26400.0	16000.	Barnes' Pa. . . .	20.
7619.9	8344.3	25000.0	14348.	U. S. C. S. . . .	21.
6437.333	7040.	21120.	10240.	. . . .	22.
6095 7	6666.6	20000.0	9183.	U. S. C. S. . . .	23.
5079.8	5555.5	16666.6	6372.	U. S. C. S. . . .	24.
4827.93	5280.0	15840.0	5760.	Ludlow's Rep. .	25.
4063.8	4444.4	13333.3	4448.5	U. S. C. S. . . .	26.
3804.9	4166.6	12500.0	3587.	U. S. C. S. . . .	27.
3218.66	3520.0	10560.0	2560.	Sherman's March.	28.
3057.8	3333.3	10000.0	2296.	U. S. C. S. . . .	29.
2539.9	2777.7	8333.3	1594.	U. S. C. S. . . .	30.
2031.9	2222.2	6666.6	1112.	U. S. C. S. . . .	31.
2011.7	2200.0	6600.0	1000.	. . . .	32.
1960.5	2133.3	6400.0	940.	Geol. Sur. . . .	33.
1609.3	1760.0	5280.0	640.0	Fremont	34.
1523.9	1666.6	5000 0	573.7	U. S. C. S. . . .	35.
1508.73	1650.0	4950.0	562.5	. . . .	36.
1269.9	1388.8	4166.6	398.53	U. S. C. S. . . .	37.
1206.975	1320.	3960.	360.	. . . .	38.
1015.9	1111.1	3333.3	255.05	U. S. C. S. . . .	39.
1005.83	1100.0	3300.0	250.00	U. S. C. S. . . .	40.
1000.0	1093.6	3280.8	247.00	. . . .	41.
975.24	1066.6	3200.0	235.08	Geol. Surv. Pa. .	42.
965.59	1054.3	3163.0	229.67	. . . .	43.
804.650	880.	2640.	160.0	. . . .	44.
761.9	833.3	2500.	143.48	U. S. C. S. . . .	45.
643.728	704.0	2112.0	102.2	. . . .	46.
639.673	694.4	2083.3	99.64	. . . .	47.
603.487	660.0	1980.0	90.00	. . . .	48.
535.897	586.6	1760.0	70.859	. . . .	49.

Table of Map Equivalents giving for each

No.	Scale.	Miles.	Kilometers.	Chains.	Poles.
50.	$\frac{1}{20\,000}$	0.31565	0.50798	25.2525	101.01
51.	$\frac{1}{19\,800}$	0.31250	0.50290	25.000	100.
52.	$\frac{1}{19\,200}$	0.30303	0.48762	24.242	96.96
53.	$\frac{1}{18\,818}$	0.29700	0.47796	23.760	95.04
54.	$\frac{1}{15\,840}$	0.25000	0.40232	20.	80.
55.	$\frac{1}{15\,000}$	0.23674	0.38099	18.9393	75.75
56.	$\frac{1}{11\,800}$	0.18750	0.30174	15.	60.
57.	$\frac{1}{10\,000}$	0 1578	0.25417	12.626	50.505
58.	$\frac{1}{9\,900}$	0.15625	0.25100	12.500	50.
59.	$\frac{1}{9\,600}$	0.15151	0.24376	12.121	48.484
60.	$\frac{1}{7\,920}$	0.12500	0.20112	10.	40.
61.	$\frac{1}{7\,200}$	0.1136	0.18378	9.0909	36.363
62.	$\frac{1}{6\,000}$	0.09471	0.15285	7.5757	30.303
63.	$\frac{1}{5\,940}$	0.09375	0.15092	7.5000	30.
64.	$\frac{1}{5\,000}$	0.078913	0.12695	6.31313	25.252
65.	$\frac{1}{4\,950}$	0.078123	0.12582	6.250	25.
66.	$\frac{1}{4\,800}$	0.07575	0.121881	6.0606	24.242
67.	$\frac{1}{3\,960}$	0.06250	0.100561	5.	20.
68.	$\frac{1}{3\,600}$	0.05681	0.091391	4.5303	18.121
69.	$\frac{1}{3\,333}$	0.05261	0.08463	4.2060	16.824
70.	$\frac{1}{3\,168}$	0.05	0.080466	4.	16.
71.	$\frac{1}{3\,000}$	0.04734	0.07610	3.7787	15.151
72.	$\frac{1}{2\,970}$	0.04687	0.07541	3.75	15.
73.	$\frac{1}{2\,500}$	0.03945	0.06396	3.1565	12.626
74.	$\frac{1}{2\,400}$	0.03787	0.06098	3.0379	12.1515
75.	$\frac{1}{1\,980}$	0.03125	0.05029	2.5	10.
76.	$\frac{1}{1\,280}$	0.02020	0.032507	1.6016	6.406
77.	$\frac{1}{1\,250}$	0.019728	0.031697	1.5767	6.307
78.	$\frac{1}{1\,200}$	0.018939	0 030578	1.5151	6.060
79.	$\frac{1}{1\,080}$	0.017046	0.027520	1.3636	5.454
80.	$\frac{1}{1\,000}$	0.0157	0.0254	1.2626	5.0505
81.	$\frac{1}{960}$	0.01515	0.024376	1.2121	4.848
82.	$\frac{1}{840}$	0.013258	0.021399	1.06057	4.2420
83.	$\frac{1}{792}$	0.0125	0.02011	1.	4.
84.	$\frac{1}{720}$	0.01136	0.018378	0.9091	3.6363
85.	$\frac{1}{600}$	0.009471	0.015285	0.75757	3.0303
86.	$\frac{1}{500}$	0.0078913	0.012695	0.63131	2.5252
87.	$\frac{1}{480}$	0.007575	0.012188	0.60606	2.4242
88.	$\frac{1}{360}$	0.00568	0.009139	0.45303	1.8121
89.	$\frac{1}{300}$	0.004734	0 007610	0.37787	1.5151
90.	$\frac{1}{240}$	0.003787	0.006098	0.30379	1.2151
91.	$\frac{1}{198}$	0.003125	0.005029	0.25	1.
92.	$\frac{1}{120}$	0.001894	0.003057	0.15151	0.6060
93.	$\frac{1}{60}$	0.000947	0.001528	0.07575	0.3030
94.	$\frac{1}{39.37043}$	0.0006213	0.001	0.0497101	0.1988405
95.	$\frac{1}{36}$	0.000568	0.0009139	0.045303	0.181212
96.	$\frac{1}{12}$	0.0001894	0.0003057	0.015151	0 0606
97.	$\frac{1}{1}$	0.00001578	0.00002536	0.0012595	0.00505

lineal inch of Map, the following number of

Meters.	Yards and Feet { of Actual Distance.		No. of Acres to the sq. inch.	Where Used.	No.
507.98	555.5	1666.6	63.72	. . . .	50.
502.906	550.0	1650.0	62.50	U. S. C. S. . . .	51.
487.617	533.3	1600.0	58.767	. . . .	52.
477.96	522.72	1568.1	56.45	U. S. C. S. . . .	53.
402.325	440.	1320.	40.00	. . . .	54.
380.99	416.66	1250.	35.87	U. S. C. S. . . .	55.
301.744	330.	990.	22.475	. . . .	56.
254.177	277.77	833.33	15.942	U. S. C. S. . . .	57.
251.004	275.	825.	15.625	. . . .	58.
243.533	266.66	800.	14.070	2d Geol. Surv. Pa.	59.
201.125	220.	660.	10.	. . . .	60.
183.782	200.	600.	8.264+	. . . .	61.
152.854	166.66	500.	5.739+	. . . .	62.
150.924	165.	495.	5.625+	. . . .	63.
126.950	138.888	416.66	3.985+	U. S. C. S. . . .	64.
125.8238	134.166	412.50	3.906	. . . .	65.
121.88175	133.333	400.	3.672	2d Geol. Surv. Pa.	66.
100.5625	110.	330.	2.5	. . . .	67.
91.391	100.	300.	2.066+	. . . .	68.
84.6334	92.592	277.7	1.7713+	U. S. C. S. . . .	69.
80.0466	88.	264.	1.6	. . . .	70.
76.1057	83.333	250.	1.434+	. . . .	71.
75.4138	82.5	247.5	1.406+	. . . .	72.
63.9673	69.444	208.33	.9963+	U. S. C. S. . . .	73.
60.9811	66.666	200.	.9182+	U. S. C. S. . . .	74.
50.2906	55.55	166.66	.6376+	. . . .	75.
32.5079	35.555	106.66	.2611+	U. S. C. S. . . .	76.
31.6973	34.7222	104.166	.2491+	U. S. C. S. . . .	77.
30.578	33.3333	100.	.229+	U. S. C. S. . . .	78.
27 520	30.	90.	.185+	. . . .	79.
25.4177	27.777	83.333	.1594	. . . .	80.
24.3763	26.666	80.	.146+	. . . .	81.
21.4046	23.3333	70.	.112+	. . . .	82.
20.1125	22.	66.	.100+	. . . .	83.
18.3782	20.	60.	.0826+	. . . .	84.
15.2854	16.666	50.	.0573+	. . . .	85.
12.695	13.8888	41.666	.0398+	U. S. C. S. . . .	86.
12.18817	13.3333	40.	.0367+	. . . .	87.
9.1391	10.	30.	.0206+	. . . .	88.
7.61975	8.3333	25.	.0143+	. . . .	89.
6.09811	6.6666	20.	.0092+	. . . .	90.
5.02906	5.555	16.666	.00637+	. . . .	91.
3.0578	3.3333	10.	.00229+	U. S. C. S. . . .	92.
1.52854	1.6666	5.	.00057+	. . . .	93.
1.	1.0936	3.28087	.000247+	. . . .	94.
0.91391	1.	3.	.000206+	. . . .	95.
0.3047972	0.3333	1.	.0000229+	. . . .	96.
0.025368	0.02777	0.083	.000000158+	. . . .	97.

A Reciprocal Table of Map Equivalents showing the number of inches of

No.	Scale.	1 Mile.	1 Kilometer.	1 Chain.	1 Pole.
1.	$\frac{1}{7\,349\,760}$	0.0086205	0.005359	0.00010775	0.00002693
2.	$\frac{1}{2\,090\,880}$	.03030	.01882	.000378	.0000945
3.	$\frac{1}{1\,267\,200}$	.05000	.03106	.000625	.00015625
4.	$\frac{1}{1\,200\,000}$	.05280	.03280	.000660	.0001650
5.	$\frac{1}{1\,013\,760}$	.06250	.03883	.000781	.00019525
6.	$\frac{1}{1\,000\,000}$	0.06336	.03937	.000792	.00019800
7.	$\frac{1}{823\,680}$	.076923	.04780	.0009615	.0002404
8.	$\frac{1}{811\,008}$	.078125	.04854	.0009765	.0002441
9.	$\frac{1}{760\,320}$	.08333+	.05177	.001041	.00026025
10.	$\frac{1}{696\,960}$	.090909	.056490	.001136	.000284
11.	$\frac{1}{635\,000}$	0.09979	.06199	.001247	.00031175
12.	$\frac{1}{633\,600}$	.10000	.06213	.001250	.0003125
13.	$\frac{1}{600\,000}$	.10560	.06561	.00132	.0003300
14.	$\frac{1}{506\,880}$	.12500	.07766	.001562	.0003905
15.	$\frac{1}{500\,000}$	.12672	.07874	.001584	.0003960
16.	$\frac{1}{443\,520}$	0.142857	.089736	.001786	.000446
17.	$\frac{1}{400\,000}$	.15840	.09842	.00198	.0004950
18.	$\frac{1}{380\,100}$	.16666+	.10355	.002083	.00052075
19.	$\frac{1}{375\,000}$	.16896	.10498	.00211	.00052800
20.	$\frac{1}{316\,800}$	.20000	.12426	.002502	.0006250
21.	$\frac{1}{300\,000}$	0.21120	.13122	.00264	.0006600
22.	$\frac{1}{253\,440}$	.250000	.155335	.003125	.0007812
23.	$\frac{1}{240\,000}$	.26400	.16403	.003300	.0008250
24.	$\frac{1}{200\,000}$	.31680	.19684	.003960	.0009900
25.	$\frac{1}{190\,080}$	.33333+	.20711	.004166	.0010415
26.	$\frac{1}{160\,000}$	0.39600	.24605	.004950	.0012325
27.	$\frac{1}{150\,000}$	.42240	.26245	.005280	.0013200
28.	$\frac{1}{126\,720}$	.50000	.31067	.006250	.0015625
29.	$\frac{1}{120\,000}$	.52800	.32807	.006600	.0016500
30.	$\frac{1}{100\,000}$	.63360	.39368	.00792	.0019800
31.	$\frac{1}{80\,000}$	0.79200	.49210	.009900	.0024750
32.	$\frac{1}{79\,200}$	.8	.49710	.01	.0025
33.	$\frac{1}{76\,800}$	.82500	.512611	.010312	.0025780
34.	$\frac{1}{63\,360}$	1.00000	.62130	.012500	.0031250
35.	$\frac{1}{60\,000}$	1.05600	.65614	.013200	.003300
36.	$\frac{1}{59\,400}$	1.066666	.662801	.013333	.00333
37.	$\frac{1}{50\,000}$	1.26720	.78737	.01585	.0039625
38.	$\frac{1}{47\,520}$	1.333333	.82844	.016664	.0041660
39.	$\frac{1}{40\,000}$	1.58400	.98421	.019800	.004950
40.	$\frac{1}{39\,600}$	1.6	.994202	.02	.00500
41.	$\frac{1}{39\,369}$	1.60934	1.00000	.020116	.0050290
42.	$\frac{1}{38\,400}$	1.65000	1.02522	.020662	.00515550
43.	$\frac{1}{38\,016}$	1.66666	1.03509	.0208333	.0052083
44.	$\frac{1}{31\,680}$	2.000000	1.24260	.02500	.0062500
45.	$\frac{1}{33\,792}$	1.875000	1.16537	.023437	.005859
46.	$\frac{1}{30\,000}$	2.11200	1.31228	.026400	.0066000
47.	$\frac{1}{25\,344}$	2.50000	1.55334	.031250	.0078125
48.	$\frac{1}{25\,000}$	2.53440	1.57474	.031680	.0079200
49.	$\frac{1}{23\,760}$	2.66666+	1.65692	.03333+	.008333+
50.	$\frac{1}{21\,120}$	3.00000	1.86403	.037500	.0093750

Map and parts thereof, of the various scales now in use, which represent

1 Metre.	1 Yard.	1 Foot.	Where Used.	No.
.000005359	.00000489	.00000163	. . . . [tary).	1.
.00001882	.0000172	.00000573+	Sherman's March Map (Mili	2.
.00003106	.0000284	.00000946+	Sherman's March	3.
.00003280	.0000300	.00001000	U. S. C. S.	4.
.00003883	.0000355	.00001183+	Δ India	5.
.00003937	.00003600	.00001200	U. S. C. S.	6.
.0000478	.0000437	.0000145	. . . .	7.
.00004854	.00004438	.00001479	. . . .	8.
.00005177	.0000473	.00001576+	R. R. Va.	9.
.0000565	.0000516	.0000172	. . . .	10.
.00006199	.0000566	.00001886+	U. S. C. S.	11.
.00006213	.0000568	.00001893	U. S. Eng's	12.
.00006561	.0000600	.0000200	U. S. C. S.	13.
.00007766	.0000710	.0000236+	Eng. Ord. Sur.	14.
.00007874	.0000720	.0000240	U. S. C. S.	15.
.0000897	.0000811	.0000270	. . . .	16.
.00009842	.0000900	.0000300	U. S. C. S.	17.
.00010355	.0000946	.00003153+	Ludlow's Rep.	18.
.00010498	.0000960	.00003200	U. S. C. S.	19.
.00012426	.0001136	.00003753+	Barnes' Pa. Map, 1851 . .	20.
.00013122	.0001200	.0000400	U. S. C. S.	21.
.0001553	.000142	.000047	. . . .	22.
.00016403	.0001500	.0000500	U. S. C. S.	23.
.00019684	.000180	.0000600	U. S. C. S.	24.
.00020711	.0001893	.00006310	Ludlow	25.
.00024605	.0002250	.00007300	U. S. C. S.	26.
.00026245	.0002400	.0000880	U. S. C. S.	27.
.00031067	.0002840	.0000946+	Sherman's March	28.
.00032807	.0003000	.0001000	U. S. C. S.	29.
.00039368	.0003600	.0001200	U. S. C. S.	30.
.00049210	.0004500	.00015000	U. S. C. S.	31.
.0004971	.0004545	.00015151	. . . .	32.
.00051261	.00046875	.00015625	Geol. Surv.	33.
.00062130	.00056800	.00018933+	Fremont	34.
.00065614	.000600	.000200	U. S. C. S.	35.
.000662	.00060606	.00020202	. . . .	36.
.00078737	.000720	.0002400	U. S. C. S.	37.
.000828	.000857	.000286	. . . .	38.
.00098421	.000900	.000300	U. S. C. S.	39.
.0009941	.0009090	.0003030	. . . .	40.
.0010000	.0009144	.0003048	. . . .	41.
.00102522	.0009375	.0003125	Geol.	42.
.001035	.000947	.0003156	. . . .	43.
.0012426	.001136	.0003786	. . . .	44.
.0011653	.0010653	.0003551	. . . .	45.
.00131228	.0012000	.0004000	U. S. C. S.	46.
.00155334	.0014190	.0004730	. . . .	47.
.00157474	.00144000	.0004800	. . . .	48.
.00165692	.00151515	.00050505	. . . .	49.
.00186403	.0017040	.0005680	. . . .	50.

A Reciprocal Table of Map Equivalents showing the number of inches of

No.	Scale.	1 Mile.	1 Kilometer.	1 Chain.	1 Pole.
51.	$\frac{1}{20\,000}$	3.16800	1.96842	.03960	.009900
52.	$\frac{1}{19\,800}$	3.2	1.988404	.04	.010
53.	$\frac{1}{19\,200}$	3.30000	2.05044	.04125	.0103125
54.	$\frac{1}{18\,818}$	3.36698	2.09206	.042087	.0105275
55.	$\frac{1}{15\,840}$	4.0	2.485507	.05	.0125
56.	$\frac{1}{15\,000}$	4.22400	2.62456	.052800	.0132000
57.	$\frac{1}{11\,880}$	5.33333	3.314009	.06666	.016666
58.	$\frac{1}{10\,000}$	6.33600	3.93685	.079200	.0198000
59.	$\frac{1}{9\,900}$	6.4	3.976808	.08	.020
60.	$\frac{1}{9\,600}$	6.60000	4.10088	.082500	.020625
61.	$\frac{1}{7\,920}$	8.	4.971014	.10	.025
62.	$\frac{1}{7\,200}$	8.80000	5.46784	.11000	.027500
63.	$\frac{1}{6\,000}$	10.56000	6.561423	.132000	.033000
64.	$\frac{1}{5\,940}$	10.6666	6.628018	.133333	.03333
65.	$\frac{1}{5\,000}$	12.67200	7.8737	.15840	.039600
66.	$\frac{1}{4\,950}$	12.8	7.953616	.16	.04
67.	$\frac{1}{4\,800}$	13.20000	8.201770	.165000	.041250
68.	$\frac{1}{3\,960}$	16.	9.942028	.2	.05
69.	$\frac{1}{3\,600}$	17.6	10.93568	.22	.055
70.	$\frac{1}{3\,333}$	19.00990	11.81173	.237623	.05940575
71.	$\frac{1}{3\,168}$	20.	12.42434	.25	.0625
72.	$\frac{1}{3\,000}$	21.12	13.122846	.264	.066
73.	$\frac{1}{2\,970}$	21.33333	13.256036	.26666	.06666
74.	$\frac{1}{2\,500}$	25.34400	15.74740	.31680	.079200
75.	$\frac{1}{2\,400}$	26.40000	16.40354	.330000	.082500
76.	$\frac{1}{1\,980}$	32.	19.88405	.4	.1
77.	$\frac{1}{1\,280}$	49.50000	22.94414	.618750	.1546875
78.	$\frac{1}{1\,250}$	50.68800	31.49480	.63360	.158400
79.	$\frac{1}{1\,200}$	52.80000+	32.80708	.660000	.165000
80.	$\frac{1}{1\,000}$	63.36000	39.368538	.792000	.198000
81.	$\frac{1}{1\,080}$	58.66666	36.45231	.73333+	.18333+
82.	$\frac{1}{960}$	66.00000	41.00885	.825000	.206250
83.	$\frac{1}{840}$	75.42857	46.86726	.942857	.23571425
84.	$\frac{1}{789}$	80.30418	49.89670	1.003802	.2509505
85.	$\frac{1}{720}$	88.00000	54.67847	1.100000	.275000
86.	$\frac{1}{600}$	105.60000	65.61416	1.320000	.33000
87.	$\frac{1}{500}$	126.72000	78.73700	1.584000	.39600
88.	$\frac{1}{480}$	132.00000	82.01770	1.650000	.412500
89.	$\frac{1}{360}$	176.00000	109.35694	2.2000	.550000
90.	$\frac{1}{300}$	211.20000	131.22833	2.640000	.66000
91.	$\frac{1}{240}$	264.00000	164.03541	3.300000	.825000
92.	$\frac{1}{198}$	320.	198.8405	4.	1.
93.	$\frac{1}{120}$	528.00000	328.07083	6.600000	1.65000
94.	$\frac{1}{60}$	1056.00000	656.14166+	13.20000	3.3000
95.	$\frac{1}{39.3704}$	1609.330	1000.	20.11663	5.02916
96.	$\frac{1}{36}$	1760.	1083.5694	22.	5.5
97.	$\frac{1}{12}$	5280.00000	3280.7083	66.00000	16.5000
98.	$\frac{1}{1}$	63360.00000	39368.5000	792.0000	198.000
99.	$\frac{4}{3}$	84480.00	52491.0333+	1056.000	264.000
100.	$\frac{2}{1}$	126720.00	78737.0000	1584.000	396.000

Map and parts thereof, of the various scales now in use, which represent

1 Metre.	1 Yard.	1 Foot.	Where Used.	No.
.00196842	.0018000	.0006060	. . . .	51.
.001988	.001818	.0006060	. . . .	52.
.00205044	.00187500	.0062500	. . . .	53.
.00209206	.0019130	.0006376+	U. S. C. S.	54.
.002485	.002272	.0007575	. . . .	55.
.00262456	.0024000	.0008000	U. S. C. S.	56.
.003314	.0030303	.0010101	. . . .	57.
.00393685	.0036000	.0012000	U. S. C. S.	58.
.003976	.003636	.001212	. . . .	59.
.00410088	.00375	.0012500	. . . .	60.
.004970	.004544	.0015150	. . . .	61.
.00546784	.005000	.001666+	. . . .	62.
.006561423	.006000	.002000	. . . .	63.
.006628	.0060606	.0020202	. . . .	64.
.0078737	.007200	.002400	U. S. C. S.	65.
.007952	.007272	.002424	. . . .	66.
.008201770	.0075000	.002500	. . . .	67.
.00994	.009088	.003020	. . . .	68.
.0109356	.01	.003999	. . . .	69.
.01181173	.0108010	.003603+	U. S. C. S.	70.
.012424	.0113181	.0037727	. . . .	71.
.0131288	.012	.004	. . . .	72.
.013256	.0121212	.0040404	. . . .	73.
.01574740	.014400	.0048000	U. S. C. S.	74.
.01640354	.015000	.005000	U. S. C. S.	75.
.0218712	.02	.007999	. . . .	76.
.02294414	.0281250	.0093750	U. S. C. S.	77.
.03149480	.028800	.0096000	U. S. C. S.	78.
.03280708	.030000	.010000	U. S. C. S.	79.
.039368	.036000	.012000	. . . .	80.
.03645231	.03333+	.011111+	. . . .	81.
.04100885	.037500	.012500	. . . .	82.
.04686726	.0428547	.0142849	. . . .	83.
.04989670	.0456273	.0152091	. . . .	84.
.05467847	.050000	.016666+	. . . .	85.
.06561416	.060000	.020000	. . . .	86.
.07873700	.072000	.024000	U. S. C. S.	87.
.08201770	.075000	.025000	. . . .	88.
.10935694	.100000	.033333+	. . . .	89.
.13122833	.12000	.040000	. . . .	90.
.16403541	.150000	.050000	. . . .	91.
.218712	.2	.079999	. . . .	92.
.32807083	.30000	.100000	U. S. C. S.	93.
.6561416+	.600000	.200000	. . . .	94.
1.	.914392	.304464	. . . .	95.
1.093569	1.	.333333	. . . .	96.
3.2807083	3.00000	1.0000	. . . .	97.
39.36850	36.0000	12.0000	. . . .	98.
52.49103+	48.00000	16.0000	. . . .	99.
78.737000	72.0000	24.0000	. . . .	100.

59. Whatever the scale may be, it should not only be expressed on the map (which is sometimes overlooked), but a drawing of it should be made and numbered on the same paper with the map, that it may be subjected to the same changes from temperature and moisture.

60. Exercises on Scales.

1. Construct the scales, in feet, represented by the fractions $\frac{1}{2400}$, $\frac{1}{2000}$, $\frac{1}{600}$.

2. Construct the scales in statute miles represented by $\frac{1}{15840}$, $\frac{1}{50000}$, $\frac{1}{80000}$.

3. What is the ratio of the first to the second, and second to the third, of the scales in 2?

4. Construct a scale of $\frac{1}{1000}$ in metres, and its equivalent in feet.

5. How many square miles may be represented on a sheet of paper 20x40 inches on a scale of 400 poles to 1 inch?

6. How many acres are there in a square inch of map drawn to a scale of 5000 feet to 1 foot?

7. It is required to change a map from a scale of $\frac{1}{4800}$ to $\frac{1}{3000}$. How can it best be done, and what is the ratio of corresponding parts? Is the resulting map larger or smaller?

8. A plot is discovered upon which no scale is marked—but the field is readily accessible. How may the omission be supplied.

9. Should any recorded distance be found upon the above plot (8), how can the scale be found?

10. If a pace be taken as equal to 31 inches, construct a scale of paces for the fraction $\frac{1}{1200}$.

CHAPTER IV.

FORMS OF RECORD.

Taking and Recording Notes.

61. The amateur topographer should bear in mind that it is always better to have the notes too full than too meagre; but above all they should be clearly recorded, so that they may be readily understood and "worked up" by one not familiar with the ground.

He should be careful never to omit any essential data as "a course" in a line survey, and should frequently describe and mark his stations so as to be readily recovered. Even a stake well driven is a very uncertain mark.

The form of record for the *aneroid barometer* has been given already in § 23, with the description of the instrument; that for the mountain barometer is not considered essential here, having been thoroughly treated by Col. Williamson, U. S. A., or in Lee's Tables — Professional Papers, U. S. E.—and by many other authors.

62. In a chorographical reconnaissance for *positions or principal points*, the ordinary form for a compass survey may be used to best advantage in connection with the *casella*, and a sketch, more or less minute, according to the time at command. At the top of page should be written the date and name of station, followed by a sketch and record of all the bearings read at that point.

NOTES AND SKETCH FOR TRIANGULATION POINTS taken from summit of Bald Knob, (4448 feet), Giles county, Va., July 3 and 5, 1878. L. M. H., observer. Weather, clear, with cumulus clouds. Wind, S. E.; light. 0° north; 90° east, etc.

Degrees.	To Object.	Approximate Distance.	Remarks.
		Miles.	
71¾	Thunder Hill on Blue Ridge . . .	70	
72½	Knob near Belle View	18–20	On Walker's Mts.
74½	Hunting Gap Mts	63	Distance from map.
78¼	Point near Petit's Gap, Bl. R . .		High, good for Δ.
82½	Flat Top	52½	
83½	South Peak (of Otter)	50	Very good Δ pt.
84½	Buffalo Ridge . . . . etc. . . .	80	Very distant, faint

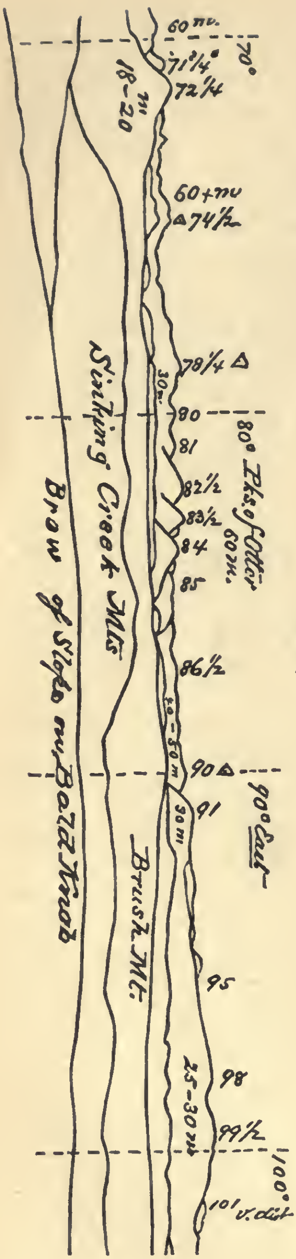


FIG. 21.

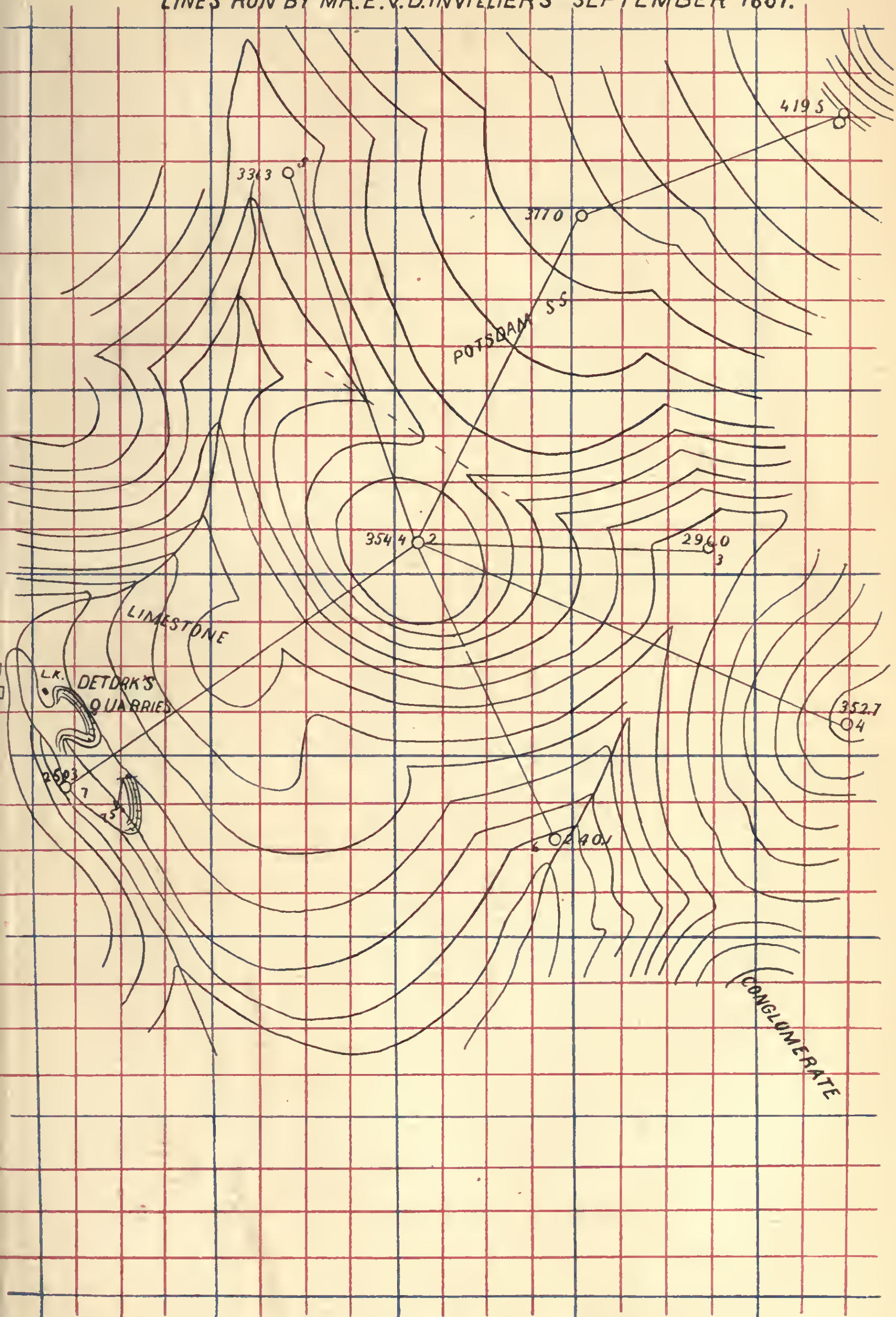
The accuracy of the sketch will be greatly increased by dividing the sheet of paper or note book into vertical columns of say 10° to two inches, and confining the various sections to these limits. See Fig. 21.

63. The form of record for an *itinerary* through a new country should include the following items—which may be arranged in any convenient order: Date, hour, route (by compass bearings), distances (by odometer revolutions), position of camps and halts, time of arrival and departure, delays from various causes, character of country, of roads, of river-bottoms, of water, of vegetation, of minerals; approximate latitude and longitude by sextant observations; sources of all information—temperature, weather, etc. Portions of these data may be entered in any ordinary transit note book, beginning at the *bottom* of the page and working up, reserving the right-hand page for sketch of line and surrounding country. For this purpose, the usual topographical sketch paper, divided into quarter-inch squares, is very appropriate. The balance may be entered in a journal or memoir. See § 100.

64. For an ordinary *linear*, *transit or compass survey*, with numerous "shots" to outlying points, serving as "checks," or for new stations, the record should contain, as a heading, the description of the general loca-

PLATE 4.

LINES RUN BY MR. E. V. D. INVILLIERS SEPTEMBER 1881.



SCALE 400' TO 1." CONTOUR LINES 10 FEET APART.

tion of the line, with date, name of assistant, and columns of Stations, Bearings, Distances, Remarks and Sketch.

Line from ——— to ———, Date.

Right-hand Page.

Station.	Bearing or angle.	Distance.	Remarks.	Sketch.

When numerous pointings are made from a single station they should be entered in regular order in the column of bearings, and on the same line under remarks should be given a full description of the object.

In such cases it is well to record the next foresight last with the distance, or if read first it should be tested again before leaving the station, to detect any slipping of the instrument, especially when traversing.

65. For *topography*, the annexed form, used on the Second Geological Survey, is sufficiently comprehensive where the heights are determined by vertical angles, and the distances by the stadia.

TOPOGRAPHY IN THE NEIGHBORHOOD OF READING, BERKS COUNTY, PA.

From Station . .	To Station.	Bearing .	Observed distance by stadia . .	Vertical angle . .	Difference of level.	Above datum* .	Above ocean . .
2	7	S. 54° 45′ W.	952	−6° 17′	104.1	246.6	250.3
	6	S. 21° 30′ E.	723	−9° 06′	114.4	236.3	240.0
	5	N. 17° 30′ W.	864	−1° 32′	23.1	327.6	331.3
	4	S. 66° 15′ E.	1020	−0° 06′	1.7	349.0	352.7
	3	S. 88° 15′ E.	629	−5° 20′	58.4	292.3	296.0
1	2	S. 31° 30′ W.	719	−1° 48′	22.6	350.7	354.4
0	1	S. 60° 30′ W.	660	−2° 49′	32.4	373.3	377.0
Sta. 0 =	1047					405.7	409.5

Station.	Notes of Side Lines; Outcrops; Dips; Houses; Specimens.
	From station 1047=0 of line of September 20th, S. W., along foot hills around Neversink Station, P. & R. R. R. to Station — on P. & R. track, near Big Dam.
4	On knob to left.
5	In valley to right.
3 & 6	In valley to left.
7	Large double limestone quarry of Jonas De Turk. Stone is blue, with top covering of 20′ dirt, under which the limestone is of good quality, though very much twisted and crushed in places. Dip at top of quarry, S. 20° W. 75°.
	Potsdam opposite to Station 1+600′, then limestone.

* This column is generally used for the corrected distances.

For sketch of left hand page see Plate 4.

When topography is taken by traversing, two sets of notes should be kept—one of levels, q. v.—the other of angles and distrances, or polar coördinates, as for transit survey.

66. For extended topographical maps requiring the principal points to be connected by *triangulation*, the form of record for repeating angles is as follows:

Station . . . . Date . . . .

Observer . . . . Recorder . . . . Weather . . . .

Names of signals between which angles are read.	Time	No. of repetitions.	D. R.	Readings.				Mean of verniers.	Angles	Mean of D's & R's.	Mean angle . .	Remarks . . .
				A	B	C	D					

D. and R. refer here to the "Direct" or "Reversed" position of the telescope. The number of times an angle may be repeated in any set varies, but for convenience of reduction may be taken at six. The D's and R's should be read alternately, and combined in pairs, then the mean of the averages thus obtained is taken. If sufficient care has been exercised usually six sets of six repetitions of each angle will answer; but before removing the instrument, the probable error should be determined, and if it exceed seven-tenths (0.7″) of a second for a secondary triangulation, additional sets must be read until this limit is reached.

67. The *probable error* may readily be computed by the following rule. Find (X_0) the arithmetical mean of the observed values of the angle, (Δ^2) the square of the differences between X_0 and each separate value; then divide the sum of these squares (Σ) by one less than the number of sets (n—1), take the square root of the quotient, multiply it (e) by 0.6745, and divide this product (r) by the square root of the number of sets (n). Or, expressed algebraically, the rule becomes,

$$e=\sqrt{\frac{\Sigma\Delta^2}{n-1}}, \quad r = e \times 0.6745, \quad r_0=\frac{r}{\sqrt{n}}$$

68. If the instrument be one known as a *direction instrument*, the form of record must be modified as follows:

Station———— Position———— Date———— Observer———— Recorder————

Series and number of the observation . .	Object observed	Time	D. R. . . .	Micrometer	Readings.				Mean	Correction for run* . . .	Corrected mean	Remarks . . .
				A., B., etc.	°	′	d′	d				

* See Chapter on Computations, § 210.

RECORDS USED IN LEVELLING.

69. A convenient form of record for use with the *Spirit or Wye Level*, is the following:

Description of Line————————

Date———— Observer———— Rodman————

Line of Check, or Flying Levels from University of Pennsylvania to Penna. R. R., Saturday, April 14, 1883. A. E. M., Chief of Party.

Stations . . .	Distances . .	Rod readings. B. S. + .	F. S. − .	Intermediates — .	Height of Instrument ⊙ .	Elevation . .	Remarks.
B. M.	Not required.	0.916			53.449	52.533	On central bull's eye of vault light, S. Door University.*
Peg.		1.040	11.847		42.642	41.602	On stake in campus.
B. M.				2.897		39.745	Button on fire plug N. E. cor. 34th and South streets.
Peg.		0.485	6.303		36.824	36.339	Button on fire plug south side of South street.
B. M.				1.364		35.460	Button on fire plug near bridge.
Peg.		0.103	11.204		25.723	25.620	On slope S. side of South street.
B. M.				10.215		15.508	Knot on willow 3 feet above ground at P. R. R. and Alms House lane.
Peg.		11.188	1.510		35.401	24.213	On stone in Alms House lane.
B. M.		8.455	1.290		42.566	34.111	On S. W. corner of guard rail of scales.
B. M.				4.202		38.364	Button on plug in A. H. lane.
Peg.		11.100	0.128		53.538	42.438	Stake in yard on 34th street.
			1.015			52.523	On starting point.
							33.287—33.297 = .010.
		33.287	33.297			.010	

* Levels referred to city datum.

In this form the back and fore sights are kept separate, and the difference of their sums serves as a convenient check upon the computations, being equal to the difference of elevation of the first and last benches.

Here the reference or datum plane is that used by the city of Philadelphia, and is the surface of mean low tide at the Fairmount water works.

For *corrections* due to curvature and refraction, etc., see § 215, under the chapter on COMPUTATIONS.

70. For a *hydrographic survey* in waters not affected by tides, the water surface may be taken as the reference or datum plane, and the depths taken from it recorded in simple form, giving the line or range, time, sounding in feet or fathoms, character of bottom, etc., thus:

SOUNDINGS AT (*Location*).

Year——— Month——— Date——— Observer———

No. of line .	Time . . .	Soundings.		Reduction for Tide (if any) . . .	Reduced soundings.		Bottom . . .	Angles and Ranges . .	Remarks . .
		Ft., fathoms .	Tenth feet . .		Faths. or Feet.	Feet. Tenths.			

71. When the survey is conducted in tidal waters, a record must be kept of the tide gauge, extending through not less than a semi-lunation to obtain the position of mean low tide which is taken as the datum plane.

During the survey, also, a continuous record must be made of the height of water on the gauge in the immediate vicinity of the work, for reduction of observed soundings to the datum. The form in use by U. S. Coast Survey is:

OBSERVATIONS OF TIDES AT ( ).

Year——— *Month*——— *Day of Month*———

Mean time of Observation.		Reading of Tide Staff.		Wind.		Barometer.		Remarks.
Hrs.	Mins.	Feet.	Decs.	Direc.	Force.	Inches	Decs.	

The hydrographic notes should be kept in duplicate, and only the original book be taken in the boat, so that in case of an accident, the entire season's work, it may be, will not be lost.

The tidal record may be taken by a self-registering tide-gauge, or by an observer who can be depended upon to remain all day in one place, perhaps for months, watching and recording the tidal pulsations.

ALTITUDES BY ZENITH DISTANCES AND MICROMETER.*

72. The form used by the U. S. Coast and Geodetic Survey for *trigonometrical levelling by double zenith distances* of any signal, as measured by a vertical circle, is this:

Vertical Angles.

Station, ... *Instrument,* . . . . . .

MOUNT RAFINESQUE.

Date.	Hour of day . . .	Object observed upon	Above station marks.		Correction.		Observed zenith distances	No. of reps. . . .	Zenith distances between station marks . . . . .
			Object . . .	Telescope .	Feet . . .	Seconds . .			
1876.	*h. m.*		*Feet.*	*Feet.*	*Feet.*	+	° ′ ″		° ′ ″
Sep. 21	2 30 p. m.	Apex of tripod	22.15	6.0	16.15	27.5	90 25 49.7	5	90 26 17.2 †
21	4 40 p. m.	"	22.15	6.0	16.15	27.5	43.9	5	11.4 †
25	4 20 p. m.	Center of cone	43.67	6.0	37.67	64.0	17.0	5	21.0
24	3 10 p. m.	"	43.67	6.0	37.67	64.0	08.5	5	12.5
25	11 a. m.	"	43.67	6.0	37.67	64.0	01.1	4	05.1
25	1 15 p. m.	"	43.67	6.0	37.67	64.0	20.6	5	24.6 †
25	2 05 p. m.	"	43.67	6.0	37.67	64.0	20.7	5	24.7 †
25	2 45 p. m.	"	43.67	6.0	37.67	64.0	21.7	5	25.7 †
28	2 50 p. m.	"	43.67	6.0	37.67	64.0	19.8	5	23.8
29	2 50 p. m.	"	43.67	6.0	37.67	64.0	27.9	5	31.9
Oct. 4	3 05 p. m.	"	43.67	6.0	37.67	64.0	12.9	5	16.9
6	2 35 p. m.	Apex of tripod	22.15	6.0	16.15	27.5	47.0	5	14.5
Mean .	. . . .	. . . .	. . .	. .	. . .	. .	. . . . . .	.	90 26 18.3

*From a paper by Richard D. Cutts, Assistant in Charge, U. S. Coast and Geodetic Survey, published in Report of 1868, and subsequently reprinted.

† The results in brackets were obtained within so short a period of time, one from the other, that they must be considered in each case as a single result, or expression of the atmospheric refraction.

A series of such observations are taken upon every signal, and referred to one the actual height of which is known. By similar series observed at successive stations a number of values may be obtained for any one point, which with good work should not differ from one another more than 5″ in arc. The true value may be determined by the method of least squares.

73. By reducing the observed zenith-distance to the ground at each station the possibility of error is decreased. The correction in feet, being the difference between the heights of telescope and signal observed upon, is reduced to arc and applied to the observed angle. See Chapter XIV., § 217.

This reduction is effected by the formula, Seconds of arc $= \frac{r}{K \sin 1''}$, in which r represents the difference in height between the telescope and object, and K the distance, in the same denomination, between the stations.

74. When the relative heights of a series of adjacent stations are determined by a *micrometer* attached to the telescope, the form is modified as follows:

Form for Micrometrical Differences of Height.

Station, Flat Top, Va.—Date, June 24, 1876.—Observer, A. T. M.
Instrument, 14-inch Würdemann Theod., No. 10.

Object observed.	Time.	Micr.	Level. O	Level. E	Remarks.
SERIES IV.	*h. m.*	*t.*	*d.*	*d.*	
Tobacco row, crotch, v. unst.	0 28 p. m.	6.82	13.8	11.2	Crotch, 22.82 ft. above Δ.
Spear, heliotrope . . . . ft.	. . . .	1.42	14.3	10.4	Heliotrope, 11.33 ft. above Δ.
Smith, ground	. . . .	0.38	12.3	12.8	
S. W. Peak, rock . . v. unst.	. . . .	2.14	13.2	11.8	
Cahas, ground . . . . v. ft.	. . . .	14.03	13.2	11.8	
Buffalo, top of trees . . v. ft.	. . . .	12.08	13.3	11.7	Secondary objects. Tops 30 ft. above ground.
Sugarloaf, top of trees . dst.	. . . .	3.92	13.3	11.8	Same as above.
Tobacco row, crotch, v. unst.	0 45 p. m.	6.83	13.7	11.3	Weather clear. Wind light, S. W. Bar. 26.82 in. Ther. 72°.7 F. Telescope above ground, Δ 5.99 ft.
SERIES V.					
Etc., etc.					

75. *Simultaneous reciprocal zenith distances* give the best results. For stations over twenty miles apart, when observations are not simultaneous, reliable results can only be obtained by a very large number of measurements made under the most favorable circumstances. The best time of day for observation is from 10 a. m. to about 3:30 p. m., when the refraction is comparatively stationary. The form of record is that given in § 72.

The formulæ for computing results from these data will be found under the chapter on COMPUTATIONS.

76. "*Cross sections*," or transverse levels for earthworks, are recorded in a book specially provided for that purpose, having on the right-hand page a central column for the cut or fill of the station, with a space on the right and left for the slopes, which are usually expressed fractionally—the denominator being the difference of height between any two points where a change of slope occurs, and the numerator the base for that distance. Ground which rises from the center line is represented by the + sign, and that which falls by the — sign, in the denominator. Slopes taken by the clinometer or vertical circle are recorded in degrees under the horizontal distances to which they extend, or the distances may be left indefinite if the slope be uniform. Slopes taken for topography (contours) in degrees must be reduced to their rectilinear co-ordinates before sketching in the contours, and are then expressed in terms of the natural tangent of the talus or slope, thus: $1° = \frac{1}{57.3} = \frac{10}{573}$ feet, etc. In this form it is frequently known as the *gradient*. For earthwork computations the fraction is inverted for convenience in calculating areas of sections. Unless care is taken, this may produce confusion. The record should always begin at the bottom of the page and proceed up, so that the right of the book and field may correspond. When the grade is known, the height of the points at which the slope changes may be referred directly to it instead of to the surface at the centre stake, thus: in the following table only the relative levels of points where the slope changes are given on the left hand page.

Station. . .	Elevations . .	Grade . . .	Width of road bed . . .	Side Slope . .	Surface Slope .	Cross-sections on "Section G." Left.				Right.
108	508.0	516.8	14	3/2	.	$\frac{30}{-10}$	$\boxed{\frac{17.5}{-7}}$	—8.8	$\boxed{\frac{21.0}{-9.3}}$	$\frac{25}{0}$
107	514.4	516.4	14	.	.		$\frac{15}{-3}$	—2.0	$\frac{12}{0}$	
+65	516.25	516.25	16	.	.		$\frac{10}{-0.5}$	0	$\frac{12}{+1}$	
+50	516.5	516.2	18	.	.		$\frac{12}{0}$	+0.3	$\frac{15}{+1.4}$	
106	516.8	516.0	18	3/2	.	$\frac{20}{0.3}$	$\frac{14}{+1}$	+0.8	$\frac{16}{+2}$	$\frac{22.3}{+8}$

Occasionally the last three columns of left hand page are omitted, and their places supplied by areas of sections and volumes between them, as computed. The 0 points are at grade. The notes here given run from the end of a cut into an embankment. Elevations taken at slope stakes should be indicated by enclosing them in a square or ring as above.

Gradienter Notes.

77. Location, ... Date, ... Weather, etc., ...

At Station, ... Height of Inst., ...

To Station . . .	Angle	Micrometer. Before . . .	After	Difference . . .	Vertical Angles . .	Reduced Distance .	Reduced Difference of Level . . .	Corrected Elevation.	Remarks . . . .

If in the above form the gradienter be leveled, and the first micrometer reading be made zero, then the second reading will give the distance and level at once; but this is only possible on ground of gentle slopes.

CHAPTER V.

GRAPHICAL REPRESENTATIONS.

CONVENTIONAL SIGNS.

78. In filling up the sketch page of his note book, the topographer may, if time permit, represent the several features by their symbols, but in general he will find it more expeditious simply to indicate the outlines of woods, marshes, cultivated tracts, etc., writing within these spaces a suitable description as to the character of the timber or vegetation, and filling up the areas on the office plot. For the more uniform representation of such features, various countries have introduced certain conventionalized forms, a compilation of which is here given as a guide to the draughtsman. See Sheet 2.

HACHURES AND CONTOURS.

79. In representing slopes various methods have been suggested and used, but only two of these deserve any consideration. The first, known as the *hachure* system, is based upon a scale of shades so graduated as to represent the relative amount of light which may be reflected from various degrees of slope—the light being assumed in one system (Lehman's) to fall in vertical rays, and in another (Dufour's), in oblique rays.

The graduations of shade in Lehman's system, are intended to be produced by drawing a given number of short black lines, of certain thickness, to a given length of map, thus producing a constant shade for that slope. Variations are made for each 5° up to 45°, where the reflected ray becomes horizontal, and consequently beyond this limit the rule does not apply. The extremes are therefore white for a horizontal plane, and black for a slope of 45°, with eight gradations between. At 5°, therefore, the ratio of white to black is as 8 to 1 parts; at 10°, as 7 to 2, etc. In the French war maps, the diapason of tints is such that the ratio of black to white is expressed by $\frac{2}{3}$ of the tangent of the inclination.

The objections to such methods of indicating slopes are at once apparent; first, from the great skill required on the part of the draughtsman; secondly, from the necessity for counting the lines, sometimes very minute, in a given distance, before the inclination represented can be read; thirdly, the ambiguity which results from the fact that on many maps (as on Sheet I) this same method is employed to give relief to the undulations, without any reference to the scale of shade; and fourthly, the surface is so thoroughly covered by hachures as to render other and more important lines very indistinct.

This method is, therefore, only recommended for relief map where the shading is done with a pen instead of a brush. The lines should be drawn in the direction of the path of a rolling stone, or of water falling on the slope, and should be short, wavy and disconnected; light and far apart, on gentle declivities; heavier as the inclination increases, and massive and angular for vertical slopes or rock-work. Such relief is also sometimes given by horizontal hachures. (See Plate 5.)

80. The second, or contour system (Sheet 3), introduced by the geographer, Philip Bauche, in 1744, is that in which the surface is represented by the curves cut from it by a series of equidistant horizontal planes. These curves, called "*contours*," are all projected upon some basal or datum plane, called the plane of reference.

The vertical interval between the cutting planes may be assumed at pleasure, but should be constant in the same survey, and sufficiently close to show all important changes.

This system is more familiarly expressed by assuming a water-surface to be raised or lowered by successive stages, equal to the distance between the planes, so as to encircle the slopes. The various shore lines thus formed are the contours. It will thus be seen that the degree of the slope may at once be determined, at any place or in any direction; for the height between the planes of any two lines being known, and their horizontal distance apart being given from the scale of the map, the two sides, base and height, of a right-angled triangle become known. From these data the angle may be computed, or the slope may at once be read from a scale of horizontal equivalents constructed for the purpose. Fig. 22.

HORIZONTAL AND VERTICAL SYSTEMS OF HILL SHADING (FROME'S SURVEYING).

81. *To convert polar into rectilinear coördinates, and the reverse.*—When great accuracy is not desired, it will be found convenient to consider the cotangent of a 1° slope, as 60 instead of 57.29, and to assume that, for angles up to 20°, the cotangents vary as the angles. Hence a 2° slope will have a base of 30 feet for a rise of one foot, etc. These *bases for the various angles* may be laid off by scale for any given vertical interval, and thus give the graphical equivalent desired without computation. A different diagram will be required for every different interval or scale of map; for if the scale of the map be doubled to 800 feet to 1″, that of horizontal equivalents will also be doubled for the same vertical interval.

82. To *find the degree of the slope* at any point of a contour map, measure the distance between two adjacent contours and apply it to the scale until the equal segment is found, when the degrees can at once be read off.

This simple relation, 1° = 60 feet base, nearly, will solve most of the problems which arise in the field-sketching of contour lines.

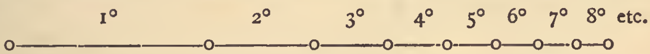


FIG. 22.—Scale of horizontal equivalents for 10 feet vertical intervals, the scale of the map being 600 feet to one inch = $\frac{1}{7200}$.

83. It is evident that since contour lines are plane curves, and since their planes are parallel, those of different heights can never intersect. Their projections on the datum plane may do so, however, when contours cross a vertical surface or wall. Neither can a single line in any one plane be resolved into two others, since a shore line or water edge can not be split into two such edges. Each line must preserve its identity, and if the surface be sufficiently extensive, must close on itself as does the edge of water in a bowl, or a shore line around an island.

Elevations and depressions should always be indicated by writing the number of the contour above the datum upon it; but they may also be shown relatively, and give greater relief to the drawing by shading those portions of the slopes from which the light is obscured. In a basin or hollow, then, the slopes towards the direction of light will be represented by heavier lines, while on a hill those away from the light will be the heavier.

It will be observed also that in rising ground, spurs, projections, or "fills" will be represented by the contour being pushed out from the general direction of the slope of the hillside, while a ravine or gully will be shown by receding lines.

The utility of a contour map is almost wholly dependent upon the frequency and accuracy with which the lines have been run, and this is determined by the object and method of the survey, as well as by the experience of the topographer.

84. Occasionally these two systems of representation, by contours and hachures, are combined; but since the hachures should always be drawn normal to the contours, their direction is sufficiently determined by the latter system, which also gives the degree of slope with greater accuracy, and with much less work and confusion, so that nothing is gained by the combination.

"Col. Olsen has modified the horizontal system by combining two or more of the horizontal zones into one, and by designating such combinations by a progressive intensity of shading (by hachures). In this manner the topographical map of Denmark, $\frac{1}{20000}$ has been executed." *

USE OF COLORS IN TOPOGRAPHY.

85. Slopes are frequently represented by flat tints blended together in such a manner as to give a pictorial projection, or the color may be laid on in successive layers or zones, increasing in depth of tint in descending, being limited by the successive contours. The conventional forms used for other features are the same as for pen and ink work. The following code of colors will be found of service in filling them in:

The manner of applying them has been so frequently described in other works on topographical drawing, as to render a repetition of these details unnecessary; but the novice is recommended to take a few lessons from a competent instructor in this department.

CONVENTIONAL COLORS.

Brass	Exterior	Gamboge.
	Interior	Dark Indian yellow.
Brick.	Exterior	Lt. red with carmine.
	Section	Crimson lake or carmine.

* Enthoffer's Topography.

Brushwood		Green and bt. sienna, marbled.	
Buildings		Crimson lake.	
Buildings, shadows of		Indigo, bt. sienna and lake.	
Cast iron		Payne's gray.	
Clay or earth		Burnt umber.	
Concrete work		Sepia.	
Contours		India ink, sepia, or bt. sienna.	
Copper		Gamboge and crimson lake.	
Cultivated land		Bt. sienna.	
Earth and clay		Bt. umber.	
Fir timber		Indian yellow.	
Granite		Violet, carmine.	
Grass		Light Hooker's green.	
Gravel		Yellow ochre dotted with bt. sienna.	
Gun metal		Dark cadmium or orange.	
Iron	Cast	Payne's gray.	
	Wrought	Prussian blue and indigo.	
Mahogany		Indian red.	
Meadow land		Hooker's green.	
Mud		Sepia or India ink.	
Oak timber		Bt. sienna, grained.	
Roads and streets		Yellow ochre and sepia.	
Sand		Yellow ochre.	
Sky		Cobalt.	
Slopes		Sepia with bt. umber.	
Steel		Indigo or Prussian blue and lake.	
Stone		Sepia and yellow ochre.	
Trees	Light	Gamboge and bt. sienna	on a green ground.
	Shade	Gamboge and indigo	
	Shadows	Bt. sienna and indigo	
Uncultivated land		Green and bt. sienna, marbled.	
Vineyards		Purple.	
Water		Indigo or Prussian blue.	
Wood	Exterior	Yellow ochre or raw sienna.	
	Sections	Bt. sienna.	
Wrought Iron		Prussian blue and indigo.	

86. Exercises in Contours.

1. Project a hill 100 feet high in 10 feet contours; slope 25° on the sides, 15° on ends—oval or irregular base. Scale, 50 feet to 1 inch.

2. Project two hills in irregular contours in such a manner that the surfaces intersect in a vertical plane, and so that the slope lines in this plane shall be on one side 10° and on the other 45°; contours 20 feet apart; scale, 100 feet to 1 inch.

3. Construct a profile through the crest of one of the above hills and at right angles to the plane of intersection, marking upon it the degrees of the slopes between every two contours. Same scale.

4. Sketch a river with rolling ground on one side and bluffs on the other in 100 feet contours, and to altitudes of 1,000 feet. Scale, 1 mile to 12 inches.

5. Fill in the same with conventional signs.

6. What is the scale of a plot on which a slope of 15°, 90 feet high, has a base of 3 inches?

READING CONTOUR MAPS.

87. See Plate 15, page 126.

Seek first the lowest point on the map. This can readily be found either by reference to the numbers of the contours or by the directions of the water-courses. Follow the thalwegs to the divides; sketch in the water-sheds, both primary and secondary, and an excellent skeleton of the surface will be formed. The important points on the divides are the low passes where a ready connection is formed between two basins or water-sheds.

88. To determine whether one point is visible from another, construct a section through the two points, and note whether any portion of the section rises above the right line joining the points. If the ground between them is convex, the line will be invisible; if concave, possible; and if rolling, the profile will give the desired solution, or it may be determined by a proportion. Thus, it would be possible to see from Signal to Toll Gate, as the intervening country is all lower, or concave, but not from Church to Quarry, in consequence of the convexity of the Neversink.

The same method will exhibit the field of view to an observer stationed at any given point, assuming no surface obstructions, as trees, rocks, etc.

These questions are of especial moment to the military engineer in selecting positions for pickets or batteries, and in moving troops under cover in an enemy's country.

The engineer may also project a system of triangles with every probability of the signals being mutually visible. He may project roads on given grades with great accuracy, and select a route for a pipe line or irrigating ditch without a survey, all of which will be more fully considered under the head of APPLICATIONS.

89. EXERCISES IN CONTOURS.

What is the general form of the basin at the eastern end of the chart?

Describe its drainage.

Draw in the water-shed between the Schuylkill River and the Creek systems.

Where is the highest point on the map?

Select a site for a base line and project a system of triangulation for this area so that signals may be intervisible.

Is the summit of the Neversink Mountain visible from Naomi Station, W. & N. R. R.? What is the distance between them in miles?

Assuming a picket stationed upon the summit, and the surface denuded of vegetation, which road would furnish most cover to an enemy approaching from the east?

Where is the steepest gradient on the road from Mount Penn Hotel to Claperthal?

Is it accessible for heavy wagons or artillery? See § 116.

PROJECTIONS OF THE GEODETIC POSITIONS.

90. When the territory to be represented is so extensive as to include, say thirty or more minutes of arc, it is desirable to give, when possible, its true position on the earth's surface as determined by its latitude and longitude arcs. To this end, several projections are applicable, but the one in general use is that known as the Polyconic Method, which is as follows: Imagine a series of cones tangent to the earth's surface along the various circles of latitude; their vertices will be in the axis produced, and their slant heights, which are the radii of the developed circles, will be equal to the tangent of the polar distances of those circles. Let E A L′ represent a meridian section of a hemisphere, A A′ the section of the arctic circle, L L′ the section of any circle of latitude; A O and L O will be the tangents of their respective polar distances, P A and P L, or the

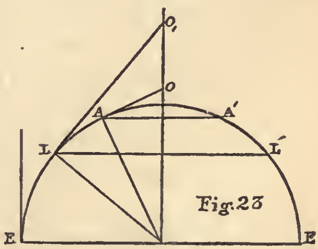


Fig. 23

co-tangents of the latitudes E A and E L, which may be taken from a table of natural tangents, and being multiplied by the radius of the earth, will give the length of the radius of the developed circles. But as the polar distance approaches 90°, the tangent increases in length until it becomes infinity at the equator; and as it is difficult to construct arcs of long radius, another method of drawing them must be devised. This is accomplished by assuming a tangent to the developed circles at points along a central meridian. By computing and tabulating the deflection of each circle of latitude (d_p) at various longitudes, as well as the values of the latitude arcs (d_m) the curves may be plotted by co-ordinates.

91. As the tables are extensive, and it is seldom, in general practice, that they are required, they are not appended; but the draughtsman is referred to those in the U. S. Coast Survey Reports for 1853, 1856, 1859 and 1865, giving results in metres, and to No. 12 Professional Papers of the U. S. Corps of Engineers, known generally as "Lee's Tables," giving the co-ordinates in yards.

To use them draw a vertical line, known as the central meridian, in the centre of the sheet, and at its middle point erect a perpendicular. On this perpendicular lay off symmetrically, and to scale, the values of d_m for one, two, three, etc., degrees as given by the table, all measurements to be from the central meridian as an origin. At these several points of division erect short perpendiculars and lay off on them upwards the values of d_p; the line joining these points will be the central parallel.

For the adjacent circles, the points must be found at which they intersect the central meridian. This distance will be the value of a degree of longitude at that latitude, and may be taken from other tables giving the values of d_m, or degrees of meridian, and d_p, or degrees of the parallel. The same operation repeated from these points will give the parallels passing through them. The points on the parallels at the extremities of the ordinates d_p being joined will give the meridian.

92. For limited areas it will suffice to determine the values of the longitude arcs at the limiting latitudes, and draw the meridians as right lines between them, and the parallels perpendicular to the central meridian at the proper interval by scale.

The various methods of plotting notes are so fully described in the numerous texts on surveying, that it is unnecessary to repeat them here. Suffice it to say that the ordinary courses may be reduced to their equivalent latitudes and departures, graphically, by ruling a protractor around any point of a cross-section sheet, as a centre, and making a movable paper scale to revolve about the same point, as its zero. The reduced rectilinear co-ordinates may then be read off from the horizontal and vertical divisions of the cross-section sheet to within the nearest tenth.

Very accurate and rapid plotting may also be done by the use of a Kimber-Cleaver protractor, which is graduated to read to one minute, by the aid of a vernier attached to a revolving frame, which is square, so that its edges may be set parallel and perpendicular to the bearing. By placing a parallel ruler against the appropriate edge, the bearings may be run off very quickly.

LETTERING.

93. The effect of a good drawing may be wholly destroyed by inappropriate or bad lettering. Topographical maps generally admit of some latitude in free-hand or ornamental letters, especially when the conventional signs are introduced; but for neatness and beauty of form, the Roman alphabet, when properly drawn, is a standard not to be surpassed. The size of the letter should conform to the scale and to its position in the title or on the chart. Script is well adapted to field sketches. More than this need not be said here, as the subject has been so thoroughly treated in texts on this part of the topographer's work.

CHAPTER VI.

RECONNAISSANCE.

94. The topographer is now about ready to begin field operations. Assuming that his first duty will be an examination FOR A LINE OF COMMUNICATION, he must inform himself as to the character of the proposed work, whether it be intended for a common road, a railroad, or a canal; and since his best line will be that which for least cost will offer the least resistance to traffic over it, he must, if possible, establish in advance a relation between cost and distance in construction and cost of maintenance and operation.

These quantities are functions of the probable amount of traffic or tonnage, the character of the motive power of the vehicles, and of the surface-covering, as well as of the grades and curves, all of which affect directly the equation between the power and resistance. Having a given power and load moving over a specified surface, the topographer is chiefly concerned in finding that line on which the adopted ruling gradient will fall within a maximum limit. To this end he will need an approximate idea of the high and low points along the proposed routes, with the distances between them; the character of the ground with reference to facility of access and ease of removal, danger from slides, porosity, productiveness, mineral resources, and geological formations.

The general inspection of the map, previously mentioned, will aid him in selecting a route for examination; and it may be safely assumed that a side-hill line along a valley will be less expensive than one crossing a drainage system at right angles to its general direction.

95. Should he be so fortunate as to be able to follow a valley, he must note especially the position of high-water mark, as determined by drift-wood, ice, striæ, or local records; the position, number and size of the tributary streams; the character of the slopes and bottoms, and the best positions for crossing ravines and streams. Should the valley be very tortuous and full of interlock-

ing spurs, a more direct and cheaper line would doubtless be found at the junction of the spurs with the main ridges. In a rolling or broken country, many ravines involving expensive embankments and culverts or high trestling may be avoided by following the divides.

96. Aside from the topographical features, the report should contain a memoir or description of the settlements, with their populations, industries, wealth, and any other items which may be of interest to the projectors of a new line, such as the animus of the residents with reference to it, and the amount of aid they will furnish by grants of right-of-way or by contributions from counties or townships, etc. The securing of these concessions from owners is frequently of far more importance than the evading of imposing natural obstacles, and it is always a wise policy to obtain, so far as possible, a preliminary release from the owner even before it is definitely known where the line will be located, than to wait until the work is staked out and prices have advanced to unreasonable figures.

97. Should the examination be intended FOR THE IMPROVEMENT OF A RIVER, the topographer must determine the source, width, depth and velocity of current; the discharge at different seasons and various sections; the number and size of the tributaries; the area of the entire drainage basin; the character of the soils in same; the amount of precipitation at different seasons; whether subject to floods, and if so, the height of flood line; character of banks and bottom; position of riffles, rapids, falls, pools, etc.; nature and amount of traffic; kind of vessels used or proposed to be used in navigation; suitable positions for dams for navigation or water power; sites of bridges, if any, and the water way under them; fords and ferries; character of timber and stone on banks, and whether it is accessible or not; positions of towns, with their population, etc., as for roads, so that an intelligent opinion may be formed as to the cost of and necessity for the proposed work.

98. FOR A CANAL the same general observations should be made, giving especial attention to the amount of water available for the summit level in crossing a divide, the porosity of the soil, amount of evaporation, length of time when traffic would be suspended

by freezing, number and size of feeders, aqueducts and locks required, etc., as above.

99. Of a road.—If a road has already been constructed, and it is merely desired to form an opinion as to its passability, a reconnaissance becomes very simple. It is then only necessary to follow the route, noting its directions by compass, its grades by barometer or clinometer, its distances by odometer, pedometer, or by time in riding over it; the nature and condition of its soil or metalling, if any; its width, drainage, bridges, fords; and for military purposes, the topography should be taken at least within gun-shot range on either side, noting particularly the position of commanding knolls or ridges; defiles, timber, or brush, suitable for ambuscade; towns or villages; facilities for subsistence, etc.

The degrees of slope most necessary to note are 60° or $\frac{7}{4}$, which is inaccessible for infantry; 45° or $\frac{1}{1}$, which is difficult; 30° or $\frac{4}{7}$, inaccessible for cavalry; 15° or $\frac{1}{4}$, inaccessible for vehicles, and 5° or $\frac{1}{12}$, easy.

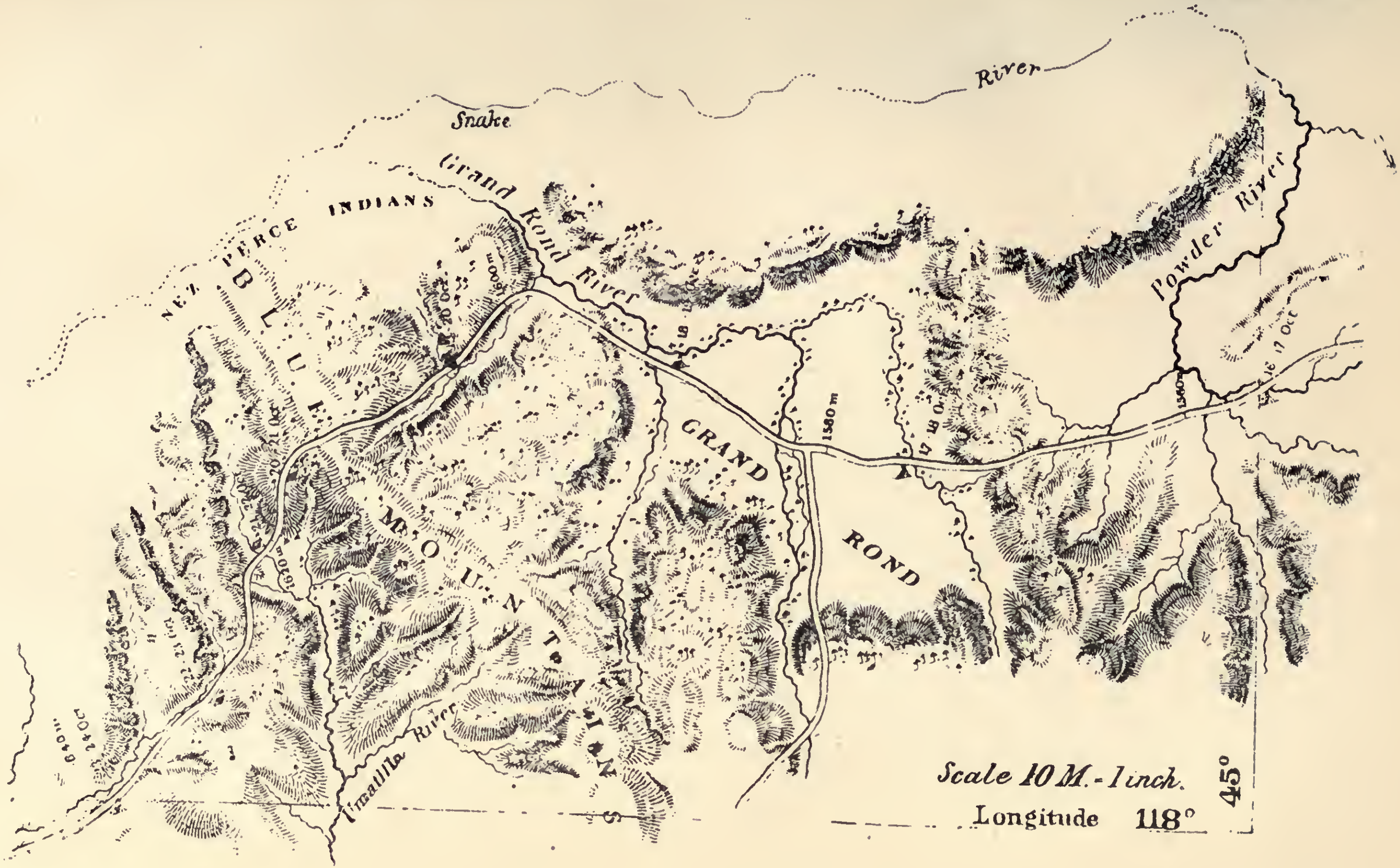
All intersections of roads—streams, paths, and especially of "cut-offs" or "short cuts"—should be recorded, with the distance to the nearest towns or hamlets; but in quoting these distances the authority should be given, as little dependence is to be placed upon either finger-boards or the opinion of residents. It should be remembered, also, that odometer distances give the actual number of revolutions of the wheel, and hence the inequalities of the surface, so that the record must be corrected by the degree of the slope before it can be correctly plotted.

100. The accompanying extracts from Col. J. C. Frémont's journal, of an expedition from the junction of the Kansas and Missouri rivers to the mouth of the Wallah-Wallah river in Oregon, will illustrate this point.

The entire distance of 1670 miles was traversed between June 11 and October 25, 1842, or in 137 days, making an average march of 12.2 miles. The sketches and topography were taken by Chas. Preuss. The notes read as follows:

October 16. Powder river (see Plate 6). We traveled this morning across the affluents to Powder river, the road being good, firm and level, and the country became constantly more pleasant and interesting. The soil appeared to be very deep, and is black and extremely good, as well among the hollows of the hills on the elevated

PLATE 6.


Snake
River
Grand Rond River
Powder River
NEZ PERCE INDIANS
BLUE MOUNTAINS
GRAND ROND
Umatilla River
1580 m
Scale 10 M. - 1 inch.
Longitude 118°
45°

plats as on the river bottom, the vegetation being such as is usually found in good ground. The following analytical result shows the precise quality of this soil, and will justify to science the character of fertility which the eye attributes to it:

Silica	72.30
Alumina	6.25
Carbonate of lime	6.86
Carbonate of magnesia	4.62
Oxide of iron	1.20
Organic matter	4.50
Water and loss	4,27
	100.00

October 18. GRAND ROND. About two in the afternoon we reached a high point of the dividing ridge, from which we obtained a good view of the Grand Rond—a beautiful level basin, or mountain valley, covered with good grass, on a rich soil, abundantly watered, and surrounded by high and well-timbered mountains; and its name descriptive of its form—the great circle. It is about 20 miles in diameter, and may in time form a superb country. Probably, with the view of avoiding a circuit, the wagons had directly descended into the Rond, by the face of a hill so very rocky and continuously steep as to be apparently impracticable; and following down on their trail, we encamped on one of the branches of the Grand Rond River, immediately at the foot of the hill. The old grass had been recently burnt off from the surrounding hills, and wherever the fire had passed, there was a recent growth of strong, green and vigorous grass; and the soil of the level prairie which sweeps up to the foot of the surrounding mountains appears to be very rich, producing flax spontaneously and luxuriantly in various places.

October 21. LARGE TREES. Some of the white spruces, which I measured to-day, were twelve feet in circumference, and one of the larches ten; but eight feet was the average circumference of those measured along the road. I held in my hand a tape-line as I walked along, in order to form some correct idea of the size of the timber. Their height appeared to be from 100 to 180, and perhaps 200 feet, and the trunks of the larches were, sometimes, 100 feet without a limb, but the white spruces were generally covered with branches nearly to the root. All these trees have their branches, particularly the lower ones, declining.

October 22. BLUE MOUNTAINS. The white frost this morning was like snow on the ground; the ice was a quarter of an inch thick on the creek, and the thermometer at sunrise was at 20°. But in a few hours the day become warm and pleasant, and our road over the mountains was delightful and full of enjoyment.

The trail passed sometimes through very thick young timber, in which there was much cutting to be done; but soon the mountains became more bold, and we reached a point from which there was a very extensive view to the N. W. We were here on the western verge of the Blue Mountains, long spurs of which, very precipitous on either side, extended down into the valley, the waters of the mountain roaring between them. On our right was a mountain plateau covered with a dense forest; and to the westward, immediately below us, was the great Nez Percé (pierced nose) prairie, in which dark lines of timber indicated the course of many affluents to a considerable stream that was seen pursuing its way across the plain to what appeared to be the Columbia River. This I knew to be the Wallah-Wallah River, and occasional spots along its banks, which resembled clearings, were supposed to be the mission or Indian settlements, but the weather was smoky and unfavorable to far views with the glass.

THE ROCK displayed here in the escarpments, is a compact, amorphous trap, which appears to constitute the mass of the Blue Mountains in this latitude; and all the region of country through which we have traveled since leaving the Snake River, has been the seat of violent and extensive igneous action. Along the Burnt River Valley, the strata are evidently sedimentary rocks, altered by the intrusion of volcanic products, which in some instances have penetrated and essentially changed their original condition. Along our line of route from this point to the California Mountains, there seems but little essential change. All our specimens of sedimentary rocks show them to be much altered, and volcanic productions appear to prevail throughout the whole intervening distance.

The road now led along the mountain side, around heads of precipitous ravines; and keeping men ahead to clear a road, we passed alternately through bodies of timber and small open prairies, and encamped in a large meadow, in view of the great prairie below.

At sunset, the thermometer was at 40°, and the night was very clear and bright. Water was only to be had here by descending a bad ravine, into which we drove our animals, and had much trouble with them, in a very close growth of small pines.

Mr. Preuss had walked ahead, and did not get into camp this evening. The trees here maintained their size, and one of the black spruces measured fifteen feet in circumference. In the neighborhood of the camp, pines have re-appeared among the timber."

October 23. WALLAH-WALLAH RIVER. Grass and horses. The morning was clear, with a temperature at sunrise of 24°. Crossing the river, we traveled over a hilly country with good bunch grass; the river bottom, which generally contains the best soil in other countries, being here a sterile level of rock and pebbles. We had found the soil in the Blue Mountains to be of excellent quality, and it appeared to be good here among the lower hills. Reaching a little eminence, over which the trail passed, we had an extensive view along the course of the river, which was divided, and spread over its bottom in a net-work of water, receiving several other tributaries from the mountains. There was a band of several hundred horses grazing on the hills about two miles ahead; and as we advanced on the road, we met other bands, which Indians were driving out to pasture. True to its general character, the reverse of other countries, the hills and mountains here were rich in grass, the bottoms barren and sterile.—*Frémont's Report.*

On the plate (6), the topography is shown to a distance, in places, of 20 miles from the route. This is, therefore, largely hypothetical, based upon such general views as were obtained from the summit of the Blue Mountains, and the descriptions of guides and trappers.

101. A CHOROGRAPHICAL RECONNAISSANCE is one conducted chiefly for the purpose of selecting principal points for determina-

ON CRANBERRY GRADE.

tions of areas or positions in a plane or on the surface of the earth considered as a spheroid. In such cases the observer should use either a field telescope with a horizontal limb, or, better, the Casella and field glass, with the sketch book for horizons recommended in § 62.

102. Thus equipped, he should note especially and with care the sectors of the horizon which are *obscured* by near objects, as hills, trees, and buildings, as well as those which are *open* and give elevated distant points good for future stations. Thus, on plate 7 will be seen an open sector of perhaps 30° to 45°, with a high distant peak which, if found to be in position to give a well conditioned triangle, would make an excellent station point. By this means he will be greatly assisted in an extensive reconnaissance.

103. By plotting the bearings on tracing paper or vellum, and orienting the plot by reference to well defined features on the map, as peaks, gaps, or towns, as in the three-point problem, he may discover at once what sectors of country are visible for any distance and what are not. This same operation repeated at a second station will give the open sectors from that point, and the intersection of two or more such open sectors will reveal the possible position of a third point visible from the first and second. If the map indicates high ground there, as shown by the streams, the observer may feel reasonably certain of his point, and need not consume time in fruitless searches in other localities indicated by residents of the vicinity who may have no conception of what he requires, and who will send him on many a useless tramp only to obtain a very limited view from a rock on a side-hill of the valley beneath.

104. As the highest points are generally timbered, it is of course necessary to select one of the tallest trees on the top of the crest, and ascend to its uppermost branches, where, perched in a crotch, the bearings may be taken and called out to a recorder below. If at all possible, these observations should be followed by a sketch. It may happen that a young growth of timber of uniform height will effectually prevent a sight being obtained even by climbing trees on different portions of the hill. In such cases some other expedient must be resorted to for elevating the observer. Probably the simplest and cheapest is that shown in

Plate 8, consisting of three ladders, spliced together and braced by guys in the manner indicated, by which an altitude of 60 feet above ground was obtained. From the top of this ladder, erected at Principio, and by a careful application of the above system of reconnoitering, a connection was made between the triangles of the U. S. Coast Survey in Maryland, Delaware and Pennsylvania, which was not otherwise found to be possible.

105. Having marked the available points thus determined on the map, a selection of the system best adapted to the objects of the survey may now be made. For the sake of convenience they may be classified as primary, secondary and tertiary.

106. A primary triangulation is characterized by the maximum development of which the configuration of the country admits. Its sides may be 100 statute miles in length in countries where the relief is great, about 19 to 20 miles in rolling country, and from 12 to 15 miles on level ground.

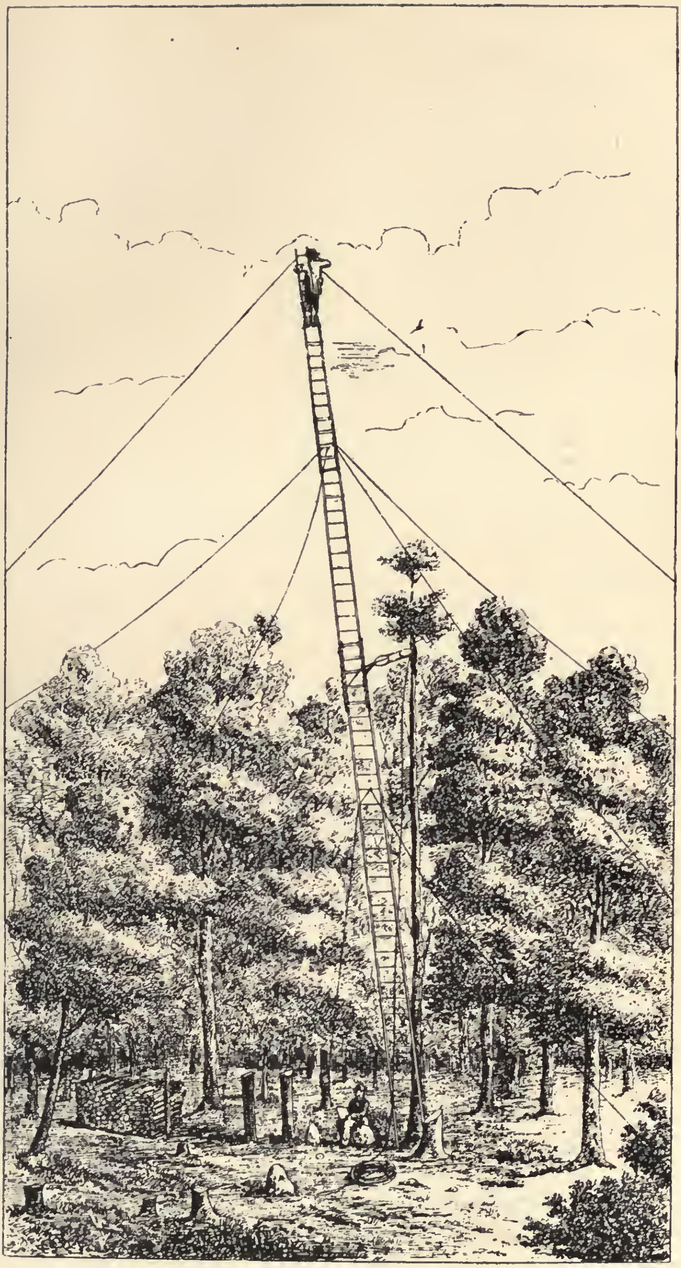
Tertiary triangulation, which should be accommodated to the wants of the topographer and hydrographer, brings the sides down to the minimum length required for plane table work on a large scale (about $\frac{1}{5000}$ to $\frac{1}{10000}$). They may be as short as one mile, but will average about three miles. The probable error of such work should not exceed $\frac{1}{5000}$ in the resulting distances.

Secondary triangulation is simply a connecting link between the two systems just mentioned. The sides may vary in length from five to thirty miles. The object of the triangulation may be to connect two distant points; to determine the length of an arc; to cover an area, or to furnish bases for the filling in; and this will determine the system to be employed if the form of the ground renders it practicable.

When a large area is to be covered it is better to select one or more chains of triangles encircling the tract to serve as a framework, in which other series may be subsequently measured at pleasure, rather than to spread out promiscuously, thus introducing unmanageable conditions.

107. Each system is adjusted separately and finally, before the next series is joined to it. In general, to close any circuit four equations must be satisfied, arising from: 1st, the *length* of connecting side, which must be the same in whatever direction it may

PLATE 8



RECONNAISSANCE AT PRINCIPIO
JUNE 1878

have been computed; 2d, its direction or *azimuth* must be constant; 3d and 4th, the *latitude* and *longitude* of one of the end-posts of the line must come out the same respectively.

A series of triangles may have one side on the crest of a mountain range and the other on the foot-hills or valleys at its base; but the most advantageous formation is that of a valley of proper width having the overlying chain resting on the encompassing mountains.

108. As to the forms composing the series there may be a single string of triangles, or a double string; a string of hexagons or other polyglons, or of quadrilaterals, or any combination of triangles.

For economy and rapidity of execution the single string of

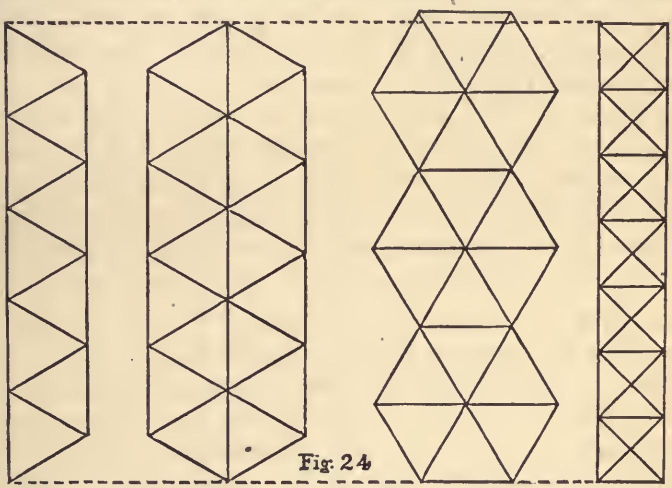


Fig. 24

(theoretically) equilateral triangles is the one to be adopted. For covering a large area the system of hexagons, connected either axially or hinged, is the best. And for greatest accuracy and strength, that of the quadrilaterals must be selected.

Taking for the unit of length the greatest distance at which it is advisable to place two stations, in conformity to the nature of the ground, the efficiency of the instrument, and means at our disposal, the relative values of the above systems may be estimated by comparing the results for a given equal length—Fig. 24.

Since nine equilateral triangles, reaching to five units, carry us nearly as far as three hinged hexagons ($3\sqrt{3}=5.20$) and slightly exceed seven quadrilaterals, having diagonals of unit length ($7\sqrt{\frac{1}{2}}=4.95$), a length of five may be taken as a convenient unit of comparison for efficiency. The following numbers will be found useful for comparison:

System.	Composition.	Range.	No. of stations.	Total length of sides.	Area.	No. of conditions.
I	Triangles . .	5.00	11	19	4.5	9
II	Hexagons .	5.20	17	34	9	21
III	Squares . .	4.95	16	29.6	3.5	28

109. From this table it appears that the first system is more economical in *number of stations*, whilst the second and third are about equal; with reference to *length of sides*, the first again has the advantage, which is of special importance when long lines have to be cut through heavy timber; with respect to *area*, system II is by far the best, but if axially arranged, the hexagons are less favorably disposed, being narrower and lacking the salients of the ordinary connections. With respect to the number of geometrical condition,* III is the most favorable, and is, therefore, capable of giving the greatest accuracy, but at the expense of area.†

STATION MARKS.

110. The points thus selected should then be permanently fixed, both by underground and surface marks.

The underground mark should be at least three feet in the clear below the surface, or beyond the reach of frost or plow. Its requirements are: indestructibility, peculiarity, capacity to resist displacement, cheapness, and want of value for any of the ordinary purposes of life.

The following objects will be found to answer the purpose: Stoneware or iron frustrums of cones made specially for the purpose; a hollow stoneware pyramid; a short column of hewn

* If in system I., n equal the number of stations (not less than 3), then the number of conditions $= n-2$; for system II., with not less than 7 stations, forming complete hexagons, the number of conditions $=\frac{7n-14}{5}$; for system III., with at least 4 stations, the number of conditions $= 2n-4$.

† For fuller particulars see Appendix No. 15, U. S. Coast Survey Report for 1871; contribution by Chas. A. Schott, Assistant.

stone; a block of bricks or stone laid in cement; a glass or stone bottle, neck downward, with three others at a less depth pointing towards the centre; or any earthenware vessel, as a crock, jug, or flower pot.

In all instances the mark must be carefully centered, and after fixing reference lines on the surface, the hole should be filled by packing small stones or earth in and around the mark, covering it with a flat slab, if one is at hand, and planting a stake or stone over it to indicate position for centres of signals which may afterward be erected.

The *surface mark* on ROCK consists of a bolt of copper, lead or iron, wedged or soldered into a hole drilled in the rock, and surrounded by the initials of the survey, and the date. In earth, the mark may be a block of cut stone, a stake, or a rough stone, with a cross cut or hole to indicate the centre, and three witness stones, two in line and one at right angles, at equal distances from the centre.

These marks may vary according to the locality and resources, but they should be further determined by a carefully prepared sketch, giving the bearings and distances to all natural objects within several hundred feet, showing all roads, trees, fences, etc., with the topography, and accompanied by a full description of the locality, names of property owners, near residents, persons who may have witnessed the fixing of the marks, guides, date, character of mark in detail, etc.

On important surveys, too great care cannot be taken to secure and identify the station points.

111. An OROGRAPHICAL RECONNAISSANCE, is one made to select points for carrying on a complete topographical or hypsometrical survey, in which shall be shown not only relative positions, directions and distances, but all the surface inequalities.

The instruments used are the same as those for linear work, and the method of proceeding differs but little from that already given under this head. The main question to be determined here will be the selection of the proper instruments and methods to be used in the subsequent filling in of the work; the selection and establishment of reference points, and the arrangement of a system of lines to be run by the several field parties, which will give the best results for the purposes intended. To this end the divides and the peaks commanding the greatest extent of country should be visited, and their elevations determined.

112. The general character of the surrounding territory will be visible from these commanding positions, which may also be utilized to determine the heights of many distant points without visiting them. From the extremities of any measured or known base, the distances to the several peaks may be obtained by intersecting bearings on the plot, or by computation. Their heights may then be determined rapidly, by finding the points on the side of the peak occupied, from which a horizontal line will pass tangent to any distant point whose height is desired. The distance being known, the combined correction for curvature and refraction may be added to the altitude of the point of observation as given by the corrected barometer reading, and the result will be the desired height of the distant peak. Thus a large number of secondary elevations may be obtained with sufficient accuracy for ordinary purposes. This method was employed by Mr. V. Colvin, in his survey of the Adirondack Wilderness in New York, with great success. (Plate 9.)

IN A MILITARY RECONNAISANCE.

113. Where rough approximations only are desired, such as may be obtained by a *coup d'œil*, as when, in the presence of an enemy, there is not time to use instruments, the topographer becomes dependent upon his *personal units*, as indicated in § (2).

It will assist him in this work to have a clear idea of the object of the reconnaissance with reference

1st. To the natural obstacles imposed to the passage of troops.

2d. With reference to the possibility of an engagement, and the adaptability of the ground to aggressive or defensive movements.

3d. To determine the probable amount of subsistence and shelter afforded by the country to be examined.

In making up his sketch for a report to the commanding officer, the distances from point to point should have been taken, either by pacing or riding over the ground, by range of vision, or by time, and the latter is generally to be preferred, if based

Colvin's Reconnaissance in the Adirondacks.

upon an accurate determination of the units of computation, and a careful record of all intervals or stoppages.

The attention is thus free from the monotony of counting, and may be employed in sketching or making notes of the surroundings.

114. The pace of a horse should be determined by observation, and be reduced to the equivalent human pace. It will be found to vary in different animals; it may average

At a walk,	120 human	paces	per	minute;
At a gentle trot,	180 "	"	"	"
At a strong trot,	240 "	"	"	"
At a gallop,	300 "	"	"	"

The length of the human pace (about 31 inches) should be determined by comparison with a measured base line. A horse may take 110 leaps on a gallop and 290 steps walking, over a distance of 900 feet. A rider rises in the saddle about 90 times in trotting the same distance.

The length of a "pace" is generally three feet; of a step or pace in common time with troops, it is 28 inches, taken at the rate of 90 per minute, equal to 210 feet; and at double time it is 33 inches in length, and at the rate of from 165 to 180 per minute. Some authorities give 30 inches as the length of a military pace.

DISTANCES BY VISIBILITY.

115. Such distances are modified by the condition of the observer's eyes, as well as by the atmospheric condition and amount of illumination. On a cool and bright day after a rain, when all mists have been precipitated, objects stand out with clearly-cut outlines, and can readily be distinguished at more than double the distance at which they are visible on a hot sultry day; whilst a fog may obliterate everything even at a few rods distance.

Again, in looking towards the east in the morning, or west in the afternoon, the shady side of an object is presented to the observer, and it may entirely escape his attention; whilst the same object viewed in an opposite direction, under a full sunlight, may be visible at more than triple the distance.

High objects look nearer, low ones more remote; hence a careful comparison must be made, and even then results are uncertain

"An object becomes invisible in clear weather when its distance is 6,000 times its greatest dimension." *

Another authority gives the least visible angle to ordinary eyesight at about $\frac{1}{300}$ of a degree = 12 seconds or 1 foot at 3¼ miles = $\frac{1}{17160}$, which is believed to be more nearly correct—at least for the writer, to whom a lightning rod is visible, against a clear sky, at about 4,000 feet.

116. In general, the same features and details require to be shown for military as for civil purposes, more stress, however, being laid upon the limiting slopes for the various arms of the service, and the "cover" afforded by the details with reference to the commanding positions.

The following table, compiled from Reichlin von Meldegy and Lehmann, will give the accepted limits of slope for the movement of troops:

Slopes.		Infantry.	Cavalry.	Artillery.
2° 23′ 4° 45′ or 5°	$\frac{1}{24}$ $\frac{1}{12}$	Has nearly the same tactical value as a plane. Accessible to all arms without great exertion; more difficult for cavalry charging down hill; artillery fire more effective down than up hill.		
9° 27′ or 10°	$\frac{1}{6}$	Close movement difficult.	Charge down hill almost impossible.	Moves up with difficulty. Cannot be aimed up the slope.
15° 16′ or 15°	$\frac{1}{3}$	Can only move a very short distance in order.	Passable—can trot up and walk down.	Moves with double teams, but cannot fire.
20°	$\frac{1}{2.7}$	Cannot move in order, and only fire singly with effect.	Can ascend at a walk and descend obliquely.	Impassable for guns or wagons.
26° 34′	$\frac{1}{2}$	Can only move and fire singly.	May ascend singly and obliquely.	Impassable.
30°	$\frac{1}{1.7}$	Can only move in open order very slowly.	Only as above, when slope is of soft earth.	Impassable.
35° to 40°	$\frac{1}{1.4}$ $\frac{1}{1.2}$	Lightly equipped and with the help of their hands.	Impassable.	Impassable.
45°	$\frac{1}{1}$	Sharp shooters and light infantry used to climbing, holding on with their hands, but in great danger of falling.		

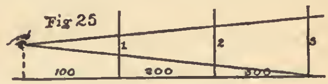
* O'Etzel.

CHAPTER VII.

INSTRUMENTS AND METHODS USED IN "FILLING IN."

THE STADIA.

117. Before proceeding to describe the filling in of the topography, it becomes necessary to give a brief account of the instruments most generally used for that purpose. They consist simply in improvements of the older forms of instruments, whereby distances may be read on a rod or staff, instead of being chained or paced. The improvement known as the stadia or telemeter, is based upon the simple principle of the proportionality of the sides of similar triangles. Thus, if two wires, *a* and *b*, be placed before the eye, Fig. 25, the length of the segments of a rod held beyond them will increase as the distance increases.



This principle was first utilized for measuring distances by the Piedmontese military engineer, Porro, who published an account of it in 1852. It was used by Mr. B. S. Lyman in a topographical survey of Schuylkill county, Pa., in 1862 to 1865, of which Sheet 4 is a portion, in a geological survey of Cape Breton, 1863 to 1866, and by the Coast and Lake Surveys soon after its discovery.

The principle is applied by placing two additional wires in the diaphragm of the telescope. These wires may be either fixed or movable (adjustable), and the rod to which the readings are taken may be held perpendicular to the line of collimation, or else vertically. In the latter case, if on higher or lower ground than that on which the instrument rests, the rod will be cut obliquely, and the reading will be too great. By the interposition of the telescope, the vertex of the angle is shifted from the focus of the eye to that of the object lens in front of the instrument, whilst the distance desired is that from the stake under the centre of the transit.

118. These modifications make certain corrections necessary for both distance and heights in very accurate work. They are given by the following general equations, derived by Prof. S. W. Robinson, formerly assistant on the Lake Survey:

$$D = \frac{R'}{R} B \cos.^2 V - (c+f) \cos. V \left(\frac{R'}{R} \cos. V - 1\right) \text{ and,}$$

$$H = \frac{R'}{R} B \sin. 2 V - (c+f) \sin. V \left(\frac{R'}{R} \cos. V - 1\right),$$

in which, the rod being held vertically,

D = the horizontal distance from its foot to the stake under the centre of the instrument.

H = the corrected height of the point on the rod, cut by the middle wire, above the axis of revolution of the telescope.

R' = the distance as given by the rod reading.

B = the length of a measured base.

R = the length of same base as given by stadia.

V = the angle of elevation or depression, as given by the vertical circle.

c = the distance from centre of object-glass to centre of instrument.

f = principal focal length of object-glass.

c and f are measured when the glass is focussed for a sight of medium length, and are then considered constant for the same instrument. Their sum is the distance from the centre of instrument to the apex of visual angle, where rays finally diverge, and it rarely exceeds 1.5 feet. As it is independent of the length of the sight, its effect is much greater on short than on long distances; and hence for readings of less than 200 to 300 feet it should be applied, when its omission would be cumulative, as in running a traverse line.

In most cases, the second terms of the above equations will be so small as to be omitted without sensible error, and since the rod is usually graduated to read the measured length of the base, in which case R and B become equal—the formulæ reduce at once to $D = R' \cos.^2 V$,

$$\text{and } H = \frac{R'}{2} \sin. 2 V.$$

In these formulæ, the quantity R' is composed of two factors, viz: The actual length of the rod included between the wires, and the ratio of that length to the entire distance, or the ratio of the focal length of the object lens to the distance between the wires. This ratio is usually 100 : 1, so that the observed distance on the rod must be increased by this multiple. Thus a rod reading of 5.31 feet gives on level ground a distance of 531 feet; for in this case, V becomes zero, and $\cos.^2 V = 1$, so that the formulæ reduce to $D = R'$, and $H = 0$, since $\sin. 0^\circ = 0$.

119. Even on undulating ground, the corrections for slope may be neglected, when the stadia is used in the telescope of a plane table, by selecting stations in such a manner that the vertical angles need seldom exceed 4 or 5 degrees. This may be done by placing the table on the opposite bank of a ravine or slope, if not too distant from that on which the lines are to be run, or else by zigzagging up the slope in such a manner that none of the shots shall be directly up or down hill. When it is considered that the largest scale generally used in such work is seldom greater than $\frac{1}{1200}$, or 100 feet to one inch, and that the initial point of the stadia, in plane-table work, may be on either side of the "centre" or station point, having a play of two feet on most tables, it is evident that errors in contouring amounting to as much as three or four feet in distance, may be neglected, being fully covered by slight inequalities in the surface of the ground, throwing the point found in or out of its true position, or by errors of reading the rod, due to wind, radiation of heat, inclination, and other causes. Even an error of five feet on this scale would be but $\frac{1}{20}$ of an inch, which is immaterial, when, as in contours, it is not cumulative.* With a long rod, the errors of observation may be diminished by taking the reading from the top when the point at which it is held is lower, and from the bottom when higher than the instrument

Where the vertical angle must be observed, as in traversing on slopes with a stadia-transit, a target may be used on the rod, set to the height of the horizontal axis of the telescope above the ground, to give the angle of the slope; but even this is an unnecessary encumbrance, as in self-reading rods no target will be required.†

* See § 162, on Limits of Error.

† For further information the student is referred to a paper in course of prepara-

120. THE ROD.

In stadia measurements the rod must be adapted to the instrument or the instrument to the rod. If the wires are "*fixed*," that is, all on one diaphragm, then the rod must be graduated to suit them; but if the wires are adjustable, then they may be set to cover the divisions of any given rod, and in this case the ordinary level rod may be used. As it is difficult to distinguish the red from the black figures at long range, Mr. E. V. d'Invilliers, Assistant on Second Geological Survey of Pennsylvania, has improved his rods by inserting small mirrors at each foot mark, giving a series of luminous points readily counted at any distance within reach of the wires.

121. *Self-Reading or Speaking Rods* are those which are so marked as to be read from the instrument, and various designs have been proposed and used in their graduation. In many the rod is divided into feet and tenths, either by numbered lines or by various geometrical forms, the angles of which give the subdivisions. Some of these are very difficult to read at long distances. The marks at the feet divisions are usually red, the rest black, on a white ground.

RODS.

122. In Fig. 26 the subdivisions are read to half-tenths on the rod, equivalent to distances of five feet. The feet marks in red must be counted, requiring the segment between wires to be uncovered.

Fig. 27 shows the form used in the U. S. Coast Survey, drawn to a larger scale ($\frac{17}{60}$) than the others, which are $\frac{1}{12}$. It is intended for micrometer measurements, having a permanent target painted at the top. It is subdivided into .05 of a foot.

Fig. 28 is a 15-foot rod, resting on its top, reading to tenths—or ten feet horizontal distances. Single feet must be estimated in all cases.

Fig. 29 shows a graduation reading to 2½ feet on the even, and 5 feet on the odd-numbered feet. By setting the zero wire properly, the reading wire can always be brought on one of the even

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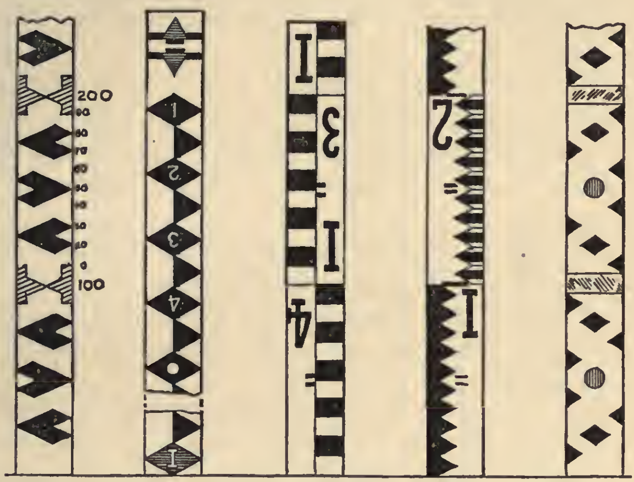
tion, entitled "The Theory of Stadia Measurements," accompanied by Reduction Tables by A. Winslow, to appear in Appendix B of Report AA of the 2d Geol. Survey of Penna.

segments. This form also aids in counting the feet when figures cannot be distinguished.

Fig. 30 contains strips of mirrors at the feet-marks, and is readily counted, as the points are symmetrically placed, on one side being 10, 40, 60 and 90, on the other 30 and 70, with a red disc at 50. The least count here is five feet on the rod.

The figures are all inverted, to correspond with the eye-piece of the instrument.



FIGS. 26, 27, 28, 29, 30.

123. For an instrument with fixed wires, the rods may be so graduated as to eliminate the errors represented by c and f, in this manner.

Lay off on level ground a base line in multiples of 100 feet, measured from the centre of instrument, or point of plumb-bob. Let the rodman hold the rod to be graduated at these points of division, and mark by aid of a target the points at which the lower wire cuts the rod. (The upper one in an inverting telescope being sighted to the top of the rod.) These unequal divisions are numbered as full feet, and are then each subdivided into any convenient number of equal parts, usually tenths, by any of the symbols represented in Figs. 26–30, above.

NOTE.—In 1869, on shore line of Lake Superior, the author read distances of over a quarter of a mile, but the difficulty of seeing the figures and correcting the spaces renders it unreliable, as well as injurious.

The quantity $(c+f)$ on the rod amounts to about one-eight of an inch, and is therefore, hardly appreciable.

124. If the wires are adjustable, and the rod one which has already been graduated, measure off any convenient distance as 500 feet + the correction $(c+f)$ and set the wires to cover five feet of the rod, being careful to space them equally from the centre wire.

In some instruments the distance from centre to one wire is made double that to the other, for reading very long distances across water.

125. The reductions for inclination may be made graphically; but it is quite as convenient (more so in the field) to use the tables. Those computed by Alfred Noble and W. T. Casgrain, and published in 1871 by the U. S. Engineer Department, U. S. A., are standard.

They are used in the same manner as a traverse table, and are fully explained in the manual containing them.

126. A simpler table computed from the general formulæ, by Mr. A. Winslow, C. E., for use on the Second Geological Survey, is appended.

To find the corrected distance and height, take from the table the values corresponding to the observed angle, and multiply them by the rod reading. Thus, if the vertical angle were $+ 6° 18'$, and $R' = 5.70$, multiply 98.80 by $5.70 = 563.16$ for D, and $10.91 \times 5.70 = 62.21 = H$. For greater accuracy, the constant $(c + f)$ must be multiplied by its corresponding values, as given in table, and properly applied.

127. In *holding the rod* it should be kept as nearly vertical as possible—2° being an extreme limit from verticality. The suggestion of so inclining the rod backward or forward that it shall be perpendicular to the line of collimation, when on a slope, is frequently impracticable, and has no other advantage than to reduce the formula for the correction from the second to the first power, which is of no consequence after the tables are computed.

It has been suggested that by making the wires vertical, the rod may be held horizontally, but this also is impracticable, as it would be too unsteady to be read, and would more frequently be entirely obscured by brush. For long sights where the full

M.	0°		1°		2°		3°		4°		5°		6°		7°		8°		9°		10°		M.
	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	
0′,	100.00	.00	99.97	1.74	99.88	3.49	99.73	5.23	99.51	6.96	99.24	8.68	98.91	10.40	98.51	12.10	98.06	13.78	97.55	15.45	96.98	17.10	0′
2,	"	.06	"	1.80	99.87	3.55	99.72	5.28	"	7.02	99.23	8.74	98.90	10.45	98.50	12.15	98.05	13.84	97.53	15.51	96.96	17.16	2
4,	"	.12	"	1.86	"	3.60	99.71	5.34	99.50	7.07	99.22	8.80	98.88	10.51	98.48	12.21	98.03	13.89	97.52	15.56	96.94	17.21	4
6,	"	.17	99.96	1.92	"	3.66	"	5.40	99.49	7.13	99.21	8.85	98.87	10.57	98.47	12.26	98.01	13.95	97.50	15.62	96.92	17.26	6
8,	"	.23	"	1.98	99.86	3.72	99.70	5.46	99.48	7.19	99.20	8.91	98.86	10.62	98.46	12.32	98.00	14.01	97.48	15.67	96.90	17.32	8
10,	"	.29	"	2.04	"	3.78	99.69	5.52	99.47	7.25	99.19	8.97	98.85	10.68	98.44	12.38	97.98	14.06	97.46	15.73	96.88	17.37	10
12,	"	.35	"	2.09	99.85	3.84	"	5.57	99.46	7.30	99.18	9.03	98.83	10.74	98.43	12.43	97.97	14.12	97.44	15.78	96.86	17.43	12
14,	"	.41	99.95	2.15	"	3.90	99.68	5.63	"	7.36	99.17	9.08	98.82	10.79	98.41	12.49	97.95	14.17	97.43	15.84	96.84	17.48	14
16,	"	.47	"	2.21	99.84	3.95	"	5.69	99.45	7.42	99.16	9.14	98.81	10.85	98.40	12.55	97.93	14.23	97.41	15.89	96.82	17.54	16
18,	"	.52	"	2.27	"	4.01	99.67	5.75	99.44	7.48	99.15	9.20	98.80	10.91	98.39	12.60	97.92	14.28	97.39	15.95	96.80	17.59	18
20,	"	.58	"	2.33	99.83	4.07	99.66	5.80	99.43	7.53	99.14	9.25	98.78	10.96	98.37	12.66	97.90	14.34	97.37	16.00	96.78	17.65	20
22,	"	.64	99.94	2.38	"	4.13	"	5.86	99.42	7.59	99.13	9.31	98.77	11.02	98.36	12.72	97.88	14.40	97.35	16.06	96.76	17.70	22
24,	"	.70	"	2.44	99.82	4.18	99.65	5.92	99.41	7.65	99.11	9.37	98.76	11.08	98.34	12.77	97.87	14.45	97.33	16.11	96.74	17.76	24
26,	99.99	.76	"	2.50	"	4.24	99.64	5.98	99.40	7.71	99.10	9.43	98.74	11.13	98.33	12.83	97.85	14.51	97.31	16.17	96.72	17.81	26
28,	"	.81	99.93	2.56	99.81	4.30	99.63	6.04	99.39	7.76	99.09	9.48	98.73	11.19	98.31	12.88	97.83	14.56	97.29	16.22	96.70	17.86	28
30,	"	.87	"	2.62	"	4.36	"	6.09	99.38	7.82	99.08	9.54	98.72	11.25	98.29	12.94	97.82	14.62	97.28	16.28	96.68	17.92	30
32,	"	.93	"	2.67	99.80	4.42	99.62	6.15	99.38	7.88	99.07	9.60	98.71	11.30	98.28	13.00	97.80	14.67	97.26	16.33	96.66	17.97	32
34,	"	.99	"	2.73	"	4.48	"	6.21	99.37	7.94	99.06	9.65	98.69	11.36	98.27	13.05	97.78	14.73	97.24	16.39	96.64	18.03	34
36,	"	1.05	99.92	2.79	99.79	4.53	99.61	6.27	99.36	7.99	99.05	9.71	98.68	11.42	98.25	13.11	97.76	14.79	97.22	16.44	96.62	18.08	36
38,	"	1.11	"	2.85	"	4.59	99.60	6.33	99.35	8.05	99.04	9.77	98.67	11.47	98.24	13.17	97.75	14.84	97.20	16.50	96.60	18.14	38
40,	"	1.16	"	2.91	99.78	4.65	99.59	6.38	99.34	8.11	99.03	9.83	98.65	11.53	98.22	13.22	97.73	14.90	97.18	16.55	96.57	18.19	40
42,	"	1.22	99.91	2.97	"	4.71	"	6.44	99.33	8.17	99.01	9.88	98.64	11.59	98.20	13.28	97.71	14.95	97.16	16.61	96.55	18.24	42
44,	99.98	1.28	"	3.02	99.77	4.76	99.58	6.50	99.32	8.22	99.00	9.94	98.63	11.64	98.19	13.33	97.69	15.01	97.14	16.66	96.53	18.30	44
46,	"	1.34	99.90	3.08	"	4.82	99.57	6.56	99.31	8.28	98.99	10.00	98.61	11.70	98.17	13.39	97.68	15.06	97.12	16.72	96.51	18.35	46
48,	"	1.40	"	3.14	99.76	4.88	99.56	6.61	99.30	8.34	98.98	10.05	98.60	11.76	98.16	13.45	97.66	15.12	97.10	16.77	96.49	18.41	48
50,	"	1.45	"	3.20	"	4.94	"	6.67	99.29	8.40	98.97	10.11	98.58	11.81	98.14	13.50	97.64	15.17	97.08	16.83	96.47	18.46	50
52,	"	1.51	99.89	3.26	99.75	4.99	99.55	6.73	99.28	8.45	98.96	10.17	98.57	11.87	98.13	13.56	97.62	15.23	97.06	16.88	96.45	18.51	52
54,	"	1.57	"	3.31	99.74	5.05	99.54	6.78	99.27	8.51	98.94	10.22	98.56	11.93	98.11	13.61	97.61	15.28	97.04	16.94	96.42	18.57	54
56,	99.97	1.63	"	3.37	"	5.11	99.53	6.84	99.26	8.57	98.93	10.28	98.54	11.98	98.10	13.67	97.59	15.34	97.02	16.99	96.40	18.62	56
58,	"	1.69	99.88	3.43	99.73	5.17	99.52	6.90	99.25	8.63	98.92	10.34	98.53	12.04	98.08	13.73	97.57	15.40	97.00	17.05	96.38	18.68	58
60,	"	1.74	"	3.49	"	5.23	99.51	6.96	99.24	8.68	98.91	10.40	98.51	12.10	98.06	13.78	97.55	15.45	96.98	17.10	96.36	18.73	60
c — .75,	.75	.01	.75	.02	.75	.03	.75	.05	.75	.06	.75	.07	.75	.08	.74	.10	.74	.11	.74	.12	.74	.14	c — .75
c — 1.00,	1.00	.01	1.00	.03	1.00	.04	1.00	.06	1.00	.08	.99	.09	.99	.11	.99	.13	.99	.15	.99	.16	.98	.18	c — 1.00
c — 1.25,	1.25	.02	1.25	.03	1.25	.05	1.25	.08	1.25	.10	1.24	.11	1.24	.14	1.24	.16	1.23	.18	1.23	.21	1.23	.23	c — 1.25

M.	11° Hor. Dist.	11° Diff. Elev.	12° Hor. Dist.	12° Diff. Elev.	13° Hor. Dist.	13° Diff. Elev.	14° Hor. Dist.	14° Diff. Elev.	15° Hor. Dist.	15° Diff. Elev.	16° Hor. Dist.	16° Diff. Elev.	17° Hor. Dist.	17° Diff. Elev.	18° Hor. Dist.	18° Diff. Elev.	19° Hor. Dist.	19° Diff. Elev.	20° Hor. Dist.	20° Diff. Elev.	M.
0,′ . . .	96.38	13.73	95.68	20.34	94.94	21.92	94.15	23.47	93.30	25.00	92.40	26.50	91.45	27.96	90.45	29.39	89.40	30.78	88.30	32.14	. . . 0′
2, ...	96.34	13.78	95.65	20.39	94.91	21.97	94.12	23.52	93.27	25.05	92.37	26.55	91.42	28.01	90.42	29.44	89.36	30.83	88.26	32.18	. . . 2
4, ...	96.32	18.84	95.63	20.44	94.89	22.02	94.09	23.58	93.24	25.10	92.34	26.59	91.39	28.06	90.38	29.48	89.33	30.87	88.23	32.23	. . . 4
6, ...	96.29	18.89	95.61	20.50	94.86	22.08	94.07	23.63	93.21	25.15	92.31	26.64	91.35	28.10	90.35	29.53	89.29	30.92	88.19	32.27	. . . 6
8, . . .	96.27	18.95	95.58	20.55	94.84	22.13	94.04	23.68	93.18	25.20	92.28	26.69	91.32	28.15	90.31	29.58	89.26	30.97	88.15	32.32	. . . 8
10, ...	96.25	19.00	95.56	20.60	94.81	22.18	94.01	23.73	93.16	25.25	92.25	26.74	91.29	28.20	90.28	29.62	89.22	31.01	88.11	32.36	. . 10
12, ...	96.23	19.05	95.53	20.66	94.79	22.23	93.98	23.78	93.13	25.30	92.22	26.79	91.26	28.25	90.24	29.67	89.18	31.06	88.08	32.41	. . 12
14, ...	93.21	19.11	95.51	20.71	94.76	22.28	93.95	23.83	93.10	25.35	92.19	26.84	91.22	28.30	90.21	29.72	89.15	31.10	88.04	32.45	. . 14
16, ...	93.18	19.16	95.49	20.76	94.73	22.34	93.93	23.88	93.07	25.40	92.15	26.89	91.19	28.34	90.18	29.76	89.11	31.15	88.00	32.49	. . . 16
18, ...	96.16	19.21	95.46	20.81	94.71	22.39	93.90	23.93	93.04	25.45	92.12	26.94	91.16	28.39	90.14	29.81	89.08	31.19	87.96	32.54	. . 18
20, ...	96.14	19.27	95.44	20.87	94.68	22.44	93.87	23.99	93.01	25.50	92.09	26.99	91.12	28.44	90.11	29.86	89.04	31.24	87.93	32.58	. . . 20
22, ...	96.12	19.32	95.41	20.92	94.66	22.49	93.84	24.04	92.98	25.55	92.06	27.04	91.09	28.49	90.07	29.90	89.00	31.28	87.89	32.63	. . . 22
24, ...	96.09	19.38	95.39	20.97	94.63	22.54	93.81	24.09	92.95	25.60	92.03	27.09	91.06	28.54	90.04	29.95	88.96	31.33	87.85	32.67	. . 24
26, ...	96.07	19.43	95.36	21.03	94.60	22.60	93.79	24.14	92.92	25.65	92.00	27.13	91.02	28.58	90.00	30.00	88.93	31.38	87.81	32.72	. . . 26
28, ...	95.05	19.48	95.34	21.08	94.58	22.65	93.76	24.19	92.89	25.70	91.97	27.18	90.99	28.63	89.97	30.04	88.89	31.42	87.77	32.76	. . 28
30, . . .	96.03	19.54	95.32	21.13	94.55	22.70	93.73	24.24	92.86	25.75	91.93	27.23	90.96	28.68	89.93	30.09	88.86	31.47	87.74	32.80	. . . 30
32, ...	96.00	19.59	95.29	21.18	94.52	22.75	93.70	24.29	92.83	25.80	91.90	27.28	90.92	28.73	89.90	30.14	88.82	31.51	87.70	32.85	. . . 32
34, . . .	95.98	19.64	95.27	21.24	94.50	22.80	93.67	24.34	92.80	25.85	91.87	27.33	90.89	28.77	89.86	30.19	88.78	31.56	87.66	32.89	. . 34
36, ...	95.96	19.70	95.24	21.29	94.47	22.85	93.65	24.39	92.77	25.90	91.84	27.38	90.86	28.82	89.83	30.23	88.75	31.60	87.62	32.93	. . . 36
38, . . .	95.93	19.75	95.22	21.34	94.44	22.91	93.62	24.44	92.74	25.95	91.81	27.43	90.82	28.87	89.79	30.28	88.71	31.65	87.58	32.98	. . 38
40, ...	95.91	19.80	95.19	21.39	94.42	22.96	93.59	24.49	92.71	26.00	91.77	27.48	90.79	28.92	89.76	30.32	88.67	31.69	87.54	33.02	. . 40
42, ...	95.89	19.86	95.17	21.45	94.39	23.01	93.56	24.55	92.68	26.05	91.74	27.52	90.76	28.96	89.72	30.37	88.64	31.74	87.51	33.07	. . . 42
44, ...	95.86	19.91	95.14	21.50	94.36	23.06	93.53	24.60	92.65	26.10	91.71	27.57	90.72	29.01	89.69	30.41	88.60	31.78	87.47	33.11	. . . 44
46, ...	95.84	19.96	95.12	21.55	94.34	23.11	93.50	24.65	92.62	26.15	91.68	27.62	90.69	29.06	89.65	30.46	88.56	31.83	87.43	33.15	. . 46
48, ...	95.82	20.02	95.09	21.60	94.31	23.16	93.47	24.70	92.59	26.20	91.65	27.67	90.66	29.11	89.61	30.51	88.53	31.87	87.39	33.20	. . . 48
50, . . .	95.79	20.07	95.07	21.66	94.28	23.22	93.45	24.75	92.56	26.25	91.61	27.72	90.62	29.15	89.58	30.55	88.49	31.92	87.35	32.24	. . . 50
52, ...	95.77	20.12	95.04	21.71	94.26	23.27	93.42	24.80	92.53	26.30	91.58	27.77	90.59	29.20	89.54	30.60	88.45	31.96	87.31	33.28	. . 52
54, ...	95.75	20.18	95.02	21.76	94.23	23.32	93.39	24.85	92.49	26.35	91.55	27.81	90.55	29.25	89.51	30.65	88.41	32.01	87.27	33.33	. . . 54
56, ...	95.72	20.23	94.99	21.81	94.20	23.37	93.36	24.90	92.46	26.40	91.52	27.86	90.52	29.30	89.47	30.69	88.38	32.05	87.24	33.37	. . . 56
58, ...	95.70	20.28	94.97	21.87	94.17	23.42	93.33	24.95	92.43	26.45	91.43	27.91	90.48	29.34	89.44	30.74	88.34	32.09	87.20	33.41	. . 58
60, ...	95.68	20.34	94.94	21.92	94.15	23.47	93.30	25.00	92.40	26.50	91.45	27.96	90.45	29.39	89.40	30.78	88.30	32.14	87.16	33.46	. . . 60
c— .75,	.73	.15	.73	.16	.73	.17	.73	.19	.72	.20	.72	.21	.72	.23	.71	.24	.71	.25	.70	.26	c— .75
c—1.00, .	.98	.20	.93	.22	.97	.23	.97	.25	.96	.27	.86	.23	.95	.30	.95	.32	.94	.33	.94	.35	c—1.00
c—1.25, .	1.22	.25	1.22	.27	1.21	.29	1.21	.31	1.20	.34	1.20	.35	1.19	.38	1.19	.40	1.18	.42	1.17	.44	c—1.25

M.	21°		22°		23°		24°		25°		26°		27°		28°		29°		30°		M.
	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	
0′,	87.16	33.46	85.97	34.73	84.73	35.97	83.46	37.16	82.14	38.30	80.78	39.40	79.39	40.45	77.96	41.45	76.50	42.40	75.00	43.30	0′
2,	87.12	33.50	85.93	34.77	84.69	36.01	83.41	37.20	82.09	38.34	80.74	39.44	79.34	40.49	77.91	41.48	76.45	42.43	74.95	43.33	2
4,	87.08	33.54	85.89	34.82	84.65	36.05	83.37	37.23	82.05	38.38	80.69	39.47	79.30	40.52	77.86	41.52	76.40	42.46	74.90	43.36	4
6,	87.04	33.59	85.85	34.86	84.61	36.09	83.33	37.27	82.01	38.41	80.65	39.51	79.25	40.55	77.81	41.55	76.35	42.49	74.85	43.39	6
8,	87.00	33.63	85.80	34.90	84.57	36.13	83.28	37.31	81.96	38.45	80.60	39.54	79.20	40.59	77.77	41.58	76.30	42.53	74.80	43.42	8
10,	86.96	33.67	85.76	34.94	84.52	36.17	83.24	37.35	81.92	38.49	80.55	39.58	79.15	40.62	77.72	41.61	76.25	42.56	74.75	43.45	10
12,	86.92	33.72	85.72	34.98	84.48	36.21	83.20	37.39	81.87	38.53	80.51	39.61	79.11	40.66	77.67	41.65	76.20	42.59	74.70	43.47	12
14,	86.88	33.76	85.68	35.02	84.44	36.25	83.15	37.43	81.83	38.56	80.46	39.65	79.06	40.69	77.62	41.68	76.15	42.62	74.65	43.50	14
16,	86.84	33.80	85.64	35.07	84.40	36.29	83.11	37.47	81.78	38.60	80.41	39.69	79.01	40.72	77.57	41.71	76.10	42.65	74.60	43.53	16
18,	86.80	33.84	85.60	35.11	84.35	36.33	83.07	37.51	81.74	38.64	80.37	39.72	78.96	40.76	77.52	41.74	76.05	42.68	74.55	43.56	18
20,	86.77	33.89	85.56	35.15	84.31	36.37	83.02	37.54	81.69	38.67	80.32	39.76	78.92	40.79	77.48	41.77	76.00	42.71	74.49	43.59	20
22,	86.73	33.93	85.52	35.19	84.27	36.41	82.98	37.58	81.65	38.71	80.28	39.79	78.87	40.82	77.42	41.81	75.95	42.74	74.44	43.62	22
24,	86.69	33.97	85.48	35.23	84.23	36.45	82.93	37.62	81.60	38.75	80.23	39.83	78.82	40.86	77.38	41.84	75.90	42.77	74.39	43.65	24
26,	86.65	34.01	85.44	35.27	84.18	36.49	82.89	37.66	81.56	38.78	80.18	39.86	78.77	40.89	77.33	41.87	75.85	42.80	74.34	43.67	26
28,	86.61	34.06	85.40	35.31	84.14	36.53	82.85	37.70	81.51	38.82	80.14	39.90	78.73	40.92	77.28	41.90	75.80	42.83	74.29	43.70	28
30,	86.57	34.10	85.36	35.36	84.10	36.57	82.80	37.74	81.47	38.86	80.09	39.93	78.68	40.96	77.23	41.93	75.75	42.86	74.24	43.73	30
32,	86.53	34.14	85.31	35.40	84.06	36.61	82.76	37.77	81.42	38.89	80.04	39.97	78.63	40.99	77.18	41.97	75.70	42.89	74.19	43.76	32
34,	86.49	34.18	85.27	35.44	84.01	36.65	82.72	37.81	81.38	38.93	80.00	40.00	78.58	41.02	77.13	42.00	75.65	42.92	74.14	43.79	34
36,	86.45	34.23	85.23	35.48	83.97	36.69	82.67	37.85	81.33	38.97	79.95	40.04	78.54	41.06	77.09	42.03	75.60	42.95	74.09	43.82	36
38,	86.41	34.27	85.19	35.52	83.93	36.73	82.63	37.89	81.28	39.00	79.90	40.07	78.49	41.09	77.04	42.06	75.55	42.98	74.04	43.84	38
40,	86.37	34.31	85.15	35.56	83.89	36.77	82.58	37.93	81.24	39.04	79.86	40.11	78.44	41.12	76.99	42.09	75.50	43.01	73.99	43.87	40
42,	86.33	34.35	85.11	35.60	83.84	36.80	82.54	37.96	81.19	39.08	79.81	40.14	78.39	41.16	76.94	42.12	75.45	43.04	73.93	43.90	42
44,	86.29	34.40	85.07	35.64	83.80	36.84	82.49	38.00	81.15	39.11	79.76	40.18	78.34	41.19	76.89	42.15	75.40	43.07	73.88	43.93	44
46,	86.25	34.44	85.02	35.68	83.76	36.88	82.45	38.04	81.10	39.15	79.72	40.21	78.30	41.22	76.84	42.19	75.35	43.10	73.83	43.95	46
48,	86.21	34.48	84.98	35.72	83.72	36.92	82.41	38.08	81.06	39.13	79.67	40.24	78.25	41.26	76.79	42.22	75.30	43.13	73.78	43.98	48
50,	86.17	34.52	84.94	35.76	83.67	36.96	82.36	38.11	81.01	39.22	79.62	40.28	78.20	41.29	76.74	42.25	75.25	43.16	73.73	44.01	50
52,	86.13	34.57	84.90	35.80	83.63	37.00	82.32	38.15	80.97	39.26	79.58	40.31	78.15	41.32	76.69	42.28	75.20	43.18	73.68	44.04	52
54,	86.09	34.61	84.86	35.85	83.59	37.04	82.27	38.19	80.92	39.29	79.53	40.35	78.10	41.35	76.64	42.31	75.15	43.21	73.63	44.07	54
56,	86.05	34.65	84.82	35.89	83.54	37.08	82.23	38.23	80.87	39.33	79.48	40.38	78.06	41.39	76.59	42.34	75.10	43.24	73.58	44.09	56
58,	86.01	34.69	84.77	35.93	83.50	37.12	82.18	38.26	80.83	39.36	79.44	40.42	78.01	41.42	76.55	42.37	75.05	43.27	73.52	44.12	58
60,	85.97	34.73	84.73	35.97	83.46	37.16	82.14	38.30	80.78	39.40	79.39	40.45	77.96	41.45	76.50	42.40	75.00	43.30	73.47	44.15	60
c— .75,	.70	.27	.69	.29	.69	.30	.68	.31	.68	.32	.67	.33	.66	.35	.66	.36	.65	.37	.65	.38	c— .75
c—1.00,	.93	.37	.92	.38	.92	.40	.91	.41	.90	.43	.89	.45	.89	.46	.88	.48	.87	.49	.86	.51	c—1.00
c—1.25,	1.16	.46	1.15	.48	1.15	.50	1.14	.52	1.13	.54	1.12	.56	1.11	.58	1.10	.60	1.09	.62	1.08	.64	c—1.25

length of rod is required, it often happens that the bottom is covered by tall grass, brush, or a rise in the ground—in such cases the rodman must raise it off the ground and rest it on his knee, hip or perhaps shoulder, holding as steadily as possible, or he may stand upon any elevated object near by, if it does not sensibly affect either coördinate.

Portions of the rod are sometimes covered by overhanging limbs, in which case the observer must find two spots of rod which the upper and lower wires cover, and read both. If he cannot see any foot marks he may take the fractional readings, and by having the rod "waved"—moved out or raised slowly—may then be able to determine the units.

Other Forms of Instruments for Stadia Measurements.

128. Another form, based upon the same principle of similar triangles, and the additional principle that the angle between two intersecting lines remains constant, whilst the lines revolve about an axis, is known as ECKHOLD'S TELEMETER, OR STADIA.

In this instrument, an index or vernier arm is clamped to the horizontal axis of the telescope, which has the ordinary diaphragm of one vertical and one horizontal wire. The rod has only two marks on it at a constant distance apart, corresponding to the scale over which the vernier moves. Distances are obtained by sighting to the lower mark and reading; then to the upper, and reading; taking the difference and multiplying by a constant for the result. The zero of the scales is marked when the telescope is level, so that the instrument gives vertical angles at the same time with the distance.

As this involves two separate readings, and as the marks on the rod must always be visible, it is not so convenient as the Porro form, previously described.

129. Still another form consists in the use of *moveable micrometer eye pieces*, in which the number of revolutions of the micrometer in moving a wire to cover a constant space on the rod is made to give the distance, as in the filar micrometer.

130. THE GRADIENTER, (Fig. 31) a modification of the last two forms, consists of a micrometer wheel (without the wires) attached to a screw which moves an index arm clamped to the axis of the telescope. By counting the revolutions of the wheel, the angle

through which the telescope has been moved is obtained, and hence the distance and height.

The screw upon which the wheel revolves must be cut very carefully and with a constant pitch, and the value of each turn must be determined for every instrument.

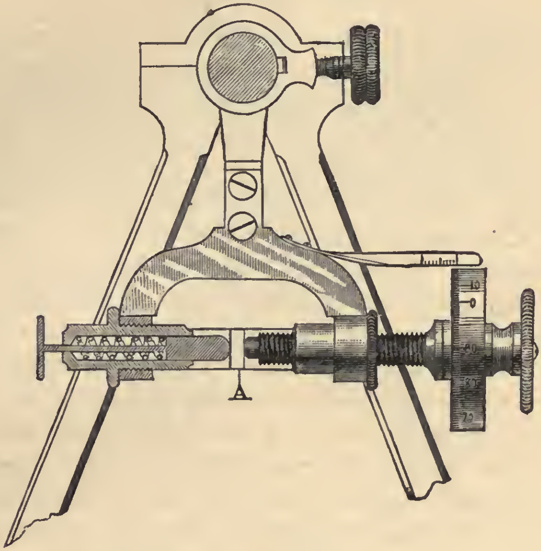


FIG. 31.

To assist in counting the revolutions, a small scale is attached to the standards of the transit, and so graduated that one division corresponds to one revolution of the wheel. The screw pitch is usually such that one turn moves the horizontal wire over $\frac{1}{2}$ of a foot of space at a distance of 100 feet, and as there are then 50 divisions on the wheel, one of these would be $\frac{1}{100}$ of a foot on the rod, equivalent to one foot of horizontal distance. Some micrometer heads are graduated in 100 parts. To determine the distance to the rod in any position, read the micrometer wheel after setting it upon some convenient unit of the rod, as 3 feet, then turn the wheel some integral number of times, preferably two, since two revolutions cover one foot at a distance of 100 feet. The second reading is then taken on the rod, and their difference multiplied by 100 will give the required distance. If in this case, the second rod reading were 5.62, the result would be 262 feet. The gradientor is, in fact, a combined transit level and stadia, and may be used by a party of only two persons with great economy in preliminary surveys. It is subject to precisely the same corrections* for elevation in topography as the stadia.

THE PLANE TABLE.

131. Although much has already been written on this instrument, describing its uses and adjustments, the introduction of stadia wires in the telescope have so greatly modified this practice as to render a few words on the subject appropriate.

The principal parts of the instrument are the board, tripod head and legs, and alidade. The board B (Pl. 10, Fig. 1) is composed of thoroughly seasoned pine, framed together so as to prevent shrinkage and warping. It is usually made two feet square, but sometimes oblong, 24×30 inches. It is connected with the tripod by a long and stiff spindle, which projects from the disc C, Fig. 2, to which it is attached by the screws D. The levelling is accomplished by means of the parallel plates H and K and levelling screws I, as in any transit. J is the socket of the shifting plate. The clamp and tangent screw are seen at E and G respectively. The legs are short and stout, with foot brackets near the ends to press them firmly into the ground. The alidade contains an inverting lens of high power, the ordinary vertical arc, attached, level and clamp, but it is mounted on a single standard which serves as a handle. In the top of the standard a small level is placed to check any settlement of the table. The most improved alidades have a movable edge, N, attached, as in the parallel ruler, thus saving some time in pointing the instrument. The cross levels and declinator or compass are shown at S and R. This is the form constructed by Messrs. Heller & Brightly, of Philadelphia, Pa.

To Set Up and Orient the Plane Table.

132. There is probably no instrument in the ordinary list used by engineers which it is more difficult for the beginner to "set up," in consequence of the eccentricity of the point at which his station falls on the sheet.

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*Tables for these corrections may also be found in the admirable catalogue of Messrs. Buff & Berger, No. 9 Province Court, Boston, Mass.

PLATE 10.

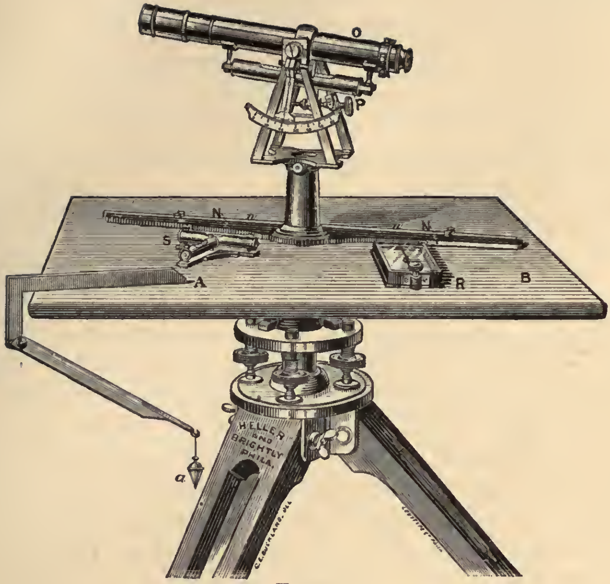

FIG. 1.

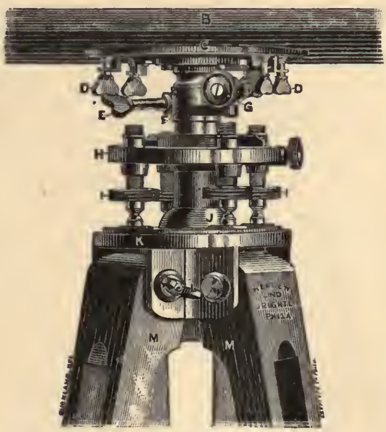

FIG. 2.

THE PLANE TABLE.

The general case which presents itself is that in which there is given a point on the table to be placed over its counterpart in the field, and a line of direction on the table to be brought into coincidence with a corresponding line of the survey. This latter operation is called "orienting."

1st. The tripod legs should be spread and clamped so rigidly that the entire table may be raised from the ground without their collapsing.

2d. Having assembled the board and paper with tripod head and legs, turn the board, before levelling, approximately in the direction of the line of orientation.

3d. See whether the station point *A* on table comes over the point *a* on the ground. This is best done by holding a fine plumb bob string in front of the eye and sighting to the points *a* and *A*, the string and eye forming a visual vertical plane. *A* may be 3 inches to the right of *a*; sight again, assuming a new position 90° from the first; the two points will probably not cover. Shift the entire table by lifting it bodily, so as to bring *A* nearer the vertical through *a*; level approximately, by eye, by pressing on the legs; orient again, approximately, and test for station point as before. If within an inch either way, the final adjustment may be made by moving the legs slightly and pressing them *firmly* into the ground, and by moving the sliding plate of the tripod head.

4th. Place the spirit levels S on the table over the screws and level accurately, testing levels by reversion.

5th. Place the edge of the alidade carefully on the line and sight through the telescope (turning the table, if necessary) to some point, P; on the line in the field.

6th. Clamp, and adjust by the tangent screw of the tripod head.

The observer should now take some shots to conspicuous permanent objects in different directions as checks, and he is ready for topography.

To Set Up on the Magnetic Meridian.

133. This may be done as before by simply placing *A* over *a*, without orienting on a given line, and after leveling and clamping in any position, place the declinator or needle-box on the table, north end towards the north, so that one edge passes through *A*; revolve the box gently to right or left, keeping its edge on *A*

until the needle settles at 0°, and draw a fine line along the edge through A for the meridian—or; *if the direction of the meridian has been assumed*, the declinator must be placed on that line, and the table must be unclamped and oriented, as in the first case, until the needle settles at zero, or north.

134. Aside from its great utility in locating contours, the stadia simplifies the problem of *finding the position of a new station with reference to other known points of a survey.*

Let any point P, be selected in the field as a good one from which to continue work. To find its position p, on the sheet, drive in a stake and level the table over it without reference to where p may fall, but simply to serve as a support for the stadia. Read the distance to two or more known points, and plot these distances *from* the position of those points on the table; the intersection of the arcs described with these radii will give p, then set up as in the first case.

If only one side of a tract, or any line of it be given, a point may be found by this method, with reference to this line, as a base.

Practical Suggestions in using the Plane Table.

135. The board should be placed so low as to be readily reached, even at the most remote corner, and yet high enough to enable the observer to take sights with comfort. This will bring it a little above the elbow.

Care must be taken that no part of the body touch or rest against the edge of the board. In using the alidade, steady the standard with the left hand while the right swings the rear end of the ruler in the proper direction.

Thumb-tacks and rollers for holding down the sheet are both found objectionable, especially in high winds. The edges may be pasted underneath, or spring clamps may be used to advantage.

A scale graduated upon the fiducial edge of the alidade is inconvenient, and in some positions impracticable and wasteful of time. A detached triangular box-wood or metal scale is greatly to be preferred.

Umbrellas or shades, whilst a great relief to the eyes, are cumbersome and troublesome, and by blowing over on the table may cause damage or derangement. Colored glasses screening the

PLATE 11.

TRANSIT.

As made by Buft and Berger, 9 Province Court, Boston, Mass.

eyes will be better, and by using tinted paper, as manilla instead of white, still more relief is given, and the sheet can be kept cleaner.

Before leaving a station, and at any interval not otherwise employed, the "check" shots should be tested to determine any displacement of the board.

Use as hard a pencil, and make as few lines, as possible. In locating points of contours, plot the distance at once along the edge of ruler by detached scale, making only a dot at the point which should receive the number of the contour.

Objects on a straight line may be quickly located by plotting the ends and determining the intermediate points by intersecting shots.

THE TRANSIT.

136. This instrument, with its attachments, may be made to do almost universal service as a transit, level, stadia, altitude and azimuth instrument, repeating circle, solar transit, gradienter, etc. So great have been the improvements of late that a brief reference to them becomes necessary. On the transit in Plate 11 is shown a shifting plate tripod head, a full vertical circle 5″ diameter reading to minutes, and a micrometer screw which may be used either for leveling, stadia-readings, or grades.

In addition to these, the new instruments of Messrs. Heller & Brightly are so constructed as to avoid the clamping of the horizontal limb and vernier plates together at the circumference. This clamp, like that for the lower limb, is transferred to the spindle. The makers have also shifted the position of the verniers to enable them to be read without change of position, by placing them directly under the axis of the telescope, in such a manner as not to interfere with its reversal.

137. Various quick leveling devices have been introduced to save time. That of Messrs. Gurley, shown in Fig. 32, consists of two hollow concave balls and sockets, clamped together by the ordinary leveling screws. That of Mr. Hoffman (not illustrated) is somewhat similar to the above, but inverted, being convex, and dispensing with the spiral springs.

138. Another ingenious arrangement is the improvement of Mr. G. N. Sægmuller, as made by Messrs. Fauth & Co., of Washing-

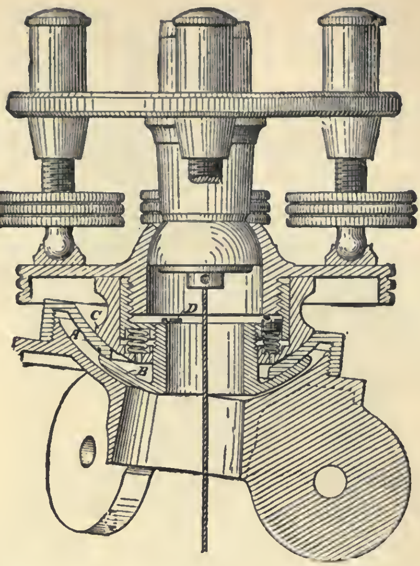

FIG. 32.—GURLEY'S TRIPOD HEAD.

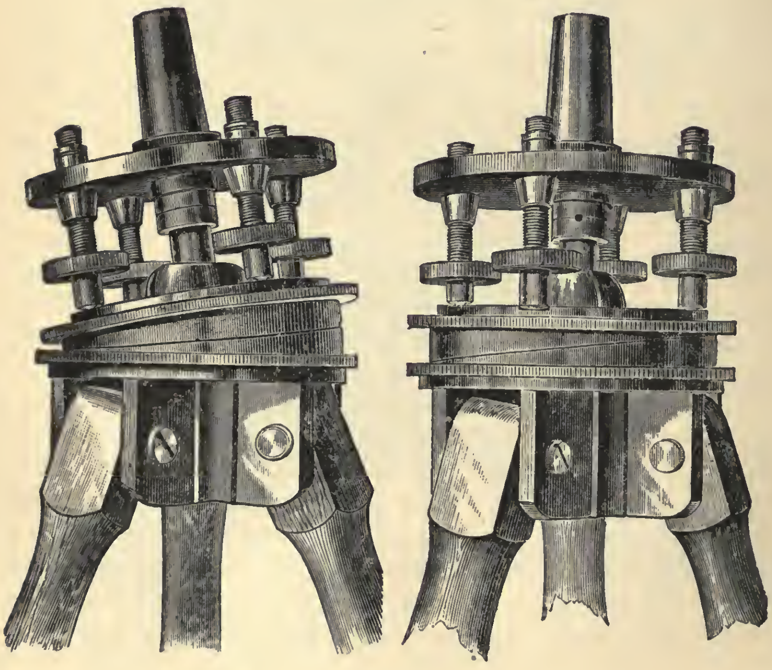

FIG. 33.

ton, D. C., consisting of two inclined circular discs, as shown in Fig. 33, interposed between the levelling-screws and tripod-head proper. By turning one or the other of them around their common centre the instrument can gradually be brought to a vertical position. The final levelling touches are given by means of the usual levelling-screws, which at the same time clamp the instrument firmly. *The great advantage of this quick-levelling tripod over other forms is that the instrument will not fall over even if it is not clamped, and no accident on this account can occur.**

There are also various important improvements on the solar attachments, a few of which will be described in the following sections.

CHAPTER VIII.

TO DETERMINE THE TRUE MERIDIAN.

139. As the magnetic pole is so unstable in its position, it is earnestly recommended, whenever possible, that all survey lines should be referred to a true meridian by means of traversing, thus removing many causes of error, and the trouble arising therefrom. This may be accomplished by turning off angles by means of a transit from an established meridian, found either by observations on the sun by day, as with a "solar transit," or on a star by night. Either of these methods involves an elementary knowledge of a few astronomical coördinates and definitions, which will now be given.

140. Whether the observations be made by day or night, the relative positions of the sun, or star and observer must be known. These are usually expressed in degrees of arc of the celestial and terrestrial spheres; thus the coördinates of the sun are given in what are known as the *hour angle* and *declination;* of the star, in its *altitude* and *azimuth*, and of the observer, in his *latitude* and *longitude*. The relations of these arcs will be better understood by reference to Plate II., in connection with the following descriptions.

METHOD BY OBSERVATIONS ON A CIRCUMPOLAR STAR.

141. The *celestial sphere* is that imaginary surface upon which all celestial objects are projected. Its radius is infinite.

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* It can be attached to any transit or levelling instrument. Price, $10.

The *earth's axis* is the imaginary line about which it revolves

The *poles* are the points in which the axis pierces the surface of the earth, or of the celestial sphere.

The *equator* is that great circle of the earth which is perpendicular to the axis.

A *meridian* is a great circle of the earth, cut out by a plane passing through the axis. All meridians are therefore north and south lines passing through the poles, and perpendicular to the equator.

From this definition it follows that if there were a star exactly at the pole it would only be necessary to set up an instrument and take a bearing to it for the meridian. Such not being the case, however, we are obliged to take some one of the near circumpolar stars as our object, and correct the observation according to its angular distance from the meridian at the time of observation.

For convenience, the bright star known as α Ursæ Minoris or Polaris, is generally selected. This star apparently revolves about the north pole, in an orbit whose mean radius is $1° 19' 13''$,* making the revolution in 23 hours, 56 minutes. During this time it must therefore cross the meridian twice, once above the pole and once below; the former is called the *upper* and the latter the *lower meridian transit or culmination*. It must also pass through the points farthest east and west from the meridian. The former is called the *eastern elongation*, the latter the *western*.

An observation may be made upon Polaris at any of these four points, or at any other point of its orbit; but this latter case becomes too complicated for ordinary practice, and is therefore not considered.

142. If the observation were made upon the star at the time of its upper or lower culmination, it would give the true meridian at once; but this involves a knowledge of the true local time of transit, or the longitude of the place of observation, which is generally an unknown quantity; and moreover, as the star is then moving east or west, or at right angles to the place of the meridian at the rate of 15° of arc in about one hour, an error of so slight a

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* This is the codeclination, as given in the Nautical Almanac. The mean value decreases by about 20 seconds each year.

quantity as only one minute (1′) of time, would introduce an error of 2¼ minutes of arc. If the observation be made, however, upon either elongation, when the star is moving up or down, that is, in the direction of the vertical wire of the instrument, the error of observation in the angle between it and the pole will be inappreciable. This is therefore the best position upon which to make the observation, as the precise time of the elongation need not be given. It can be determined with sufficient accuracy by a glance at the relative positions of the star Alioth, in the handle of the dipper, and Polaris. See Fig. 34. When the line joining these two stars is horizontal, or nearly so, and Alioth is to the *west* of Polaris, the latter is at its *eastern* elongation, and *vice versa*, thus:

FIG. 34.

FIG. 35.

But since the star at either elongation is off the meridian, it will be necessary to determine the angle at the place of observation to be turned off on the instrument to bring it into the meridian. This angle, called the

AZIMUTH OF THE POLE STAR,

varies with the latitude of the observer, as will appear from Fig. 35, and hence its value must be computed for different latitudes, and the surveyor must know his *latitude* before he can apply it. Let N be the north pole of the celestial sphere; S, the position of Polaris at its eastern elongation; then N S = 1° 19′ 13″, a constant quantity. The azimuth of Polaris at the latitude 40°

north, is represented by the angle N O S, and that at 60° north by the angle N O′ S, which is greater, being an exterior angle of the triangle O S O′. From this we see that the azimuth varies as the latitude.

143. We have first, then, to FIND THE LATITUDE OF THE PLACE OF OBSERVATION. See also Plate 12.

Of the several methods for doing this, we shall select the simplest, preceding it by a few definitions.

A *normal* line is the one joining the point directly overhead, called the *zenith*, with the one under foot, called the *nadir*.

The *celestial horizon* is the intersection of the celestial sphere by a plane passing through the centre of the earth, and perpendicular to the normal.

A *vertical circle* is one whose plane is perpendicular to the horizon, hence all such circles must pass through the zenith and nadir points.

The ALTITUDE of a celestial object is its distance above the horizon measured on the arc of a vertical circle. As the distance from the horizon to the zenith is 90°, the difference, or *complement* of the altitude, is called the *zenith distance*, or *co-altitude*.

The AZIMUTH of an object is the angle between the vertical plane through the object and the plane of the meridian, measured on the horizon, and usually read from the south point, as 0°, through west, at 90°, north 180°, etc., closing on south at 0° or 360°.

These two co-ordinates, the altitude and azimuth, will determine the position of any object with reference to the observer's place. The latter's position is usually given by his latitude and longitude referred to the equator and some standard meridian as co-ordinates.

The LATITUDE is the angular distance north or south of the equator, and the LONGITUDE east or west of the assumed meridian.

We are now prepared to prove that *the altitude of the pole is equal to the latitude of the place of observation.*

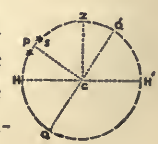


FIG. 36.

Let HPZQ′, etc., Fig. 36, represent a meridian section of the sphere in which P is the north pole and Z the place of observation, then HH′ will be the horizon, QQ′ the equator, HP will be the altitude of P, and Q′Z the latitude of Z. These two arcs are equal, for HCZ = PCQ′ = 90°, and if from these equal quadrants the common angle PCZ be subtracted, the remainders, HCP and ZC′Q will be equal.

144. To *determine the altitude of the pole*, or in other words, *the latitude of the place.*

Observe the altitude of the pole star *when on the meridian*, either above or below the pole, and from this observed altitude corrected for refraction, subtract the distance of the star from the pole, or its *polar distance*, if it was an upper transit, or add it if a lower. The result will be the required latitude with sufficient accuracy for ordinary purposes.

The time of the star's being on the meridian can be determined with sufficient accuracy by a mere inspection of the heavens. The refraction is *always negative*, and may be taken from the table appended by looking up the amount set opposite the observed altitude. Thus, if the observed altitude should be 40° 39′, the nearest refraction 01′ 07″, should be subtracted from 40° 39′ 00″, leaving 40° 37′ 53″ for the corrected altitude. From this remainder subtract the co-declination for an upper transit, or add it for a lower, and the result will be the required latitude.

TO FIND THE AZIMUTH OF POLARIS.

145. As we have shown the azimuth of Polaris to be a function of the latitude, and as the latitude is now known, we may proceed to find the required azimuth. For this purpose we have a right-angled spherical triangle, ZSP,* Fig. 37, in which Z is the place of observation, P the north pole, and S is Polaris. In this triangle we have given, the polar distance PS = 1° 16′ 23″; † the angle at S = 90°; and the distance ZP, being the complement of the latitude as found above, or (90°—L). Substituting these in the formula for the azimuth, we will have sin. Z $= \frac{\text{sin. PS}}{\text{sin. PZ}}$, or $\frac{\text{sin. of polar distance}}{\text{sin. of co-latitude}}$, from which, by assuming different values for the co-latitude, we compute the following table:

FIG. 37.

* Since the vertical plane ZS is tangent to the orbit of Polaris, the lines ZS and radius PS will be at right angles to each other.

† For 1891, and it decreases by 56″ every three years.

146. AZIMUTH TABLE FOR POINTS BETWEEN 26 AND 50 DEGREES OF LATITUDE.

Y'r.	26°	28°	30°	32°	34°	36°	38°	40°	42°	44°	46°	48°	50°
	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″
1892	1 24 36	1 26 12	1 27 48	1 29 42	1 31 48	1 34 00	1 36 30	1 39 18	1 42 24	1 45 48	1 49 30	1 53 42	1 58 24
1893	16	25 48	30	18	24	33 36	06	38 54	00	18	00	20	57 54
1894	23 54	24	10	00	00	12	35 42	30	41 30	44 54	48 36	52 48	24
1895	36	06	26 48	28 36	30 36	32 54	18	06	06	24	12	18	56 54
1896	16	24 50	26	04	18	32	34 56	37 42	40 42	03	47 45	51 50	26
1897	22 56	25	03	27 54	29 54	07	35	18	18	43 36	17	22	55 58
1898	36	04	25 42	31	32	31 44	11	36 54	39 51	11	46 51	50 56	28
1899	13	23 40	20	09	10	21	33 47	24	28	42 46	24	27	54 57
1900	21 53	20	24 58	26 46	28 46	30 56	23	04	01	18	45 57	49 59	29
1901	31	22 59	37	24	23	34	32 58	35 39	38 36	41 52	28	30	00
1902	10	38	16	02	00	10	35	14	12	25	02	02	53 30
1903	20 49	18	23 52	25 39	27 36	29 47	11	34 49	37 45	40 59	44 34	48 34	00
1904	27	21 54	30	18	14	23	31 46	24	19	32	06	05	52 31

An analysis of this table shows that the azimuth for the year 1892 increases with the latitude from 1° 24′ 36″ at 26°, to 1° 58′ 24″ at 50 degrees. It also shows that the azimuth of Polaris at any one point of observation decreases slightly from year to year. This is due to the increase in declination or decrease in the star's polar distance. At 26° north latitude this annual decrease in the azimuth is about 22 seconds, while at 50° north it is about 30″. As the variation in azimuth for each degree of latitude is small, the table is only computed for the even numbered degrees, the intermediate values being obtained by interpolation. We see also that an error of a few minutes of latitude will not affect the result in finding the meridian, *e. g.:* the azimuth at 40° north latitude is 1° 39′ 18″, that at 41° would be 1° 40′ 53″, the difference (01′ 35″) being the correction for one degree of latitude between 40° and 41°. Or in other words, an error of one degree in finding one's latitude would only introduce an error in the azimuth of one and a half minutes. With ordinary care, the probable error of the latitude as determined from the method already described need not exceed a few minutes, making the error in azimuth as laid off on the arc of an ordinary transit graduated to single minutes, practically zero.

In the following table the refractions are given for every degree of altitude within the limits of the United States. For low altitudes the refraction is very variable, and hence should not be used. As the altitude approaches the zenith, the refractions diminish rapidly to zero. For altitudes not given in the table the proper value may be determined by interpolation.

147. MEAN REFRACTION TABLE FOR TEMPERATURE 50°; PRESSURE 29.6 INCHES.

ALTITUDE.	REFRACTION.	ALTITUDE.	REFRACTION.	ALTITUDE.	REFRACTION.
1°	24′ 29″	15°	3′ 30″	35°	1′ 21″
2	18 35	16	3 17	40	1 08
3	14 36	17	3 04	45	0 57
4	11 51	18	2 54	50	0 48
5	9 54	19	2 44	55	0 40
6	8 28	20	2 35	60	0 33
7	7 20	21	2 27	65	0 26
8	6 29	22	2 20	70	0 21
9	5 48	23	2 14	75	0 15
10	5 15	24	2 08	80	0 10
11	4 47	25	2 02	85	0 06
12	4 23	27	1 51	90	0 00
13	4 03	29	1 42		
14	3 45	31	1 38		

APPLICATIONS.

148. In practice, to find the true meridian, two observations must be made at intervals of six hours, or they may be made upon different nights. The first is for latitude, the second for azimuth at elongation.

To make either, the surveyor should provide himself with a good transit having a vertical circle, a bull's eye or hand lantern, plumb-bobs, stakes, etc.* Having "set up" over the point through which it is proposed to establish the meridian, at a time when the line joining Polaris and Alioth is nearly vertical, level the telescope by means of the attached level, which should be in adjustment; set the vernier of the vertical arc at zero, and take the reading. If the pole star is about making its *upper* transit, it will rise gradually until reaching the meridian as it moves westward, and then as gradually descend. When near the highest part of its orbit, point the telescope at the star, having an assistant to hold the "bull's eye" so as to reflect enough light down the tube from the object-end to illumine the cross wires, but not to obscure the star; or better use a perforated silvered reflector, clamp the tube in this position, and as the star continues to rise keep the *horizontal* wire upon it by means of the tangent screw

* A sextant and artificial horizon may be used to find the *altitude* of a star. In this case the observed angle must be divided by 2.

until it "rides" along this wire and finally begins to fall below it. Take the reading of the vertical arc, and the result will be the observed altitude.

ANOTHER METHOD.

149. It is a little more accurate to find the altitude by taking the complement of the observed zenith distance, if the vertical arc has sufficient range. This is done by pointing first to Polaris when at its highest (or lowest) point, reading the vertical arc, turning the horizontal limb half way around, and the telescope over to get another reading on the star, when the difference of the two readings will be the *double* zenith distance, and *half* of this subtracted from 90° will be the required altitude. The less the time intervening between these two pointings, the more accurate the result will be.

Having now found the altitude, correct it for refraction by subtracting from it the amount opposite the observed altitude as given in the Refraction Table, and add or subtract the co-declination of the star as given by the Nautical Almanac, according as it a lower or upper transit, and the result will be the latitude. The observer must now wait about six hours until the star is at its western elongation, or may postpone further operations for some subsequent night. In the meantime he will take from the azimuth table the amount given for his date and latitude, now determined, and if his observation is to be made on the western elongation, he may turn it off on his instrument so that when moved to zero, *after* the observation, the telescope will be brought into the meridian or turned to the right, and a stake set by means of a lantern or plummet lamp.

It is, of course, unnecessary to make this correction at the time of observation, for the angle between any terrestrial object and the star may be read and the correction for the azimuth of the star applied at the surveyor's convenience. It is always well to check the accuracy of the work by an observation upon the other elongation before putting in permanent meridian marks, and care should be taken that they are not placed near any local attractions. The meridian having been established, the magnetic variation or declination may readily be found by setting an instrument on the meridian and noting its bearing as given by the nee dle. If, for example, it should be north 5° *east*, the variation is west, because the north end of the needle is *west* of the meridian, and *vice versa*.

150. *Local time* may also be readily found by observing the instant when the sun's centre* crosses the line and correcting it for the equation of time as given below—the result is the true or mean solar time. This compared with the clock will show the error of the latter, and by taking the difference between the local time of this and any other place, the difference of longitude is determined in hours, which can readily be reduced to degrees by multiplying by fifteen (15) as $1^h = 15°$.

151. APPROXIMATE EQ. OF TIME.

Date.	Minutes.	Date.	Minutes.	Date.	Minutes.	Date.	Minutes.
Jan. 1	4 Clock faster than sun.	April 1	4 Faster.	Aug. 9	5 Faster.	Oct. 27	16 Clock slower than sun.
3	5	4	3	15	4	Nov. 15	15
5	6	7	2	20	3	20	14
7	7	11	1	24	2	24	13
9	8	15	0	28	1	27	12
12	9			31	0	30	11
15	10	19	1 Clock slower.			Dec. 2	10
18	11	24	2	Sept. 3	1 Clock slower.	5	9
21	12	30	3	6	2	7	8
25	13	May 13	4	9	3	9	7
31	14	29	3	12	4	11	6
Feb. 10	15	June 5	2	15	5	13	5
21	14	10	1	18	6	16	4
27	13	15	0	21	7	18	3
Mch. 4	12			24	8	20	2
8	11	20	1 Clock faster.	27	9	22	1
12	10	25	2	30	10	24	0
15	9	29	3	Oct. 3	11		
19	8	July 5	4	6	12	26	1 Faster.
22	7	11	5	10	13	28	2
25	6	28	6	14	14	30	3
28	5			19	15		

METHOD BY SOLAR TRANSIT.

152. In the U. S. Government Surveys of public lands, where the bounding lines are meridians and parallels, it was found necessary to have recourse to a method more frequently available than that just described, and this want led to the invention by Wm. A. Burt, in 1836, of the solar compass, upon which various modifications have since been made for improving its accuracy

* To obtain this time by observation note the instant of first contact of the sun's limb and also of last contact of same, and take the mean.

and efficiency, until at present it has assumed, among others, the from shown in Plate 12, in which EE′ is the equator, NP the north pole, NS the horizon, Z the zenith, N the nadir, and NE′E the principal meridian through the place of observation.

153. The *hour angle* is only another name for longitude. It is generally reckoned in hours and minutes from Greenwich west, instead of in degrees—24 hours or one revolution = 360°; hence 1 h. = 15°, 1 m. = 15′, and 1 sec. = 15″ of arc.

The *declination* of a heavenly body is its distance north or south of the equator measured on the arc of a meridian passing through it. It is the complement of its polar distance.

In the solar transit of Plate 12* this arc is represented by the meridian marked "declination," and the hour circle by the equator. It is, in fact, a miniature globe, in which the co-ordinate planes of either celestial or terrestrial bodies are represented and made to occupy their proper relative positions in space. To use it the positions of the sun and of the observer must be known.

The latter is given by the latitude determined as in § 143, and the longitude is given by the watch or mean solar time; the former's position is taken from a nautical almanac or ephemeris, for the day and hour. But since the declination is affected by the refraction due to altitude, this latter quantity must also be determined and applied.

The MERIDIAN ALTITUDE of a celestial body is its distance from the horizon, measured on a vertical circle, and is, therefore, equal to the polar distance or co-latitude of the place of observation plus or minus the declination, according as they have the same or different names; thus,

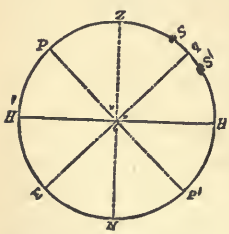


FIG. 38.—MERIDIAN SECTION OF CELESTIAL SPHERE.

HS = Altitude.

qS = Declination.

Hq = ZP = co-latitude or polar distance of Z.

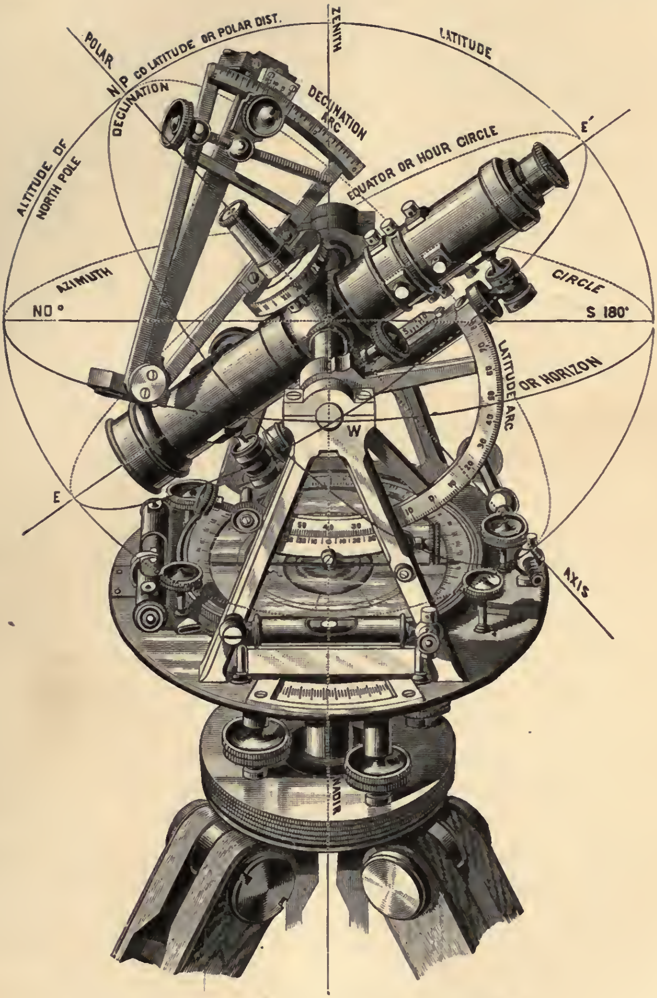
HS, the altitude, is therefore equal to Hq (co-latitude) + qS (the declination).

Z is the zenith of the place of observation.

Should S be at S′, the altitude would then be HS′ = Hq, the co-latitude, — qS′, the declination.

* This plate was designed by the author for this work, in 1883, and furnished to Messrs. Gurley, of Troy. It has been extensively copied in other publications.

PLATE 12.



SOLAR TRANSIT, WITH CIRCLES OF SPHERES.

AS MADE BY

W. & L. E. GURLEY, OF TROY, N. Y.

154. Thus knowing the latitude of the place, its complement, ± the apparent declination, will give the required altitude, the refraction corresponding to which is found from the table § 147 by interpolation. The apparent declination is then corrected for the refraction thus found, and by adding or subtracting the hourly change in declination as given in the Nautical Almanac, a table is formed for the various hours in the day, by which the declination arc is set.

155. The latitude arc is also set to the latitude of the place, and the hour circle to the time of day. Then, by turning the instrument (in azimuth) around its vertical axis until the sun's image falls upon the silvered plate at right angles to the plane of the declination arc, the telescope will be in the meridian and the various circles of the instrument will be paralled to their prototypes in the sphere. The following example will further illustrate these principles.

156. TO DETERMINE THE DECLINATION AT DIFFERENT HOURS OF THE DAY FROM THAT GIVEN IN THE ALMANAC FOR GREENWICH APPARENT NOON.—If the observer is west of the Greenwich meridian, his LOCAL time will be as many hours EARLIER as he is hours WEST, and *vice versa.* As 15° of arc = 1 hour of time, or 15′ = 1 m., at Philadelphia, which is 75° 10′ *W.* Long., the local time corresponding to Greenwich noon will be 5 h. 0.66⅔ m. earlier, or 6 o'clock 59⅓ minutes—say 7 a. m. The sun's declination is, therefore, the same at Philadelphia at 7 a. m. as at Greenwich at noon, for any day of the year. AFTER CORRECTING FOR REFRACTION, by adding his "hourly change in declination" when it is increasing, or subtracting it when decreasing, a table of his position is formed for each hour of the day and for any latitude.

TO CORRECT THE DECLINATION FOR MERIDIONAL REFRACTION.* To the co-latitude ADD the tabular declination WHEN both are of the SAME name, for the altitude, the refraction corresponding to which is given in § 147. THIS REFRACTION MUST BE ADDED TO THE DECLINATION WHEN IT AND THE LATITUDE ARE OF THE SAME NAME, AND *vice versa.*

Having given the place of observation—University of Pennsylvania, Latitude 39° 57′ *N.*, Longitude 75° 10′ W. = 5 h. 00⅔ m. Date, March 1, 1883, when Sun's declination is SOUTH and is DECREASING.

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* This correction is a function of the hour angle and increases with it. See Chauvenet's Sph. Astronomy, Vol. I, p. 171.

90° 00′ 00″
39° 57′ 00″ (North.)

50° 03′ 00″ = Co-lat. of University.
−7° 35′ 47″ = Apparent dec. at DATE, from Nautical Almanac (S., therefore subtract).

42° 27′ 13″ = Altitude of sun. The meridian refraction corresponding to which is — 01′ 03.5″; negative because the lat. and declination have different names.

7° 35′ 47″ Tabular Declination from Nautical Almanac.
— 01′ 03.5″

7° 34′ 43.5″ = Corrected declination for noon at Greenwich, or 7 a. m. at University. As declination is decreasing, subtract for each hour the hourly change (57″) as given by almanac.

Thus, dec. at 7 a. m. = 7° 34′ 43.5″ — 57″ = 7° 33′ 46.5″ at 8 o'clock, and so on throughout the day.

Again, for the same place of observation, May 2, 1883, when sun's declination is North and increasing.

50° 03′ 00″ = Co-lat. of University.
15° 21′ 24″ = Apparent dec. (N., therefore add).

65° 24′ 24″ = Altitude of sun at date, the refraction for which is 27.2″ (+) because lat. and dec. have the same name.

15° 21′ 24″
27.2″

15° 21′ 51.2″ = Corrected declination; increasing, therefore add hourly change, 45.42″.
45.42″

15° 22′ 36.62″ = 8 a. m.—etc.

The direction of the meridian being thus found, it may be run in by back and fore sights as a straight line.

157. Plate 13 represents a new form of

SOLAR ATTACHMENT

Invented and patented by G. N. Sægmuller, May 3, 1881, which is claimed to be the simplest and most accurate yet devised. Attached to any engineer's transit, the true meridian and deviation of the needle can be readily obtained with great accuracy.

The foregoing plate represents the "Solar Attachment" fixed to an engineer's transit. It consists essentially of a small telescope and level, the telescope being mounted on standards, in which it can be elevated or depressed. The standards revolve around an axis, called the polar axis, which is fastened to the

PLATE 13.

SOLAR TRANSIT.

telescope axis of the transit instrument. The "solar telescope," can thus be moved in altitude and azimuth. It is provided with shade-glasses to subdue the glare of the sun, as well as a prism to observe with greater ease when the declination is far north. Two pointers attached to the telescope to approximately set the instrument are so adjusted that when the shadow of the one is thrown on the other the sun will appear in the field of view.

Adjustment of the Apparatus.

This is very simple, and requires even less work than to adjust the common transit.

First. Attach the "polar axis," hereafter called simply *the axis*, to the main telescope axis in the centre at right angles to the line of collimation. The base of this axis is provided with three adjusting screws for this purpose; by means of the level on the solar telescope, this condition can be readily and accurately tested.

Second. Point the transit telescope—which instrument is assumed to be in adjustment—exactly horizontal, and bisect any distant object. The transit level will then be in the middle of the scale. Make the "solar telescope" also horizontal by observing the same object, and adjust its level to read zero, for which purpose the usual adjusting-screws are provided.

Directions for Using the Attachment.

First. Take the declination of the sun as given in the Nautical Almanac for the given day, and correct it for refraction * and hourly change. Incline the *transit telescope* until this amount is indicated by its vertical arc. If the declination of the sun is north, the telescope pointing southward, depress the eye end; if south, elevate it. Without disturbing the position of the transit telescope, bring the solar telescope to a horizontal position by means of its level. The two telescopes will then form an angle which equals the amount of the declination, and the inclination of the solar telescope to its vertical axis will be equal to the polar distance of the sun.

Second. Without disturbing the *relative* positions of the two

* This correction is equal to the refraction of the sun in altitude, multiplied by the cosine of the angle at the sun between the pole and the zenith. The meridional refraction may be used as an approximation when the sun is not very near the horizon.

telescopes, incline them and set the vernier to the co-latitude of the place.

By simultaneously moving the transit around its vertical axis, and the "Solar Attachment" around its polar axis, the image of the sun will be brought into the field of the solar telescope, and after accurately bisecting it, the *transit telescope must be in the meridian, and the compass-needle indicates its deviation at that place.*

The axis of the "Solar Attachment" will then point to the pole, the apparatus being, in fact, a small equatorial.

TIME and AZIMUTH are calculated from an observed altitude of the sun, by solving the spherical triangle formed by the sun, S, the pole, P, and the zenith, Z, of the place. The three sides, SP, PZ, ZS, complements respectively of the declination, latitude and altitude are given, and we hence deduce PSZ, the hour angle, from apparent noon, and PZS the azimuth of the sun.

The "Solar Attachment" solves the same spherical triangle by construction, for the second process brings *the axis* of the solar telescope to the required distance, Z P, from the zenith, while the first brings it to the required distance, S P, from the sun.

If the two telescopes, both being in position—one in the meridian and the other pointing to the sun—are now turned on their *horizontal* axes, the vertical remaining undisturbed, until each is level, the angle between their directions (found by sighting on a distant object) is SPZ, the time from apparent noon.

This gives an easy observation for correction of time-piece, etc., reliable to within a few seconds.

Advantages of this "Solar Attachment" over the old form.

First. It is more accurate.

Second. It is simpler and easier of adjustment.

Third. It can be used when the sun is partly obscured by clouds, when the ordinary "solar" fails altogether.

Fourth. It can be used with the sun quite close to the meridian.

Fifth. The time can be obtained with it reliable to within a few seconds with the greatest ease.

Sixth. It is much cheaper.

It is as superior to all forms hitherto used as the transit is to the ordinary compass, or as the telescope is to common sights. For the ordinary surveyor's compass the degree of accuracy of the old attachment will answer, although even on a compass this "Solar Attachment" would be an improvement.

When angles are laid off with a transit, however, it is certainly going back a step to attempt to establish a meridian with a less precise instrument, or one that has less pointing power.

The sights of an ordinary solar compass consist merely of a small lens and a piece of silver with lines ruled on it placed in its focus. This is simply a *very primitive* telescope, since the exact coincidence of the sun's image with the lines has to be determined by the unaided eye, or at best with a simple magnifying glass.

That far greater precision can be attained by means of a suitable telescope is apparent; in fact, the *power* of the solar telescope is in keeping with the transit telescope, as it should be.

A glance at the cut will show that the "Solar Attachment" is far simpler than the ordinary form. By raising or depressing, it can be set to north or south declination. To effect this with the ordinary solar compass *two* sets of *primitive telescopes*—one answering for north, the other for south declination—are required, which are difficult to adjust.

The addition of the level on the solar telescope dispenses with the declination arc altogether, the arc or circle on the transit also serving for that purpose in conjunction with it.

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* The above description, with some slight modifications, is from the pen of the inventor. The instrument is manufactured and for sale by Messrs. Fauth & Co., of Washington, D. C.

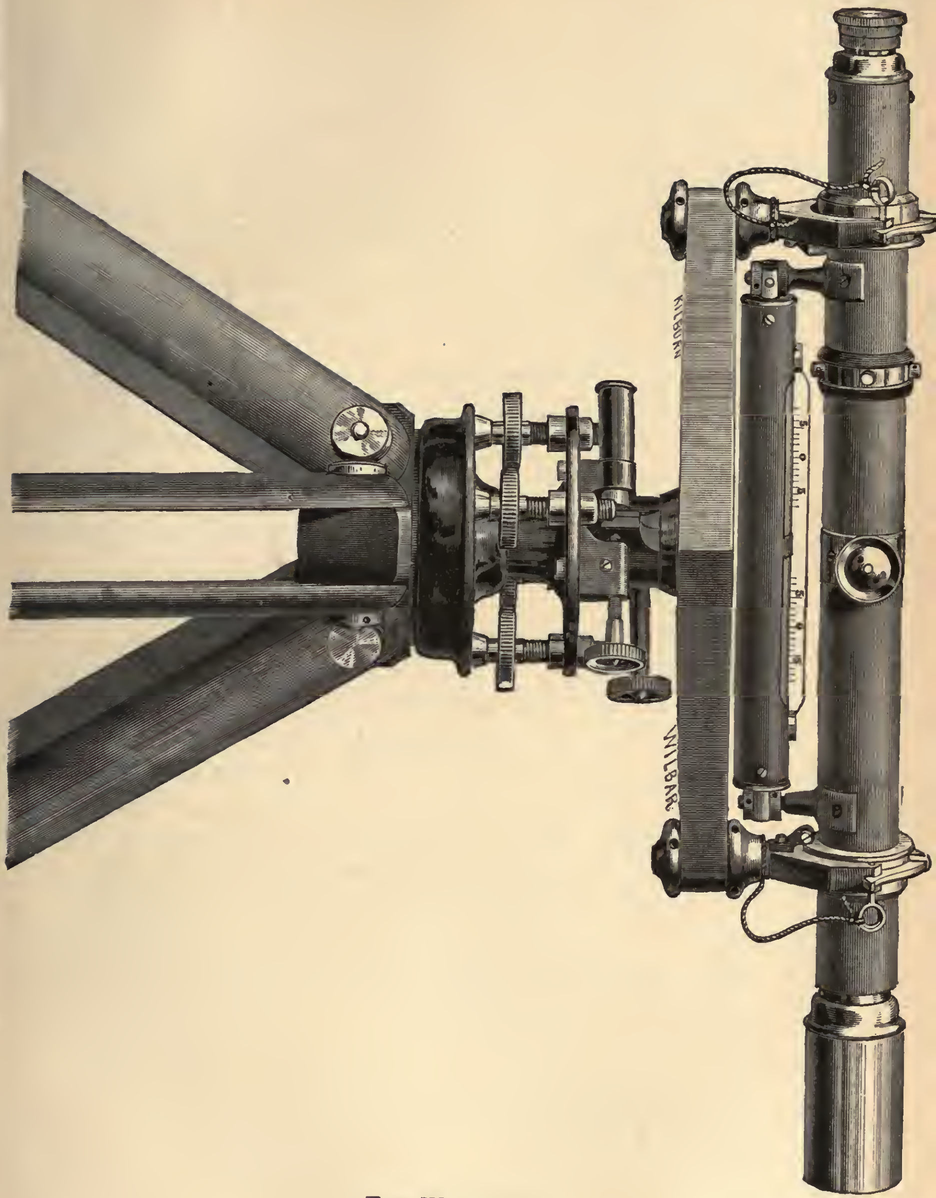
CHAPTER IX.

LEVELLING.

158. The level used is known as the *Wye* or *engineer's level.* It is the embodiment of an imaginary level plane formed by a horizontal line revolving about a vertical axis. This plane, which can be transferred from place to place, forms a temporary reference surface below which all depths to the ground are measured just as in taking soundings under water, only in the former case the rodman moves about on the lower or ground surface, and measures up to his imaginary plane, whilst in the latter he floats around in a boat and measures down. The principle is the same in both.

159. The first thing to be determined, then, after setting up a level, is the height of the plane formed by its horizontal wire and the eye. This is obtained by holding a graduated rod vertically upon a point of known height, called a bench mark (B. M.), and noting the point at which the rod is cut by the plane of sight. This rod-reading, added to height of bench, gives height of instrument (H. I.), which remains constant for that setting; and as *all* points on the ground within reach of the rod and instrument are *below* this plane, to find their elevations their rod readings must be *subtracted* from H. I. See form of notes, § 69. The vertical range of the instrument is, therefore, limited to the length of the rod, or to a zone of 12 feet depth. For points outside of this limit the level must be moved up or down hill, and before doing so a new B. M. or "peg" must be established, the height of which becomes known before the instrument is removed. In levelling down hill the rodman should extend his rod full length, and walk down the slope until the leveller calls halt as the target comes near the wire. Here a stake may be driven, or a *firm* stone, root, or other resting place be found, and its "level" taken. The instrument is then pulled up and moved down the slope so far that when set up it will cut the rod about one foot above the bottom (to avoid the clamp), and a back sight is taken. No difficulty *can*

PLATE 14.



THE WYE LEVEL.

arise in levelling if it be remembered that *the first sight after setting up is a back sight, and that it is always +. It must be added to height of peg or B. M., for H. I., from which* ALL *subsequent readings at that setting are to be deducted for elevations, referred to the datum plane.*

The relative levels of two or more points may be obtained by taking the difference of their elevations.

The accuracy attainable will vary according to the ground, instruments, care, weather, personal equation, etc., and every leveller should make his own limit. In some instances it has been as low as $\frac{1}{10}$ of a foot in 50 miles.

160. The sources of error are thus summarized by Lewis D'A. Jackson in his AID TO SURVEY-PRACTICE, London, 1880:

1. Unsteadiness of the stand, and dislevelment by wind or accidental motion.

2. Looseness of any attachment of the instrument, or of any screw not firmly set.

3. Settlement of the stand in the soil, or of any part of the instrument.

4. Dislevelment by the sun from unequal expansion during reading the sight.

5. Want of instrumental adjustment.

(*A.*) Focus error or parallax.

(*B.*) Collimation error.

(*C.*) Level error.

6. Want of correction for curvature of the earth.

7. Result of atmospheric effect on the visual ray.

(*A.*) Refraction under the varying conditions.

(*B.*) Reflex refractive action.

(*C.*) Apparent depression of the distant point.

8. In connection with level staves.

(*A.*) Unequal or unusually graduated staves.

(*B.*) Want of verticality.

(*C.*) Lateral and vertical motion at changing points.

9. Inexactitude of datum or bench mark used.

10. Personal errors:

(*A.*) In instrumental manipulation.

(*B.*) In bubble reading.

(*C.*) In staff reading.

(*D.*) From visual defects.

(*E.*) Simple mistakes from misconception.

161. *Corresponding Remedies.*

1. A heavy, firm stand, permanently attached to the lower part of the instrument.

2. A well-made instrument; a thorough knowledge of it, its peculiarities and defects; care in removing and transporting it; repeated careful examination of it from time to time.

3. To invariably examine the bubble after reading on the staff.

*   *   *   *   *   *   *

4. Cover up the instrument when not in use. Set up the instrument first with one side to the sun and then the other.

5. Keep all in good adjustment. Have an arrangement for focussing the eye as well as the object lens.

6. Allow for curvature.

7. Note barometer and thermometer, and use a refraction table.

8. Use plummets; use discs or tiles; compare staves thoroughly, and employ good men as staff holders.

9. Use three or four bench marks for reference.

10. These are mostly unavoidable, although some may be re duced on noticing the cause of error.

Make back and fore sights equal when possible, and limit the length to 650 feet.

CHAPTER X.

SURVEYING AND FILLING IN.

Limits of Error in Linear Dimensions.

162. In any survey the perceptible amount of cumulative error, depending upon the scale, should first be determined. It should be so small as not to be visible. As a space equal to the $\frac{1}{100}$ part of an inch is about this limit, anything less than it may be said to be inappreciable to the naked eye; and if $\frac{1}{200}$ be taken there will be no room left for doubt. This amount, then, taken in connection with the scale, will determine the limit of accuracy required in making field measurements. In a survey on a scale of 400 feet to 1 inch, the admissible error would, therefore, be $\frac{400}{200} = 2$ feet in any distance not cumulative, or in lines where the errors are compensating. The limit varies inversely with the scale; thus, on a scale of ¼ the above, or 1600 feet to 1 inch, the limit of error becomes 8 feet.

It is not to be inferred, however, that because an error does not show on the plot, great care need not be taken in collecting data for areas or contents, where such errors may make great differences in the results. It applies only to the location of isolated objects, as trees, etc., on topographical charts.

The limits of instrumental errors will vary with the character of the instrument, its adjustments, manipulation, manufacture, size, service, and other considerations.

The instrumental errors should be carefully determined before beginning operations, and, when possible, corrected by the observer; or when too great, the instrument should be abandoned for a better or sent to the shop. If in an emergency it must be used, its errors should be noted in the record.

The chain, when used, should be compared, if possible, with a standard, and the corrections made on each distance measured. If it be too *short*, the error, multiplied by the number of chains in a given line, should be *subtracted* from the measured length. If too long, the correction must be *added*. Thus, if a chain is one-tenth of a foot too short, it will be contained in a given distance, as 1,000 feet, 10.01 times. The correction is then, $10.01 \times 0.1 = 1.001$, which deducted from the measured distance, 1001, leaves the correct distance, 1,000; or in general, $D = D' \pm n. e.$, where D' = the measured distance in feet, n = the number of chains it contains, either whole or fractional; e = the error, in decimals of a foot; D = the correct distance.

The usual limit of error in chaining with a standard chain for ordinary work is $\frac{1}{1000}$. As compared with this, the stadia gives results, varying with the instrument and observers, ranging from $\frac{1}{100}$ to $\frac{1}{2000}$. On the Coast Survey, with micrometers, the limit of error is stated to be one metre in 400. With the fixed wires and a magnifying power of 60,* the Porro instrument gave a maximum error of $\frac{1}{2000}$ up to 660 feet, and of $\frac{1}{1000}$ between 660 and 1,320 feet. Equally good results were obtained by Mr. B. S. Lyman with a telescope magnifying only 20 diameters, and reading to the $\frac{1}{200}$ of a foot at a distance of 660. With a telescope reading to hundredths of a foot at a distance of 1,000 feet, the maximum error may be made only $\frac{1}{2500}$, for that distance.

There is, therefore, no reason why, with good instruments and careful observers and rodmen, the stadia measurements should not equal, if not exceed, in accuracy those obtained by chaining. Its superiority in other respects is self-evident.

"FILLING IN."

163. The various methods of filling in the topography from which a selection must be made are, first, by running out the crests, thalwegs, and slopes by traverse or compass lines, taking the vertical angles and interpolating the contours in sketches made in the note-book; second, by plotting the notes on a sketch tablet carried into the field, and completing the contours there; third, by running out each contour line by means of the plane-table, and plotting at once in the field; and fourth, by covering the area by a series of right lines or of ranges intersecting at fre-

*The magnifying power of a telescope may be found by dividing the focal length of the object lens by that of the eye lens, or the diameter of the apparent field of view of the object by that of the eye lens quent intervals, and taking levels at the intersections or at any other points on the lines thus fixed, plotting the altitudes and interpolating the contours.

1ST. BY TRAVERSING OR BY COMPASS WITH VERTICAL ANGLES.

164. To run a traverse from the true meridian, set up at a point, A (no figure) on the meridian, and having clamped at 0°, sight to the N. or S. point, at pleasure (but note which), turn off an angle to B. Move to B, keeping vernier plate clamped. Set up, turn the telescope over, see that verniers read the same as at A. Take the backsight, and clamp *lower* limb. Turn the *telescope* over so as to point in direction AB produced, unclamp vernier plate, and turn to C, taking the reading, and proceed as before. In an area survey the last line should be closed on the initial meridian, and the vernier should read 0°, as at first.

In this method, which is the one generally employed for extended linear surveys where minute details are not required, the direction lines are run as in a linear survey, and referred to the magnetic or true meridian either by compass bearings or backsights. To save time, the elevations may be taken by a separate party following with the level, and the latter's notes may be turned over to the topographer at the close of each day's work to serve as a basis for his subsequent sketches. The contours are put in by taking transverse sections or slopes, from which the points on the contours are found. Having given the height at centre stake and elevation of required contour, its distance out, depending on the slope, will be given from the subjoined table, easily remembered.

165. A slope of	1°	has a base of		57.3	feet to	1′ rise.
"	2°	"	"	28.6	"	"
"	3°	"	"	19.1	"	"
"	4°	"	"	14.3	"	"
"	5°	"	"	11.4	"	"
"	6°	"	"	9.5	"	"
"	7°	"	"	8.1	"	"
"	8°	"	"	7.1	"	"
"	9°	"	"	6.3	"	"
"	10°	"	"	5.7	"	"

etc., these being the natural co-tangents of the several angles, correct to within a foot, up to 19°. It will be observed that the first value, 57.3, is very nearly $\frac{1}{100}$ that of the radius of a 1° curve, 5729.′65, and that any subsequent value is obtained by dividing by the degree of the slope—up to 19°—where the base is 29.0 instead of 30, but the error is too small to be plotted on the usual scale of 400 feet to 1 inch.

166. For rough approximations, as in field sketching, it is sufficiently accurate to call the base 60 feet for one degree, in which case the following table will result:

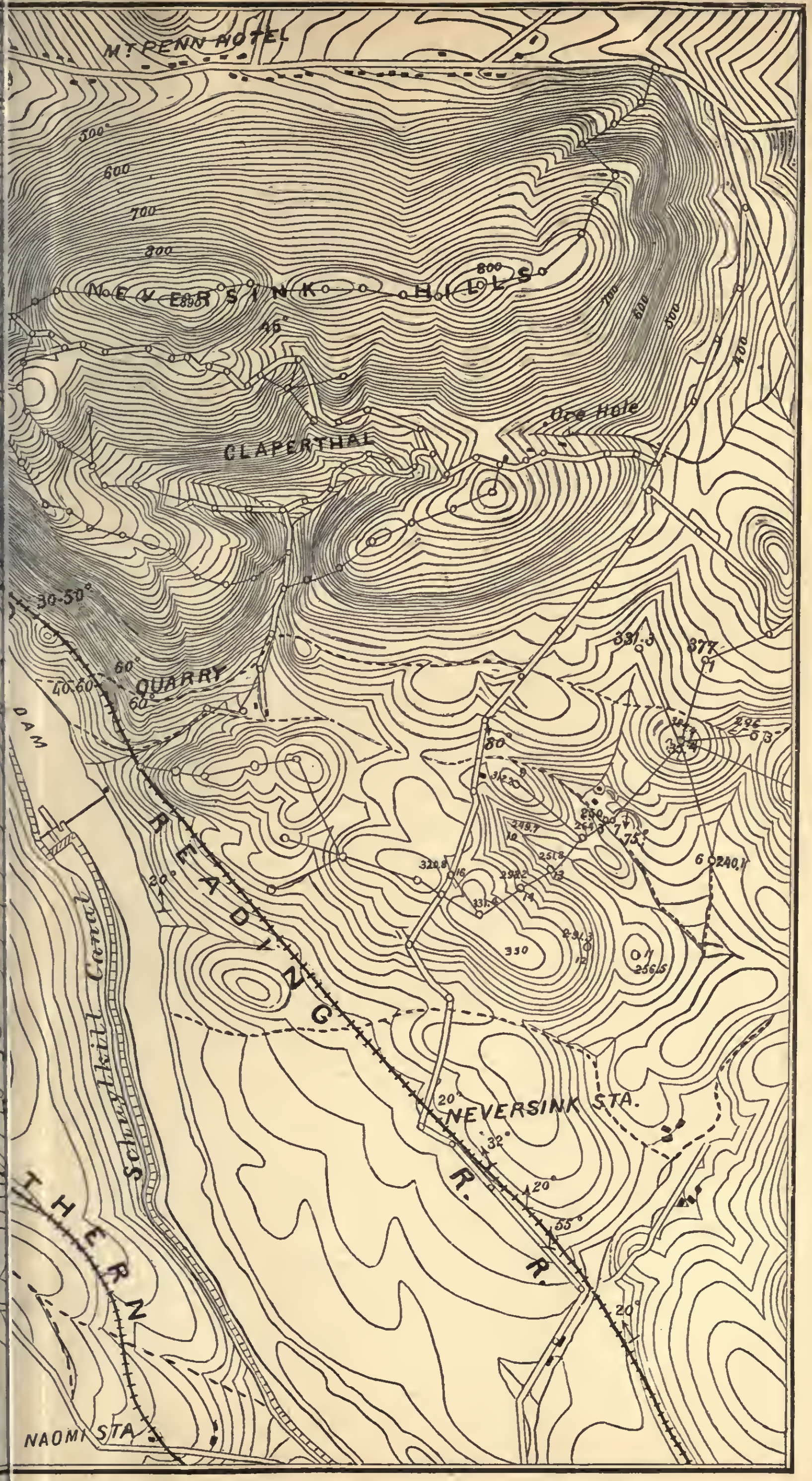
Degree of Slope.		Equivalent Fraction.	Degree of Slope.		Equivalent Fraction.
1°	=	$\frac{1}{60}$	8°	=	$\frac{1}{7}$
2°	=	$\frac{1}{30}$	9°	=	$\frac{2}{15}$
3°	=	$\frac{1}{20}$	10°	=	$\frac{1}{6}$
4°	=	$\frac{1}{15}$	12°	=	$\frac{1}{5}$
5°	=	$\frac{1}{12}$	15°	=	$\frac{1}{4}$
6°	=	$\frac{1}{10}$	20°	=	$\frac{1}{3}$
7°	=	$\frac{1}{8}$	30°	=	$\frac{1}{2}$

The distance to which the side slopes are extended will depend entirely upon the character of the ground. If the slopes are uniform and gentle, and there is no probability of the located line differing much from the preliminary, the slopes may be limited to one or two hundred feet on either side, taken at every second, or even fifth, station; but for irregular ground care must be taken to determine a sufficient number of points to represent all the changes fairly.

For points of general topography at some distance from the line, as from a quarter of a mile to a mile, bearings or shots should be taken by a light compass or "Casella," and the vertical angle by a clinometer or vertical circle. The mean height of the points thus observed from several stations on line, will furnish new points for a further extension of the topography.

167. When vertical angles are read, the differences of level may be computed in the field and entered at once in the record, to indicate the relative heights for the sketching of contours. This operation is clearly indicated in the Form of Record, given in §65, showing a page of notes from the Second Geological Survey of

TOPOGRAPHY OF THE NEVERSINK M



TAINS, S. E. OF READING, PENN'A.

Pennsylvania, on Neversink Mountain, Berks county, near Reading. The reduced map, with the corresponding lines showing their relation to the whole field, is more fully exhibited in Plate 15.* The entire mountain was encircled by a series of lines around its base, which were subsequently connected by ties across the top with numerous shots radiating from stations thus connected. The reductions from polar to rectilinear co-ordinates are made by means of a table of sines and cosines, or by use of the stadia tables attached to each note book. See §126.

2. BY SKETCHING CONTOURS IN THE FIELD.

168. In this case the topographer carries his sketch-tablet, protractor and clinometer, or hand-level, into the field, and starting from some known or assumed bench mark, runs the preliminary lines as already indicated up or down the spurs and ravines. Selecting points on these lines at the heights of the contours to be drawn, he notes the prominent points on the contours by aid of his hand-level, and estimating their position, draws the line through them on the tablet, verifying his work on a return line over another spur or ravine when possible. The table given in section 166 is invaluable in finding the contours. The great advantage of thus sketching the lines in the field is the facility with which mistakes may be detected and corrected, or omissions supplied. In this connection see also Chapter XIII on Field Sketching.

In thus sketching in the contours, the *distances* between stations must either be measured by the chain or the stadia; and as the latter requires fewer men, less labor, less time, and is, if carefully done, more accurate, it is in every respect preferable to the older method of chaining.

3. BY RUNNING IN THE CONTOURS WITH A PLANE TABLE.

169. In smaller surveys, where greater accuracy is required, the contour lines should be established by actually tracing them on the ground, and immediately locating them, either by use of the plane table, by traversing, or by ranges and pacing.

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* This is but a reproduction of a small part of a magnificent series of sheets giving the topography of the South Mountain from Easton to Reading, with the adjoining foot-hills and valleys, being a part of the invaluable work of this Survey conducted under the direction of Prof. J. P. Lesley, State Geologist, by Mr. E. V. d'Invilliers, Topographer.

For the improvement plans of parks, cemeteries, manufactories, or limited estates, the plane table is generally to be preferred, as being most accurate; for town sites, terminal facilities, drainage maps, etc., the method of location by traversing will answer; and for many estimates or general projections, that by ranging will give sufficiently good results, and be much more reliable than a field sketch unaided by instruments.

170. The method of running in contours by plane table is as follows:

To find a contour at a given elevation and trace it on the ground.

Let it be required to run in contour "100"—that is, the horizontal line cut from the surface by a plane 100 feet above the datum. The organization will consist of the topographer with the plane table, his rodman, a level-man with his wye level, rod and rodman, and an axeman to make and drive stakes.

The level must be set up within the zone* of the required contour, and its height determined by a back sight to some (B. M.) bench mark within that zone. If there be none, the levels must be started from the nearest B. M., and be carried up or down to the desired zone.

Let the elevation of the B. M. be assumed to be 102.′528. Set the level within sight of it, and so high that the rod may be read when held on the point; but as the required line is lower, the instrument need not be much above this level. Suppose the backsight to be 2.543. This added to the elevation of the "bench" will give the height of instrument (H. I.) 105.071; and as the line to be run is at 100, to bring the bottom of the rod down to that level, the target must be set at 105.071 — 100, or 5.071. It is clamped at this reading (always obtained by subtracting the height of contour desired from that of the instrument), and the rodman goes to one edge of the tract over which the lines are to be run. Here he moves the rod up or down the slope, as indicated by the leveller, until the target is cut by the cross wires, when the bottom of the rod will be at "100." A stake may be driven, or the plane table rodman holds his rod (upside down for an inverting telescope) at the same point, whilst the topographer takes the distance and direction.

* By zone is here meant that belt of territory within range of the level-rod for any given position of the level. It is contained between two horizontal planes through the top and bottom of rod, or 12 feet apart.

The level rodman having now a starting height, moves around the surface at that level, finding other points in the same manner. Some experience is required in selecting proper points, and in following the contour. The rod should always be held at every important change of direction. On long, straight reaches the distance apart may be considerably increased but on curves or sharp turns about three points should be given close together —from 30 to 50 feet apart—otherwise 100 to 200 feet will be close enough. The plane-table rodman should follow closely in the wake of the level rod, to prevent delays and avoid the necessity of driving many stakes. On steep and uniform slopes only every third or fifth contour needs to be run in, the others being sketched; but on very gently-sloping ground each line must be carefully followed. Reference stakes should be left at the beginning and end of each line for a continuation of the work, and B. M.'s should be frequently established.

The position selected for the instruments should always be such as to command the greatest scope of the terrene, and it is advisable to have them within easy communication, that the topographer may direct the movements of both parties without difficulty. The level rodman should always select points visible from the plane table as well as the level, and should be careful not to cross from one part of a line to a returning part, leaving out a large loop, as in running through a narrow pass. For an example of lines thus determined, see sheet 3.*

171 The interval between the planes of the contours may vary according to circumstances. In extensive geological or topographical surveys covering States or counties, they may be as far apart as 100 to 500 feet, thus giving only the most general features, but in small areas of flat country they may be taken from 1 to 5 or 10 feet apart.

No general rule can be given. In Fairmount Park, where the lines were all determined by the plane table, they are 3 feet apart. The original sheets being drawn to a scale of 50 feet to 1 inch, the lines on a 45° slope would be projected $\frac{1}{17}$ of an inch apart.

* The student should indicate the proper points for the rod on any lines of this plot, as on (6) or (18).

By Traversing.

172. When a plane table is not available, and accurate contours are desired, the following method will be found rapid and satisfactory: A transit with *stadia wires* is substituted for the plane table, and a series of principal points are established by traversing, or by triangulation from a measured base, from any one of which the work may be started.

Let A, (no figure) be the point on which the transit is centered and oriented on B. The contour desired is found, as before, by the level party, and followed by the transit rodman; but instead of the line being platted on the plane table sheet, the distance and direction to the point are recorded in the note book as follows:

173. Topographical Survey of Mandan, Dakota, Date, August ——, 1881. L. M. H., Topographer.

At Station A, August 1, clear and hot.

Contour Line No. 64.

Points on Line 64.	Observed Distance.	Angle.	Remarks.	Sketch.
1	689	265° 12′	At edge of slough.	
2	500	263° 05′	Along coulé.	
3	378	260° 37′	Near section corner 26 –27, 34–35.	
Etc.	Etc.	Etc.		

By changing the setting of the target on the level rod, as many lines may be run from one station as can be seen. The instruments may then be moved, and the work continued. By leaving stakes at the ends of lines, there is a certainty of making connection without overlapping, or the lines may terminate on some range or fence.

These notes are readily plotted by a protractor graduated to 360°; and if the rodman understands his work, the result will be as accurate as if obtained by the plane table.*

By Ranging and Pacing.

174. Contours may also be put in, but with less accuracy, by

* An attempt by a previous party to contour the same ground, the townsite of Mandan, by taking level sections, gave results which could not be recognized, as the ground was a prairie, surrounded by bold buttes, and the contours were very tortuous in the flat portions.

means of a hand level and range poles divided up into feet by various colored bands. These poles may be planted in such parts of the tract as to give long range lines, and at such heights that the bottom of one may be at the same elevation as the top of the next lower, etc.

Or they may all be placed along one side of the area, and their relative heights taken, while a different set of rods may be placed anywhere in front of them to give suitable ranges—which may be so fixed as to intersect or be parallel. If parallel, the topographer may pace along any selected range to the points whose heights are required, and there sight through the hand-level to the rod within that zone; noting the height on that rod, and deducting his "height of eye," he will have the elevation of ground. The contours must be put in by interpolation on the plat; or a given contour may be traced by walking along it, keeping the

Line 64. (*Continued.*)

V. Angle.	Corrected Distance.	Difference of Height.	H. of Instrument.	Corrected Total Height.
0	689	0	5	64

same point of the proper rod in sight when possible, and locating the position by intersecting ranges or by pacing from points of intersection.

Much time may be saved in ordinary sketching by the use of the ranges established by fixed objects carefully located, as the face of a house or barn, two trees, the edges of any two buildings, etc.

175. Instead of establishing the lines of "level sections" by ranges, it is more accurate, if the importance of the survey will warrant the expense, to run a series of lines by transit over the tract in various directions, marking their intersections, and thus establishing numerous reference points for stations.

By taking levels at these points of intersection, and between them whenever necessary, the contours may be interpolated. This is the method which must be pursued in contours under water, when the bottom is invisible, and then care must be taken to obtain a sufficient number of levels (soundings), that no obstruction of a character dangerous to navigation may escape detection.

On *terra firma*, however, the usual plan pursued is to lay off a system of squares or rectangles, driving stakes at every 100 feet ±, and planting monuments at every 500 or 1,000 feet. The measurements can thus be checked up very accurately, and may be further tested by a simple system of triangles.

The levels at 100 feet stakes may also be checked by contours run in by the plane table.*

* This was the combination used at Fairmount Park, Philadelphia, in making the topographical survey, which was one of the most extensive and accurate pieces of plane-table work undertaken up to that date (1869 to 1872).

CHAPTER XI.

HYDROGRAPHY.

176. To determine topography under water requires but a slight modification in the methods and instruments already described.

Here the datum plane, instead of being the height of the instrument, is the surface of the water, at the time, or that surface reduced to another water level, viz.: that of mean low tide.

The operation consists simply in measuring the depths (called soundings) from the water surface to the bottom at a sufficiently large number of points, which must be located on the map, and interpolating the contours of the bottom.

177. The surface points where the soundings are taken may be determined as follows:

1st. By buoys anchored to the bottom and located by intersection from a measured base or shore-line; or by the three-point problem; or still better, by both combined.

2d. By simultaneous intersecting pointings from observers on shore made to a signal on a mast head, at the time of the sounding.

3d. By rowing on range lines established by signals on shore, and timing the soundings; or by rowing over any line (as between buoys, or a buoy and shore-signal, or two shore-signals), and timing.

THE SHORE LINE.

In a Narrow Stream.

178. When the banks are so close that a 16-feet stadia rod can be read across the stream, the shore line may be run in by sending the rodman along one bank while the observer remains on the other, taking oblique readings and reversing every other compass bearing. The rodman should sketch in the shore line between his stations, as it is impossible from the position of the observer

on the opposite bank to estimate the correct amount of offsets for all deviations from the straight line between the rodman's stations.

A better plan consists in running a traverse line on one bank with the aid of a second rodman and taking outlying points across the stream, as before, but reading the angle from the traverse, as well as the distance, thus having checks upon the work. When signals are erected, the points across the stream may be located by intersections.

The same general method is pursued for the shore line of *broad bays and rivers*, in which case the measured line is used as a base, and from its various stations intersecting shots are taken to buoys in the water or signals on islands. The forms of islands, capes, etc., may be accurately and readily obtained by taking tangent shots to their water edges. All visible land marks should be determined in the same manner.

179. The stations may consist of any simple signal pole or centre post, made conspicuous by whitewash, and carrying a flag or number, by which they may be identified from a boat at some distance off shore. On bluffs of rock, wharves, etc., a large white disc may be painted on the face.

THE SOUNDINGS.

180. The general forms of the surface under water are the same as those above, but since they cannot be seen, they must be felt; and hence the number of soundings should be as frequent as possible, and the lines be so arranged as to cover the entire area. In preparing to sound, the following equipments will be required.

A large boat (4 or 6 oared) with one or more spare oars, and boat hook, one or more lead lines and a leadsman; and in addition to the crew there must be room for a recorder and a coxswain.

181. *The recorder* carries a chronometer, sextant, compass and note books. He calls out "heave" to the leadsman, stationed on the starboard bow, whenever a sounding is to be taken, which in shoal water may be every quarter of a minute or less, and as it deepens every half or full minute up to five-minute intervals, and records the depth opposite the time (§ 70), with the character of bottom whenever necessary. On reaching a buoy at end of line, the boat may be stopped while he reads one or more sextant angles to shore stations, or other buoys.

The compass is only necessary in case of dense fogs, but in its absence a pin or wire may be stuck in the gunwale when there is sufficient light to cast a shadow, and the boat may be steered on a straight course for camp, by keeping this shadow covering its mark.

182. The coxswain gives all orders to the crew, and steers the boat; this is done in crossing rapid streams by taking two objects in range on the intended line, and keeping them covering, and *not* by pointing the bow of the boat at the object.

183. *The leadsman* throws the lead ahead, whenever ordered, in such a manner that the line shall be vertical as the boat passes the spot where the lead touches bottom, when he notices the mark and calls out the depth either in feet or in fathoms. When the depth exceeds the danger limit, or is excessive, and the form of bottom is not desired, he may check the line at say 20 fathoms, and call out "no bottom." Such soundings are represented by a dash and dot placed over the figures indicating the amount of line paid out, thus $\frac{\cdot}{20}$.

The Lead-line, and its Care.

184. Two different lines are used for soundings—one, the ordinary sea-line, as used by the mercantile marine; the other, the hydrographer's line.

The first is divided into fathoms, and marked as follows:

"*Marks.*"	"*Deeps.*"
. . . .	1 Single strips of leather.
2 A piece of leather with two strips	
3 A piece of leather with three strips	
. . . .	4 Piece of cord with a knot in it.
5 White rag.	
. . . .	6 A knot.
7 Red rag.	
. . . .	8 A knot.
. . . .	9 A cord with two knots in it.
10 A piece of leather with a hole in it.	
. . . .	11 A knot.
. . . .	12 Cord with two knots.
13 Blue rag.	
. . . .	14 Cord with one knot.
15 White rag.	
. . . .	16 A knot.
17 Red rag.	

The second is also marked in fathoms, and the lower lengths to 5 fathoms, subdivided into feet.

The line should be one that has been used a short time to take out the stretch, and should be soaked in water before marking. The lead, weighing from 7 to 14 pounds, is first attached, and the line marked under a slight tension. The 20-ft. mark of this line is indicated by two knots, and the 4-fathom mark by a piece of leather.

As the nautical parlance requires a translation into plain English, the leadsman should be required to call out the depths in fathoms and feet, instead of "mark under water," "quarter less five," "by the deep, eight," etc.

The boat-hook handle may be marked in feet for more rapid and accurate sounding in shoal water, and a spare lead and line should be carried in case of accident.

The tallow in the heel of the lead should be examined from time to time, and the character of the bottom soil be noted, especially when it changes.

The line should be compared with a standard, both on taking the field and quitting work each day, and the error be recorded.

185. As it will be useful to the recorder to know where to expect to find shoals in alluvial rivers, a few hints on this point are appended. He will invariably observe them on the convex down stream side of any elbow or projection, as well as wherever a river widens out between its banks.

Bars and shoals are always formed wherever the velocity of water carrying sediment is checked, whether by increasing the area of its cross section, changing its direction so as to form eddies, or obstructing its flow; as at the confluence of two rivers, or of a river and ocean, where a bar will always be found.

186. In map of James River, Sheet 5, shoals will be found in every broad reach, and below every elbow on the convex side, and to a lesser extent also above the elbow, as this is a tidal river. The deep-water channel is on the concave bank. The mouth of the Appomattox is blocked up by a bar having but ten feet of water at the crest. A similar bar will be found intercepting the flow of all other affluents. The frequent deflections of the stream indicate a soft alluvial country.

187. In the map of Hampton Roads and Norfolk Harbor, Sheet 6, forming one of the safest and most commodious harbors in the country, the same effects are observed, due to the same causes.

These are of great assistance to the hydrographer in planning his work without the aid of previous surveys, as they will guide him in placing buoys and running lines. A knowledge of the plan of the shore line and direction and relative strength of currents forms the basis of his work, and should be acquired in his preliminary reconnaissance.

In these charts the ordinary signs used to represent hydrography are clearly shown. The one, two and three fathom lines are indicated by the sand dots filled in, with the depths in feet marked between them. They are made conspicuous as a warning to navigators of vessels drawing more than 18 feet at mean low water.

Beyond these contours the depths are recorded in fathoms and fractions.

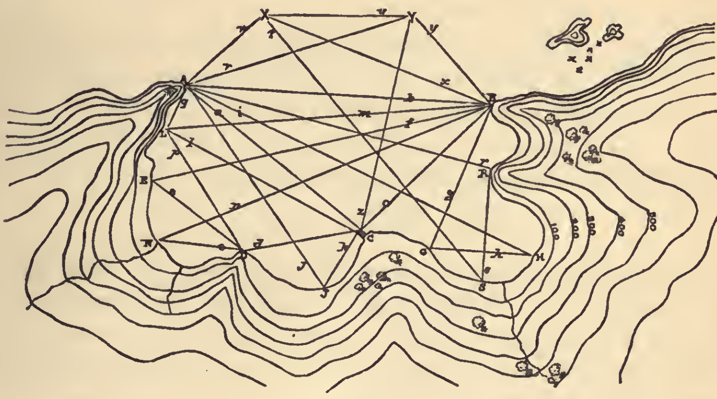

FIG. 39.

188. The practical operation of taking the depths will now be readily understood from the above. A crew is started from any station, directed on a buoy or other station, rowing at a uniform rate, the time is taken at starting and stopping, and at each sounding, and the results recorded.

189. In plotting, after correcting for stage of tide, by reference

to tidal record book at same time, the line on the plot is divided into time intervals, and the corrected depths are marked at the proper points of division.

Thus a line CA across the harbor may take 15 minutes to row over.

The soundings for the first minute may have been taken every 15 seconds, then every half minute for two minutes, and every minute for eight minutes, etc., thus.

LINE CA.

Time.	*Depth.*
1 P. M.	0 Ft.
1¼	5
1½	9
1¾	12
2	18
2½	21
3	25
3½	30
4	29
5	33
6	38
7	45
Etc.	Etc.

Assume CA to be 1½ miles. Divide it into 15 equal parts. Subdivide the first part into four, and the next two each into two divisions, and at these points plot the corrected depths.

The lines should cover every part of the survey. The checks are furnished by the depth at their intersection. By starting at the wharf-head C, and proceeding in the direction of the alphabet, Fig. 39, no time will be lost.

When the shore line is not indented, as above, or when there are no islands, buoys must be placed in one or more rows off shore to form the outer signals. Thus buoys X and Y would give stations for an extension of the surroundings beyond the line AB.

BOSTON HARBOR. (*Sheet 7.*)

190. In the contracted area of the few square feet embraced in this chart is shown the result of years of labor and thought condensed in such a manner as to convey to the navigator so intelligible an idea of the channels, tides, bars, reefs, lights, buoys and landmarks, as to enable him safely to direct his vessel into port.

A general view of the chart shows an outer and inner bay partially separated by the peninsulas of Nantasket and Winthrop Head, with the intervening islands. In front of the gap in this natural breakwater are numerous outlying danger points terminating in "The Graves," protected by the whistling buoy. An ample and safe channel is found, however, by keeping south of the range line joining the NARROWS and BOSTON LIGHTS, and north of the Bell Boat off Harding's Ledge, bringing the vessels up under the guns of Fort Warren on George's Island, whence the main channel is well buoyed out.

The inner harbor has a crescent outline, and is studded over with islands affording protection from all quarters, but contains many inequalities of bottom rendering navigation difficult and at times dangerous.

These irregularities of the bottom are indicated by the one, two and three fathom curves, by the numerous indentations in the shore line, and frequency of the islands.

Moon Island has been selected as the site for the outfall of the drainage of Boston, as it was found that floats placed in the water at that point were carried directly out to sea through Nantasket Roads.

The topography is as varied as the hydrography, including hills and valleys; marshes, rivers, and lakes; cities, towns and hamlets; roads and railroads; parks and farms. The granite hills of Quincy, from whence the first tram-road in the United States carried blocks to the Neponset, in 1826, for the Bunker Hill Monument, and the range of heights forming the line of circumvallation of the American Army in 1776, stretching from Dorchester through Roxbury to Charlestown, possess historic interest.

Boston, on her peninsula, reveals the secret of her commercial prosperity in her long line of water frontage opening directly on the bay.

Yet this very fact renders access by land, especially by rail, more difficult and expensive. The solution of the problem is, however, so clearly shown on the chart as to require no detailed description.

EXERCISES ON COAST CHART NO. 9. (*Sheet 7.*)

1. Project a system of triangles and buoy stations for the survey of the harbors of Salem and Beverly, extending to the Halfway Rock Beacon.
2. Select a base and triangulation for the survey of Broad Sound and Lynn Harbor.
3. Lay out a system for the inner Boston Bay.
4. Mark suitable sites for the tide gauges.

5. Indicate the lines to be sounded for a survey of Minot's Ledge, off Cohasset Harbor.

6. Describe a circumference around each light in colored ink, showing the extent of its range, and thus determine what harbors a vessel may safely enter on clear nights.

7. Describe the location of the Eastern R. R. from Boston to edge of map, giving character of ground, approximate number and character of bridges, whether draw or fixed, etc.

8. What must be the limit of draft of vessels trading between Boston and Medford, at high water?

9. What is the best shipping point on this chart?

191. GENERAL EXERCISES IN HYDROGRAPHY.

1. Sketch on map the thalweg, or line of deepest water. Make a profile of it, and show where pockets are formed.

2. What is its relation to the direction of the banks or mid-line of river bed.

3. Construct cross sections at City Point.

4. To what causes are the deposits of sand above City Point attributable?

5. Project a system of shore-line stations for the survey of Hampton Roads, Sheet 6, and mark places for the buoys.

6. Indicate by an arc described from Old Point Comfort Light, the limit of its range, assuming its focal plane to be 100 feet high, and the observer on the quarter deck to be twenty feet above water.

7. What must be the height of signals at Newport News and Pig Point, to be seen by an observer 5 feet above sea level at Old Point Comfort? See § 215.

8. If AC, Fig. 39, be 1½ miles long, what is the scale of the sketch?

9. How long would it take to make the survey, if the rate of progress be taken at four miles an hour, making no allowance for contingencies, 10 hours per day?

10. How many miles of lines are there as projected, and what is the extent of area to be covered in square miles?

CHAPTER XII.

SUBMERGED TOPOGRAPHY.

192. In the preceding chapter a brief outline has been given for collecting data by soundings, from which the submerged contours may be located on the chart.

There is probably no part of the topographer's work where greater skill is required in the interpretation of the results thus depicted than in submerged topography, since upon the correctness of these deductions the success or failure of the works based upon them must depend. Moreover the activity of the forces operating upon the plastic material which forms the mould of alluvial coasts and harbors, is constantly modifying its form and position, and calls for frequent examinations referred to permanent datum plains.

193. Numerous attempts have been made to apply the various hydraulic formulæ to tidal waters affected by these various agencies, but without satisfactory results.

There is no instrument known to science which will register the combined effects of so many variables which are sometimes acting in conjunction, at others in opposition and which at others are neutral. The best record of the effects produced by these physical agencies must therefore be found in a series of comparative surveys on which the quantitative results and characteristic features are carefully plotted.

THE FORCES DEFINED.

These agencies include the winds, waves, tides, currents and gravity, all of which vary greatly in intensity, direction and duration under the influence of variable physical causes.

194. *The Winds.*—The motion of the atmosphere, constituting the wind, may vary from nothing (a calm) to a velocity of 100 miles per hour, when its destructive effects are irresistible. Between these limits there are many phases which are instrumental in effecting changes both above and below water-level. The different stages of the wind are given in the following table:—

Name.	Vel. miles per hour.	Vel. feet per sec.	Pres. pounds per sq. ft.	Name.	Vel. miles per hour.	Vel. feet per sec.	Pres. pounds per sq. ft.
	1	1.467	.005		20	29.33	2 00
Light, ...	2	2.933	.02	Brisk, ...	25	36.67	3.125
	3	4.400	.045	Strong, ...	30	44.00	4.50
	4	5.867	.080	High, ...	40	58.67	8.00
	5	7.33	.125	Storm, ... Gale	50	73.33	12.50
	10	14.67	.50	Violent storm, . .	60	88.00	18.00
Fresh, ...	12.5	18.33	.781	Hurricane, ...	80	117.3	32.00
	15	22.00	1.125	Violent hurricane, .	100	146 7	50.00

SCALE FOR WIND FORCE AND VELOCITY AS IN USE BY THE U. S. SIGNAL SERVICE.

FORCE.	VELOCITY. MILES PER HOUR.	DESIGNATION.	FORCE.	VELOCITY. MILES PER HOUR.	DESIGNATION.
0	0	Calm.	6	40 to 59 miles per hour.	Gale.
1, 2	1 to 5 miles per hour.	Light.	7	60 to 79 miles per hour.	Strong gale.
			8	80 miles per hour.	Storm.
3	6 to 14 miles per hour.	Fresh.	9, 10	90 miles per hour.	Hurricane.
4	15 to 24 miles per hour.	Brisk.			
5	25 to 39 miles per hour.	High.			

As great confusion appears to exist in regard to the use of the terms designating certain winds, a few definitions will be added, taken from Dr. Wm. Ferrel's "Treatise on Winds."

"*Monsoons* are usually defined to be winds which blow six months in one direction and the other six months in the opposite direction, but, in fact, where there are strong perennial winds, the monsoon influence may merely change a little the strength and direction of these winds." They are confined to the lower latitudes and are due to the differences of atmospheric temperatures between continents and oceans. The diurnal differences cause *land and sea breezes*, while the annual, cause *the monsoon.*

Cyclones are temperature disturbances which are of short duration and extend over a comparatively small part of the earth's surface, it may be from 1000 to 2000 miles, having a gyratory motion of the air about some central point.

Tornadoes are distinguished from cyclones in being more local in character, occupying only a very small part of the earth's surface, rarely more than one mile in diameter, and being accompained by waterspouts, hail, thunder, etc. They are of far greater violence and destructiveness and have more or less of a gyratory and vertical motion. *Typhoons* are a species of cyclone.

Simoons are dust and sand whirlwinds, traversing extended, heated, arid plains.

There are many local terms also applicable to winds from certain sources, as the *Pamperos* or cold southwest, from the Pampas, which correspond to the cold northwest winds, known as *northers*, from the Rockies. The cold winds on the northern coast of the Mediterranean are called *The Mistral* in the Rhone Valley and Gulf of Lyons; *The Bora*, in the Adriatic, and the *Tramontana Negra* or black northers in Greece. All cyclonic.

The counterpart of these cold winds are the *Siroccos* or warm moist winds on the eastern side of the cyclones of this latitude.

The *Chinook* winds are the warm winds flowing over the Rocky Mountains from the Pacific, in the northwest part of the United States. They correspond to the *Foehn* on the north of the Alps.

195. *The Waves.*—By this generic term is to be understood the vibration or oscillation of any elastic medium. As applied to a broad expanse of water it is limited to the section extending from crest to crest of adjacent ridges, the hollow between being the *trough* of the wave or sea. The waves may be broken by wind so as to "comb", even in deep water, when they are known as "*white caps.*" When unbroken the surface is a "*dead swell.*" On approaching shallow water the wave is retarded at the bottom by friction, and rolling forward is transformed into the "*breaker.*" Similarly the gentle pulsations of a deep water movement on reaching shoal water are amplified into the "*ground swell.*" The water, thus projected upon the strand, returning by gravity, constitutes the "*undertow.*"

The opinion prevails that *waves* break normally upon the shore, but as a rule it will be found that their *motion is oblique*, and for any given point their direction is comparatively permanent. This is an important factor in the transportation of material and should be carefully observed. The direction of this angular movement will be found to be a function of the trend of the coast line, the direction of the tidal movements and the profile of the beach, modified at times by the winds.

By the *tidal wave* is to be understood the amplitudes occurring after the moon's transits across the meridian. Hence there are usually two such diurnal waves. However, at certain points on the coast, in consequence of an interference or a difference of time in the approaching wave from different directions, there may be but one, or, more frequently a high and a low wave alternating

The greatest effect of waves is between high and low water.

The *force* of the breaker varies greatly, from zero to three tons per square foot, and instances are on record where masses of stone weighing 1000 tons have been moved by them. The depth at which they are found to disturb the material of the foreshore may be safely placed at eighteen to twenty feet.

196. *Tides.*—Without entering here into the theory of tides, it will suffice to define their several stages. The *spring tide* is that due to the combined action of the sun and moon. It occurs when those bodies and the earth are all in line or at "conjunction," that is, at "new" and "full" moon. The *neap tide*, on the contrary, occurs when the moon is at right angles to the line from the earth to the sun, or in "opposition." The spring and neap tides therefore alternate by periods equal to a quarter of a lunation. They vary in intensity also, in consequence of the relative positions of these celestial bodies. The *flood tide* or "flow" is the period during which the surface is rising; the *ebb*, that during which it is falling, and the "*stand*" the short interval, whether at high or low water, when the surface is stationary.

The *datum* or reference plane for soundings or elevations is that of mean low water. The rise of the tide is influenced very greatly by the form of the coast line and the direction of its approach. Thus a mean rise of two feet in mid-ocean may be increased to forty feet or more in the bight of a bay, and it will be found that whatever the rise may be at the outlying capes, the tides will be increased as they approach the head of the bay or enter the rivers.

The action of the tides is antagonistic; that of the *flood* being constructive, while that of the *ebb* is destructive. The paths of their mid-volumes in tortuous channels are rarely coincident, as they are found to cross from side to side, being reflected by the banks of streams.

Along shore, the action of the flood is to eject the material with which it is charged, and, in connection with the angular movement of the breaker, to transport it in the direction of the receding coast line. This material is deposited wherever the strand is interrupted, forming the spits, hooks, bars, &c., found at inlets. "These formations extend always in the direction of the advancing flood currents." The action of the ebb is erosive, carrying material off shore and resisting the obstructions placed in its path by the flood. The measure of the relative intensities of these two opposing forces may be seen by noting the position of the crest of the bar, with reference to the gorge line of any inlet. Where the flood action is greatest the crest line will be found inside; where the ebb is greatest, outside and farthest from the gorge. Here also will be the deepest water over the crest, or the main channel. The *neutral axis* is the locus of equal movements of drift, due to flow and ebb action.

197. *Currents* are produced by changes of level in the water surface from any cause, as tides, winds, earth elevations, temperatures and pressures.

Those caused by the tidal waters entering narrow and contracted channels may have great velocities, reaching even ten miles an hour. They are always very variable at different points of any section, and at different times for the same points. Hence, the gauging of the tidal prism by determination of its mean velocity of flow through the gorge or any section becomes an extremely difficult and uncertain operation. In many places the flood currents prevail, running in sometimes for eleven hours out of the twelve, at the bottom, while at the surface the direction of movement is reversed.

The ability of currents to effect changes is a function of their velocity and volume, the scouring force being proportioned to the square, and the transporting capacity to the sixth power of the velocity—yet there are numerous cases on record where there is manifestly sufficient bottom velocity to move the material over which the current flows, without effect. What these velocities are will be seen from the subjoined table:—

APPROXIMATE BOTTOM VELOCITIES OF FLOW IN CHANNELS, AT WHICH THE FOLLOWING MATERIALS BEGIN TO MOVE.

Feet per sec.	Miles per hour.		Feet per sec.	Miles per hour.	
.25	.17	Microscopic sand and clay.	2.00	1.39	Round pebbles, 1 inch in diam.
.50	.34	Fine sand.	3.00	2.04	Small stones, 1¾ inch in diam.
1.00	.68	Coarse sand and fine gravel.	3.33	2.30	Flint stones, size of hen's egg.
1.75	1.19	Pea gravel.	5.00	3.41	2-inch square brickbats.

Whenever the velocity of a current, which is charged with sediment, is diminished, it will deposit; when increased, it will scour, and any change of direction in a current will produce these results at different parts of the section.

The great ocean currents produce secondary or *draught* currents to maintain the equilibrium. These latter are generally primarily in a direction opposed to the former, changing gradually to coincidence. Thus, along the northern coast of the Gulf of Mexico the littoral current flows westwardly and then southerly.

Littoral currents are those traversing the foreshore. They have in most instances a prevailing direction, and are important factors in earth shaping at estuaries and inlets.

The *eddy* is produced by placing an obstruction across the path of a current, which may arrest it partially or change its direction—thus developing cross currents by the *reaction* of the resisting medium. This will cause the latent or potential energy of the stream to become kinetic, and to perform work upon the bed in scouring out deep holes or in undermining banks. The eddy is the effective working element of the current. A resisting medium is necessary to develop reaction and produce scour by the centrifugal force of the current. Where changes in beds or bars are desired new conditions must be introduced to produce and maintain them, by placing works in such positions as to generate and control *continuous reactions* or eddies, where a channel is to be created.

The *bore* is a current caused by the flood tide entering contracted channels where the mouth is obstructed and the rise of tide great. It produces a sudden reversal in the direction of the movement, and forms a well-defined wave front, sometimes rising to six feet, as on the River Seine.

198. *Gravity* is that ever present force of attraction which is the cause of currents, wherever there is an inclined plane down which the fluids may move. It is expressed by $g = 32.2$ at sea level. It is the most constant factor in all physical changes.

199. *The Flood Resultant.*—All the above forces may conspire at one time to effect certain modifications, while at another time they may be acting in opposition, and, as has been shown, they are extremely variable. The effects of any one are so masked by those of another, as to make it difficult to determine how much of the work is due to one as distinguished from the other. It will be found however that in many places there is a resultant

direction of movement in those forces which have combined to produce changes in a determinate direction and through a succession of years, recurring after certain periods over the same cycle. To these combined forces has been applied, for want of a better, the term *flood resultant*, which is defined more specifically to be, not merely the flood *current*, but the combined dynamic action of the breakers rolling along the beach, with the littoral currents generated by the on-shore movements of the flood tide.

Thus there is included in this term the united action of the *flood tide*, the *littoral current*, the *angular breakers* and *gravity*, which generally co-operate, while the "wind wave" may or may not act with them. It is a characteristic feature due to this force, that along many parts of our coast line the littoral movements divide at a given point and travel in opposite directions, which could not occur were the movements caused by prevailing or storm winds. These points of division are called the *nodes*.

THE FORMS DEFINED.

The effects produced by the forces just described vary according to position. Those under water being characterized by easier slopes and smoother profiles and contours; those between wind and water being more rugged and abrupt, while those on shore, being affected mainly by wind, rain and frost, are found to have greater relief and less mobility.

200. *The submerged land features* may be divided into two distinct groups, viz: those found in rivers and those existing in large bodies of water, as the great lakes or the ocean. Although, designated by the same general names their forms will differ according to the conditions of their environment.

Banks, Bars and Shoals, are masses of alluvion which have been transported, deposited and moulded by physical agencies. They may be distinguished according to their position and mode of formation; thus, in rivers they may be *confluent*, *cross-over*, *elbow* or *expansion* bars. The cross-over bar is often called the *middle ground.* The term *coulter* may be applied to the cusp lying between two converging currents. It indicates the direction of the resultant flow.

In the ocean *the bar* is the irregular crescent-shaped ridge beyond the gorge. In wide estuaries there is often a bar formed of the material carried out from the "abutment" by the ebb tide and deposited in its lee. This may be called the *ebb bar*.

Reefs are rocky deposits, in place.

201. Of the forms between *wind and water*, or between high and low tide there may be mentioned *flats*, which are extensive tracts of land, generally marshy, often submerged at high tide and frequently covered with vegetation. They are also frequently intersected with numerous, narrow and tortuous water ways.

Spits and Hooks are the terminals of traveling beaches, where in consequence of a change of direction or a break in the continuity of the shore line, a "dump" is formed by the drift.

Points are formed by confluent currents. The *strand* and *beach* are synonymous terms, applied to the portion of the shore between high and low water.

The *foreshore* includes also that portion of the bottom extending out to the limit of wave action, which is in general indicated by the finer sedimentary deposits of silt and clay.

Traveling beaches are those which, under the influence of the flood resultant, are continually changing, sometimes in one direction, at others in the other, but in general, having a preponderating movement. The effect upon any inlet is manifest by a corresponding shifting of its position in the same direction and a gradual closure of the break in the beach until it is reëstablished by an off-shore storm opening the old path. These phenomena recur at long intervals, forming *cycles* in the movements, which thus repeat themselves. The rate of the progression is often from 100 to 300 feet per annum, but it is very variable.

The advancing point becomes the *spit* or *hook;* the receding one may be called the *buttress* or *abutment.*

202. The *on-shore* features include "*dunes*," which are hills or hummocks of sand. These shift readily with the winds and often form serious obstructions to improvements. Thus the Landes of France, which travel at the rate of about sixty feet per annum, have interred villages, lakes, roads and farms, and are a constant menace to the inhabitants of that region. These same features characterize the sandy barriers outlying the lagoons and sounds of a large extent of alluvial coasts.

203. *Channel Features.*—As the currents in traversing an inlet

or crossing a bar follow different paths they leave traces by which they may be identified. Thus the thalweg of a channel will rise gradually to the crest of the bar and thence fall more rapidly in the direction of the movement, since in moving the bottom material to the crest the currents are rolling it up hill or against gravity, and after passing the crest they are assisted by gravity; hence the relative degrees of slope will indicate generally the direction of the movement. A concave outer slope indicates instability, convex or ogee, the reverse. The *flood* or *beach channel* by which the tide first begins to enter an inlet will be found under the flood spit, and will have its outer slope gentle, its crest close to or inside of the gorge, and its inner slope steep, being abraded by the ebb. Between it and the *main channel* will be found a number of intermediate channels of lesser depths, having local names, which are all weir or *swash* channels, cut by the lateral escape of the tide at ebb.

A *slue* is a pocket or deep hole situated outside of the normal path of the currents, and produced by some local peculiarity. A remarkable instance of this kind exists on the crest of the bar obstructing the entrance to New York Bay, where the slue is over fifty-one feet in depth, a half mile long, and a quarter wide, lying between Gedney's and the East channels.

A *pit* or *pocket* is the deep hole dug out by the eddy, caused by the head of a jetty or other obstruction. It is invariably on the side towards the current, and the material scoured out is deposited on the lee side of the obstruction, when possible.

Inlets are openings through a beach connecting sounds, lagoons, etc., with the outer bodies of water. The section between the nearest points of the adjacent spits is called *the gorge*. The position of the "pit" with reference to the gorge will generally indicate the preponderating direction of bottom movements.

To produce the most effective scour the *reaction* should be of such a character as to develop the centrifugal force of the current, as in passing a bend or in moving along the face of a curvilinear structure. A slight curvature will suffice. Many channels exist in sand formations where the radius of curvature is only 3000 to 4000 feet, if protected from waves, while their depth is over thirty feet. The success of harbor works will depend largely upon a correct application of this principle of continuous reaction.

CHAPTER XIII.

COMPUTATIONS.

204. THE surveys having been completed and the records tabulated, the results may be obtained in several ways, either graphically or analytically.

In the former case the accuracy depends upon the scale of the drawing and skill of the draughtsman.

For many purposes it will be sufficient to lay down one of the longer lines of the tract as a base and determine the remaining parts by intersections and offsets, reversing the processes employed in collecting the data in the field. When the figures thus formed are geometrical, their areas may be readily found by the use of the scale, or computing scale; but when the outlines are irregular, as in case of a stream, or shore line, etc., a better and more rapid approximate result may be obtained by using the planimeter, or by weight.

205. The analytical method consists in applying the appropriate formulæ for the solution of plane or spherical triangles, after the data as recorded in Chapter IV., have been cleared of all sources of error, and made to fulfill certain geometrical conditions of plane-figures.

COMPUTATION OF PLAIN AREAS.

206. It is not intended to repeat here the well-known methods of solving plane triangles, or other geometrical figures; but to give merely an abridgment of the form generally used for irregular polygons, known as the Pennsylvania method of latitude and departures.

This modification was suggested by Mr. J. Woodbridge Davis, C. E., and published in Van Nostrand's Magazine. It is as follows:

The latitude and departure are found and balanced, as formerly. Then instead of computing the DMD's and double areas, he introduces this RULE.

Multiply the total latitude of each station by the sum of the departures of the two adjacent courses. The algebraic half sum of these products is the area.

To find the *total latitude* of each station, add to the total latitude of preceding station, the latitude of preceding course. If the latitude of last station, found in this way, be equal to the latitude of last course with reversed sign, the work is correct. However, the latitude of first station is always zero; of last station it is always the latitude of last course with reversed sign, and of second station it is always the latitude of first course.

To find the *adjacent departures*, add the departures of the two courses, one on each side of station, as exemplified below.

Station . . .	Bearing . . .	Distance . . .	Latitude . N +	Latitude . S —	Departure . E +	Departure . W —	Total Latitude.	Adjacent Departures . .	Double Areas .
1	N. 35 E.	2.70	2.21		1.55		—	—	—
2	N. 83½ E.	1.29	.15		1.28		2.21	2.83	6.2543
3	S. 57 E.	2.22		1.21	1.86		2.36	3.14	7.4104
4	S. 34¼ W.	3.55		2.93		2.00	1.15	—0.14	—0.1610
5	N. 56½ W.	3.23	1.78			2.69	—1.78	—4.69	8.3482
									2)21.8519
									10.9259 sq. chs.

Any convenient station may be taken as the beginning point of the survey. It is unnecessary to make a plot. The most advantageous station, however, to which to refer the others, is that whose latitude is most nearly an average of the latitudes of all, as it insures the smallest double area factors.

207. In the solution of plane triangles, the following systematic arrangement will be found convenient:

When the lengths of the sides do not exceed four or five miles, the correction for spherical excess may be disregarded; but in larger triangles it must be computed and deducted from the sum of the three angles to determine the errors due to observations, called the *residual* errors. These, in close work, must be distributed by the method of least squares.

In secondary triangulation, the adjustment is made either as just indicated, or in the inverse proportion to the number of measures taken of each angle, or in less important cases, equally among the three angles so that the sum shall be 180°.

In arranging the data for computation, the following form will be found most expeditious, either for plane or spherical triangles, based upon the formula.

$a = b \frac{\text{sin. A}}{\text{sin. B}}$, or log. a = log. b + log. sin. A + a. c. log. sin. B,

No.	Denomination.	Observed Angle.	Correction.	Spherical Angles	Spherical Excess	Plane Angles and Distances.	Logarithms.
		Cape to	Cactus.	. . .	. . .	. . . . .	3.270203
		° ′ ″	″			° ′ ″	
	So. Base (vertex) .	29 01 58.3	+0.8	. . .	. . .	29 01 59.1	0.313977
	Cape (left hand) . .	72 59 16.4	—0.8	. . .	. . .	72 59 15.6	9.980568
	Cactus (right hand) .	77 58 47.8	—2.5	. . .	. . .	77 58 45.3	9.990371
	S. Base to	Cactus . .	. . .	. . .	. . .	. . . . .	3.564748
	S. Base to	Cape . . .	. . .	. . .	. . .	. . . . .	3.574551

Here it should be noted that the entries are made in the order indicated; first the known side from left to right, then the angles, beginning with that at the vertex, then the left-hand object, followed by that on the right, and finally the two computed sides, from vertex to right, and vertex to left.

208. Having now the three sides, the area S may be found from the formula, $S = \sqrt{s(s-a)(s-b)(s-c)}$, in which s = the half sum of the three sides, a, b and c. Or knowing the three angles A, B and C, and any side, as a, $S = \frac{a^2 \text{ sin. B sin. C.}}{2 \text{ sin. A.}}$.

GEODETIC SURVEYS.

Corrections for Horizontal Angles.

209. If the data be recorded, as in § 68, for a direction instrument, the errors of run of the reading microscopes must be determined. The corrections for these errors are entered in the record as they are made, generally on first occupying a station, and principally for the purpose of verifying the imposed condition that the adjustment of the microscopes to the graduation of the instrument should be so far perfected that five revolutions of the micrometer-screw do not overrun or underrun a five-minute space on the circle, by a greater error than two seconds. The regular observations or readings, on all parts of the circle, supply the data

for determining the mean error of runs used in the correction of those observations.

Correction for Error of Runs.

210. Let a =nrst reading. Turn the micrometer-screw in the direction of the increasing numbers on its head until the cross-wire intersects the nearest five-minute division on the circle, and read the number of turns and parts of a revolution.

b = second reading. Reverse the movement of the screw and continue the backward motion of the cross-wire until it reaches the nearest five-minute division, and read as before.

Let the following data represent the mean of a number of observations taken from the record, the degrees and minutes read off from the circle being 65° 20′. As the micrometer overruns, the correction is subtractive from the mean of the two readings.

$a = 65^\circ\ 20' + 4'\ 42.6''$. $\quad r = a - b = +\ 0'\ 1.8''$.

$b = 65\ \ 20 + 4\ \ 40.8$. $\quad m = \frac{a+b}{2} = \quad 4\ 41.7$.

Correction to $a = \frac{r}{300''}\,a \quad . \ . \quad = \ -\ 1.70$.

Correction to $b = \frac{r}{300''}\,(b - 300'') \quad = \ +\ 0.12$.

Correction to $m = \frac{1}{2}\left(\frac{a + b - 300''}{300''}\right) r = \ -\ 0.79$.

And, hence, the corrected mean of the two readings = 65° 24′ 40.9″.

Tables of double entry are constructed, by means of which the corrections for run can be taken out by inspection. The arguments are the number of minutes and seconds in the observation and the value of $\pm r$.

211. In SPHERICAL TRIANGLES the excess is computed as follows: Let a and b represent two known sides and C the included angle.

A = the equatorial radius = 6378206.4 metres.

B = the polar radius = 6356583.8 metres.

e = the eccentricity $= \sqrt{1 - \frac{B^2}{A^2}}$

$e^2 = 0.00676815$.

L = the mean latitude of the three places.

E = the excess $= \frac{a\ b, \sin C\ (1 + e^2 \cos 2\ L)}{2\ A^2 \sin 1''}$, but the factor $\frac{1 + e^2 \cos 2\ L}{2\ A^2 \sin 1''}$ varies only with the latitude, and hence may be computed separately and tabulated. Representing these results by m, the final formula becomes $e = a\ b \sin C\ m$.*

212. Other corrections may be necessary, as for *reduction to centre* when it is impossible to set the instrument at the centre of the signal; or for *phase*, when the signal is a reflecting cone, cylinder, or sphere; or for *eccentricity*, when it may not be over the underground mark.

The formulæ for these corrections are as follows:

Let C represent the centre of station.

$x =$ eccentric position of the instrument.

$r =$ the distance from C to x.

$o =$ the angle at x between any two signals a and b.

$y' =$ the angle at x between C and the left hand signal a.

$a =$ the distance from C to a.

$b =$ the distance from C to b.

C $=$ the unknown angle at C.

The signals are all supposed to be situated to the *right* of C, taken in azimuthal order.

Then $C = o + \frac{r \sin (o + y')}{b \sin 1''} - \frac{r \sin y'}{a \sin 1''}$.

The sign given for each term will be governed by that of the sine of $o + y'$ and y'.

213. *For Phase in Tin Cones.*

Let x $=$ the station of the observer.

C $=$ the sun, or xC, the azimuth of the sun.

y $=$ angle between sun and reflecting cone.

a $=$ distance between observer and cone.

r $=$ mean radius of cone.

If the pointing is made on the bright reflecting line exhibited by the cone, then the correction $= \pm \frac{r \cos \frac{1}{2} y}{a \sin 1''}$; but if there is no such reflection, and the pointing is made on the white illuminated part of the cone, the correction $= \pm \frac{r \cos^2 \frac{1}{2} y}{a \sin 1''}$.

214. *For Eccentricity of Signal.*

Let C $=$ centre of station.

x $=$ the eccentric object, or part of signal observed upon.

r $=$ the measured eccentricity.

a $=$ the station of observer; also the distance a C.

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* See Report U. S. Coast Survey for 1868.

Then the correction $= \pm \frac{r}{a \sin 1''}$.

These corrections having been made when required, and the spherical excess having been deducted, the resulting angles should sum up 180°; but if not, the residual error must be distributed as already indicated before the triangles are ready for computation. As it is seldom that the topographer will be required to perform service of this character, only the formulæ have been given with reference to the examples as published in the U. S. Coast and Geodetic Survey Reports for 1868.

For the L, M and Z computations, reference is made to any standard work on Geodesy, or to the Coast Survey publications.

CORRECTIONS IN LEVELLING.

215. *For Curvature and Refraction.*—Since all levels are referred to the surface of the earth as a datum, but are measured instrumentally from a tangent plane to that surface, it becomes necessary to make a correction, in long sights, for the difference between these two surfaces. Denoting the correction in feet by (h), and the distance in miles by D, the formula $h = \frac{2}{3} D^2$ is readily obtained from a simple geometrical proposition.* But since every line of sight is affected by refraction, its effect must also be considered.

The average amount of refraction is found to be one-seventh that of curvature, and as it apparently adds to the elevation of an object, it must be subtracted from the observed height, hence the correction for refraction is $\frac{1}{7}$ of $\frac{2}{3} D^2 = \frac{2}{21} D^2$, and as both of these corrections are constantly operating in opposite directions, they may be combined into a single formula,

$$h = \left(\tfrac{2}{3} - \tfrac{2}{21}\right) D^2 = \tfrac{4}{7} D^2.$$

This formula is one of frequent practical application, as in determining the height of light-houses and range-lights, or the distance from the shore or from a vessel at which a floating object may be seen by an observer at a given height.

By making the back and fore sights equal in levelling, these corrections will be eliminated.

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* The general formula is $h = \frac{D^2}{2R}$ in which R is the mean radius of the earth = to 20890588 feet.

216. *Corrections for Levelling by Reciprocal Zenith Distances.**

Let Z, Z' = the measured zenith distances of the telescopes at the two stations.

K = the distance between the stations (in meters).

R = the radius of curvature of the arc joining the stations.

C = the angle at the earth's centre, subtended by the arc.

h, h' = heights of the two stations above mean tide.

$$C = \frac{K}{R \sin 1''} \qquad \text{and } h - h' = \frac{K \sin \frac{1}{2}(Z'-Z)}{\cos \frac{1}{2}(Z'-Z+C)}$$

The value of R or of the factor $\frac{1}{R \sin 1''}$, has been computed for different latitudes, and for angles varying from 0° to 90°, and will be found tabulated in U. S. C. S. Report of 1868.

217. *When Single Zenith Distances have been Read at only one Station.*

Let Z = the measured zenith distance of the signal or object.

C and K = as above.

m = the co-efficient of refraction.

$d\,h$ = difference in height between the two stations.

$$d\,h = \frac{K \cos (Z + mC' - \frac{1}{2} C)}{\sin (Z + mC - C)}$$

By the Observed Zenith Distance of the Sea Horizon.

Z = the measured zenith distance.

R = radius of curvature of arc.

m = co-efficient of refraction = 0.078.

$$h = \frac{R}{2(1-m)^2} \tan^2 (Z - 90°)$$

218. *By Observed Angles of Elevation or Depression.*

A = observed angle, expressed in seconds.

K = the distance, in meters, between the two stations.

Constant=0.00000485 log. of constant = 4.68574.

" 0.0000000667 log. of constant = 2.82413.

The formula then is:

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* Extracts from a paper on Methods, Discussions and Results. U. S. Coast Survey. By Richard D. Cutts, Assistant in Charge.

$dh = 0.00000485 \text{ KA} + 0.0000000667 \text{ K}^2$, which gives the difference of height between stations not more than ten or fifteen miles apart, with a probable error less than the uncertainty in the co-efficient of refraction.

THE CO-EFFICIENT OF REFRACTION.

219. The co-efficient of refraction, or proportion of the intercepted arc, is determined from the observed zenith distances of two stations, the relative altitudes of which have been determined by the spirit-level; or from reciprocal zenith distances, simultaneous or not, under the assumption that the mean of a number of observations taken under favorable conditions will eliminate the difference of refraction which is found to exist, even at the same moment, at two stations a few miles apart. Such a co-efficient may be established for the level of the sea, or for high elevations, or for lines over water or over land. As, however, the difference of height, deduced from trigonometrically levelling, depends upon the co-efficient multiplied by the square of the distance, it is evident that the longer the line, the greater would be the error caused by any uncertainty in the co-efficient or actual refraction, and that, consequently, there is a limit to the distance for which any assumed mean value of the refraction can be depended on for accurate results.

The average value of the co-efficient from the Coast Survey observations is:

Across parts of the sea near the coast . . . 0.078.
Between primary stations . . . . 0.071.
In the interior of the country, about . . . 0.065.

To Determine the Co-efficient of Refraction from Reciprocal Zenith Distances.

C = angle at earth's centre subtended by arc.
F = angle of refraction.
m = co-efficient of refraction.

$$C = \frac{K}{R \sin 1''} \qquad F = \frac{C}{2} - \tfrac{1}{2}(Z' + Z - 180°) \qquad m = \frac{F}{C}.$$

Stadia Reductions on Slopes.

220. When distances are read by the stadia on uneven ground, the reduced lengths and heights are obtained from the tables. See § 126.

These reductions may also be made graphically by means of a diagram, or mechanically by the use of a slide rule, but the above method is quite as expeditious and accurate.

AREAS AND VOLUMES BY GRAPHICAL AND MECHANICAL METHODS.

221. When the survey is limited by right lines, the contents may readily be obtained from a plot drawn to a suitable scale, by dividing the area into right triangles and measuring their bases and altitudes, or by determining the weight of the paper plot upon a pair of delicate balances, and comparing this weight with that of a unit of the same paper previously determined.

The accuracy of this method varies greatly with the quality of the paper, the care taken in making and cutting out the plot, and the condition of the atmosphere.

A series of experiments made by the author indicate tracing vellum as being the most homogeneous material upon which to make the drawing, giving results quite as close as the present methods where the boundaries are irregular. Thin rolls of sheet brass would doubtless be found to answer the purpose equally well.

PLANIMETRY.

222. The method of calculating areas by means of an instrument called a planimeter was first invented by Mr. Oppikoffer, of Berne, Switzerland, in 1827; but it was so expensive and impracticable that it was not until after several improvements, by Welty in 1849 and Amsler in 1854, that it came into general use. It was found that the planimeter could compute an area in 3 minutes which required 2½ hours by the analytical method, and that the resulting error was only about one-fourth of that when calculated in the old way.

The instrument (Fig. 40) consists of two arms or links connected with a registering apparatus. The pole, *b*, of one arm, P remains stationary, whilst the other arm, A, carries a style, *f*, which is passed over the outline of the tract whose area is required. The joint is supported by a roller, L, carrying a graduation and recording the number of square inches, square centimeters, etc., of area according to the reading at which the arm A is set. The geometrical principle upon which the polar planimeter is constructed is that the extent of arc developed by the roller is a simple function of the area of the sector passed over by the pointer. Every plane figure is, therefore, supposed to be made up of infinitely small circular sectors, the difference of which (when the pole is outside the figure) will equal the area required.

223. To use the planimeter, set the arm A to the assumed scale as 1:1 for square inches. Place the pole *outside* of the plot, if it be not too large, and the pointer at some station. Read the wheel and vernier. Move the pointer carefully over the perimeter, in the direction of the motion of clock hands, closing at the starting point, and read again. The difference will be the number of units, as per scale, in the plot. In this case it gives

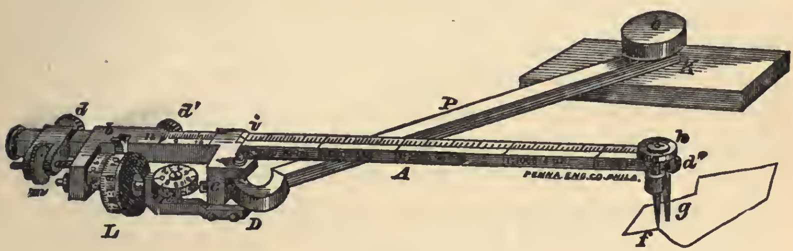


FIG. 40.

the number of square inches, from which the area in acres is readily obtained by multiplying by the number of acres to the square inch, as given in the table of map equivalents, pages 49–51.

When the pole is *inside* the plot, there must be added to the second reading the constant whose value is engraved on the arm A, back of the line of division, corresponding to the scale at which the arm is set, and from this sum the first reading must be deducted: otherwise the operation is the same.

224. For computing volumes, as in case of earthworks, etc., the abstract numbers representing the areas of the consecutive cross-sections as determined by the planimeter or otherwise, may be plotted as ordinates on a profile at their proper intervals apart; and their upper extremities being joined by a line will give an area which, when measured by the planimeter, will represent the volume of the cut or fill.

Another and perhaps more direct method of computing volumes mechanically is that described by Clemens Herschell, C. E., in the *Franklin Institute Journal* of April, 1874, based upon a development of the prismoidal formula into the form of

$$V \text{ (volume)} = \frac{H}{3}\left(S_0 + 4\ S_1 + 2\ S_2 + 4\ S_3 + 2\ S_4 + \ .\ .\ S_n\right).$$

Where H is the uniform distance between cross sections S_0, etc., the areas of the cross and end-sections and $_n$ must be an even number. The general form of the above equation is $V = C.\ \Sigma$ areas, or a constant into the sum of the areas, which can be read by a planimeter. The scale, however, introduces another constant. If the usual cross-section paper scale of 8 feet = 1 inch be taken, the C above, to give results in cubic yards, will become $\frac{2 \times 100 \times 64}{3 \times 27}$, when H = 100 feet, for each square inch of paper circumscribed. Now, since the circumscribed area is equal to the length of the tracing arm multiplied by the distance rolled by the wheel,* the appropriate length of arm to read as above desired is easily found. Should this length be inconvenient in the manipulation of the planimeter, take, say, its double, giving a final answer just one-half the true one; or, if H be 50, the final answer will be the true one; if H = 10 it will be 5 times the true one, and so on.

The operation in practice is about as follows: Take a sheet of cross-section paper ruled with 8 squares to the inch, and mark one line of it as the grade line of the cross-section to be measured. Figure the centre line heights on the sheet. Next cut out of a piece of stiff cardboard a template or cross-section of the road bed and side slopes, of sufficient extent to include the maximum of cut or of fill, and on the same scale.

Lay this over the cross-section with its road bed edge on grade line, centre on centre, and carry the style around the edges of the section S_0—taking reading before and after the operation. The difference gives S_0 multiplied by the constant, which is to be noted.

To apply the formula given above, it must be written

$$V = \frac{2 \times 100 \times 64}{3 \times 27}\left[S_0 + S_1 + S_1 + S_2 + S_3 + S_3 + S_4 + \ .\ .\ S_n - \frac{S_0 + S_n}{2}\right]$$

The next section, S_1, is then circumscribed. This can be done without moving the template, by noting the surface slopes as given by the centre and side heights on the cross-section paper,

* Rankine's Civil Engineering.

without even drawing the lines. These data may be called off by an assistant. Thus each successive section may be added up on the wheel, and a reading be taken at the conclusion of the S_{n-1} section, care having been taken to prevent any slipping. A final reading after the S_nth section will give the values for the negative fraction in the formula.

The duplication of the odd S's in formula may be taken in sequence or subsequently, and the difference between the first and final readings, less $\frac{S_0 + S_n}{2}$ is, for $H = 100$ feet and with the arm set at double the length, just one-half the contents of the cut or fill in cubic yards, with a probable error which need not be greater than two-tenths of one per cent., or two yards in a thousand.

The end or other fragmentary volumes may be divided up into lengths of 10, 20, $33\frac{1}{3}$, or any other even division of 100 feet lengths, and treated accordingly. Then the result given by the instrument will be to the true result as the standard H is to the assumed H.

225. This mechanical method of calculating earthwork is equal in accuracy to that of the usual field operations. It will give results more or less near the truth, as the latter give more or less data to work from. No tables yet devised will do anything of the kind for all cross-sections, and the amount of labor saved is very great. Mr. Herschell estimates the saving in time alone to be $\frac{1}{2}$ to $\frac{4}{5}$, according as the cross-section data of the note book are tabulated more or less perfectly; the saving in labor is still greater, and the gain in accuracy is marked and valuable, surpassing what in any ordinary work has hitherto been considered attainable.

The applications of this simple instrument are manifold, as in reading indicator diagrams, in determining the horse-power of engines, in friction-brake trials, and in a variety of problems in civil and mechanical engineering, acoustics, electricity, or other investigations where the results are functions of any two variables and one or more constants.

NOTE.—For a complete analysis and description of the planimeter, see Cosmos, vol. viii., page 213. Paris, 1856. Report on the Industrial Arts. Paris Exposition, 1867; Barnard; published by D. Van Nostrand, N. Y.; also Buff & Berger's Catalogue of Engineer's Instruments, No. 9 Province Court, Boston, Mass., and Rankine's Civil Engineering.

The standard graphical methods of computing earthworks, are by the use of Trautwine's or Wellington's Diagrams. A new diagram is in course of preparation by Mr. E. Thiange, which is claimed to be much simpler than either of the above, and yet more accurate, giving results to within $\frac{1}{1000}$ of the true contents. It will doubtless be published in Proceedings of the Engineer Club of Philadelphia for 1883, to which the reader is referred. Reference should also be made here to the analytical method of J. Woodbridge Davis, in his work entitled "Formulæ for Railroad Earthworks—Quantities and Average Haul," published by Gilliss Brothers, No. 75 Fulton Street, N. Y.

THE INTERPOLATING SCALE.

226. This is an ingenious mechanical device for interpolating points, invented by a student at the University of Tokio, Japan. It may readily be constructed of two triangles having a graduated scale of equal parts engraved upon the edges about the right angle.

To find a required point between two others by computation, requires the solution of a proportion, in which the difference of altitude between the given points is to their horizontal distance apart, as the difference of height between the required and either given point is to the required horizontal distance.

With the scale, the triangles are placed so that their backs or common edge fall on the line joining the points of known altitude and the apices of the right angles rest over these points. Then mark off on the perpendicular edge to the right and left the differences of heights between the given and required points, and where the line joining these cuts that joining the given points, will be the required point. Thus if two soundings or levels are plotted at points *a* and *b*, of which the elevations are 26 and 33 feet, and it is required to find the point for contour 30, after setting the triangles with their corners at *a* and *b*, lay off 4 units to the left and 3 to the right, and draw two pencil lines, which will intersect at 30.

Lesley's Micrometer for Field Note Plotting.

227. This little instrument was invented by Prof. J. Peter Lesley, as a substitute for the vernier scale, whereby much time and labor is saved in plotting field notes. It consists of an arc set with three or more needle-points fixed at any convenient intervals, as half inches. A movable point is placed between the last two needles, and operated by a button projecting from a circular disc, which is

divided into 100 parts, by which means this point may be set to any fraction of the equal intervals. The instrument is operated by a small handle, similar to those used in the steel-spring dividers.

When the subdivisions of the scale are not decimals, other indices may be substituted, divided into 66ths, 33ds, etc.

The micrometer is made by Messrs. Heller & Brightly, 12th and Spring Garden Streets, Philadelphia, Pa.

CHAPTER XIV.

MODELLING.

228. It is frequently desirable to represent the territory surveyed by a model, for the purpose of studying more carefully its structure, or of conveying correct ideas to minds unskilled in reading contour maps, as in the case of a jury; or it may be desired to exhibit more vividly the workings of a mine or drainage system, or the benefits to be derived from some proposed improvements. In all such cases a model will be found far more satisfactory than a map or sketch.

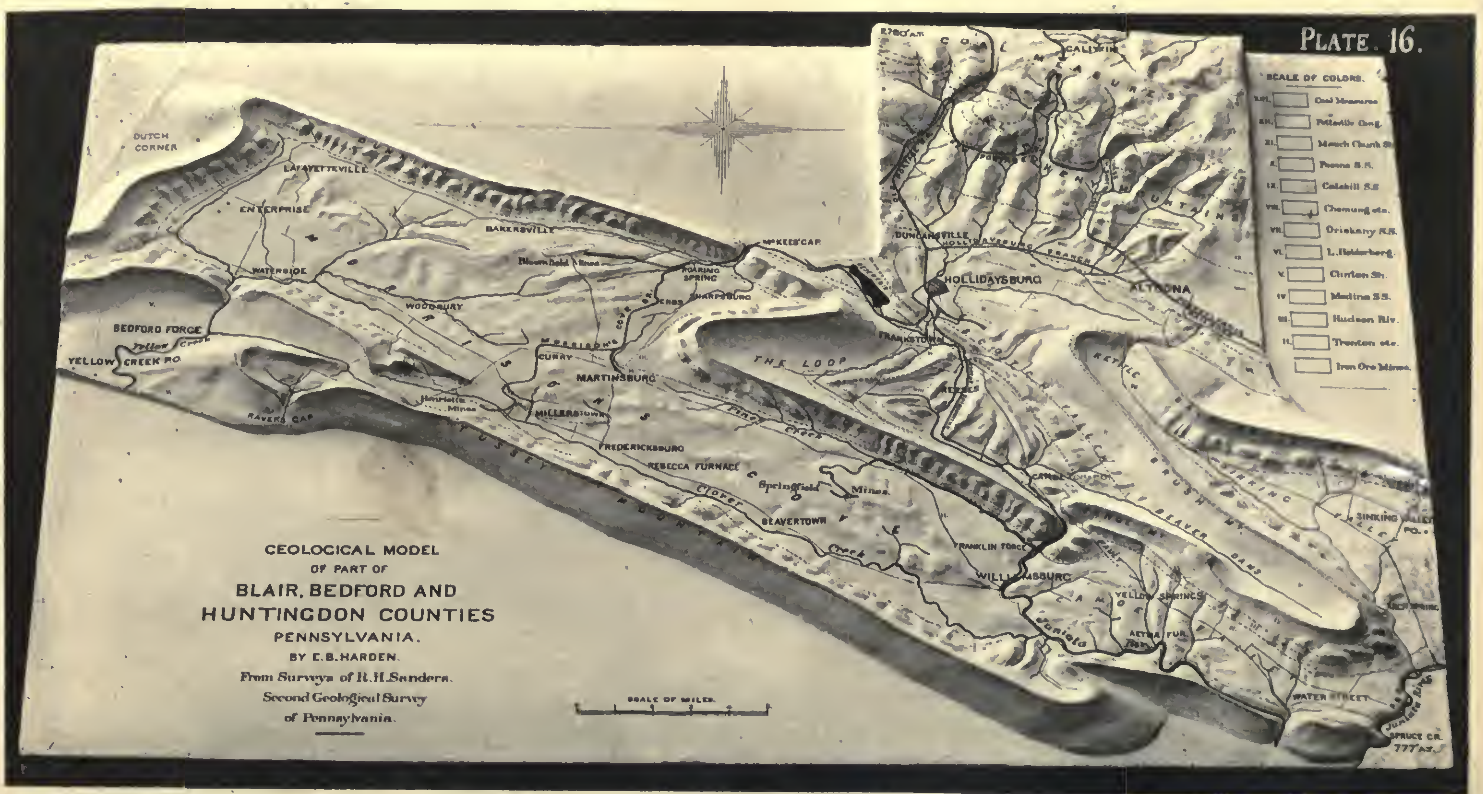
229. In preparing this miniature of the ground, a great variety of materials have been proposed and tried, as *papier maché*, gypsum, paraffine, wood, putty, clay, wax, and various compositions with more or less success, but probably the quickest and most satisfactory is the

METHOD BY WOODEN CONTOURS.

230. *To make a model by contours*, select a suitable scale, say $\frac{1}{400}$. Prepare a base of wood large enough to contain the area to be represented. If the contours be taken every 25 or 50 feet, then they must be placed $\frac{1}{16}$ or $\frac{1}{8}$ of an inch apart for this scale.

Procure some thin slabs of poplar wood or of paper boards, tracing on them the contours in pairs, and out them out on the outer line with a jig or scroll saw; then, beginning with the lower plane, tack them with small brads one over the other on the base, in their proper relative positions, thus building up the hill in steps or terraces. The re-entrant angles thus formed are filled with a composition of 16 parts of yellow beeswax, 8 of corn starch, 1 of Venetian red, 4 of Venice turpentine, and 1 of sweet oil,* applied hot and smoothed down with a spatula, giving a continuous slope. From the original model thus prepared a plaster negative may be

* As prepared by Mr. O. B. Harden, Topographical Engineer, 905 Walnut street Philadelphia.



F. GUTEKUNST, PRINT

cast, and from this latter any number of positives may be taken, which may be colored to represent surface features, structure, etc. Such models are almost invaluable to students, and furnish excellent subjects from which to make sketches.

231. Plate 16 is a phototype of a plaster model made by Mr. E. B. Harden, of the Second Geological Survey of Pennsylvania, showing a piece of interesting topography extending along the base of the Allegheny mountains for a length of 36 and breadth of 18 miles, known as Morrison's Cove.

This basin, nearly rectangular in plan, is enclosed by Tussey's mountain on the S. E., Dunning's mountain on the S. W. and N. W., called Lock mountain along its northern reach, and by the Juniata river on its N. E. border. It contains four drainage basins; the first, that of Yellow creek, which rises along the base of Dunning's mountain, and flows off to the S. E., through Pattonsville gap in Tussey's mountain; the second, containing tributaries of the Juniata, one following the base of Dunning's mountain from near Bakersville, another rising near Martinsburg and flowing north-westerly to join the first branch at McKee's gap, where their united waters break through the mountain and follow the N. W. slope down to Frankstown; third, the Clover Creek basin at the base of the N. W. slope of Tussey's mountain; and fourth, the Piney creek basin, at the foot of the Lock mountain ranges, both of these latter flowing N. E. and discharging into the Juniata. The waters of Canoe creek also empty into this latter stream through the Raystown branch, so that, though starting in such diverse directions, they all form part of the same general drainage area. Numerous other tributaries to this general system are represented on the model. The Little Juniata, with its Sinking Valley branch, shown on the right, joins the main stream about six miles below the Spruce Creek tunnel.*

The Lines of Communication.

232. The streams being unnavigable, transportation was at first conducted by means of the Pennsylvania canal, built along the Juniata river to Hollidaysburg, whence the boats were transported over the Allegheny mountains to Johnstown on the Conemaugh,

* The dividing lines of these secondary basins should be lightly sketched on the plate by the student.

via the Old Portage R. R., the location of which is still visible. This route was opened in 1834, and continued in use until 1855, when it was superseded by the present line through the tunnel. It contained 10 inclined planes, 5 on either side, having a slope of nearly 5°, and a rise of 200 feet each.

The main line of the Pennsylvania R. R. follows the Little Juniata river, which it crosses frequently from Spruce Creek tunnel northwesterly 7.4 miles to Tyrone (not on model). Thence it makes a right angle to the south-west, proceeding to Altoona 14.3 miles. From this point it rises rapidly *via* the celebrated Horse-shoe curve, with its radius of 546 feet, to the tunnel at Galitzin, 12 miles further, ascending in these 33.7 miles about 1,400 feet.

The feeders are the Morrison's Cove and Williamsburg branches, with short spurs to the Bloomfield and Springfield mines. A line is also being surveyed for an extension of the Williamsburg branch along Clover Creek at the base of Tussey's mountain, and through the Pattonville Gap *via* Yellow Creek to Mount Dallas in Bedford county, where it will connect with the Bridgeport & Cumberland R. R.

The common roads, with few exceptions, follow the valleys and wind through the gaps, which are the key points of the topography.

233. RELATIONS BETWEEN THE TOPOGRAPHY AND GEOLOGY OF BLAIR COUNTY.*

The topography of Blair county depends directly on the character and structure of the underlying rocks. The soil is made from disintegration of the rocks in place, there being only a few unimportant spots where there is any mass of foreign material. The district can be divided into limestone, slate and sandstone.

The limestones make the large level valleys of Morrison's Cove and Canoe Valley; the slates, the small valleys; and the sandstones, the mountains. The topography of the county is somewhat intricate, and beautifully illustrative of the geological structure.

There are three kinds of mountains—the anticlinal, the syncli-

* From Report T, by Flanklin Platt and R. H. Sanders, Assistants on Second Geological Survey of Pennsylvania.

nal, and the monoclinal. The first two have no well defined representatives, the only specimens are the short parts of the mountains of formation IV. (Medina S. S.), as in Tussey's and Dunning's mountains, where they turn around the dying anti- or synclinal axes.

The anticlinal points are the south end of Leathercracker Cove, west of Raven's Gap, north-east of Cove Forge, east of Williamsburg; S. W. point of Dunning's and Loop mountains, and the south end of Brush mountain. The synclinal points are S. W. of Henrietta; a point just east of Cove Forge; junction of Loop and Lock mountains; junction of Canoe and Brush mountains, and the mountain called the Blue Knob (not located).

The best illustration of an *anticlinal point* is found at the S. W. end of Brush mountain. The two prongs of the mountain approach each other at nearly the same angle to the anticlinal axis, and having about the same elevation and slope, their junction is a symmetrical formation. When the anticlinal is regular, the curve on the side is also regular, making an arc of a circle the radius of which varies with the dips.

The *synclinal point* at the junction of Brush and Canoe mountains, near Arch spring, shows a regular curve resulting from a dip nearly equal on the three slopes.

An instance of an *overturned synclinal* is found at the mountain end S. W. of Henrietta, and is the only one in the county. The rock has almost the same dip on both sides of the axis, forming a long narrow ridge, most of which has been eroded.

The general formation of the mountains in Blair county is the *monoclinal*, modified only according to the degree of the dip, and so divided into three classes.

First. *When the angle of the dip is from 40° to 60° away from the anticlinal*, as occurs in Tussey's mountain from Henrietta to Williamsburg.

The section taken S. E. shows a gentle rise from the limestone valley (II.), across the slates (III.) to the foot of the mountain, whence the ground slopes up at an angle of 13° to the top of the bench, which extends back 400 feet, flat, followed by a fall of 20 feet in 400, a gentle rise for 800 feet, and a sharper rise of 10° for 1400 feet to the main crest, which has an average width of 100 feet, and finally a slope down to the valley below, first on an angle of 7°, flattening out to one of 3°.

Second. *When the dip is vertical*, as in Dunning's mountain, north and south of McKee's gap, and south of Little Juniata gap. In this case the section is nearly the same as above, except that from the edge of the bench there is no flat, but a continuous gentle rise to the crest, increasing in steepness as it approaches the summit.

Third. *When the dip is overturned.* Here the section is similar to 2, but the crest and bench are nearer the same elevation, and the crest is cut by numerous notches.

It will be observed that the inner slopes of the mountains surrounding the basin are deeply scored by ravines and spurs, whilst the outer slopes are smooth. These spurs and benches all lie in formations III. (the Hudson river shales) and IV. (the Medina and Oneida sandstones), and are so placed as to expose the edge of the strata to the weather, dipping away from their respective anticlinals overlying the valley. These indentations are consequently attributed to the normal action of natural agents in eroding the soft rocks of III., capped by the harder of IV., which being unsupported break off, whilst the outer slopes, being formed of rocks the dip of which conforms more nearly to that of the slopes, are not so readily affected, and hence remain comparatively smooth.

234. EXERCISES.

1. Lay out a system of triangulation for the survey of the area included within this model, marking the triangle sides in red ink.

2. Select two base sites—one for the initial, the other for the verification base.

3. Trace a line for a common road from Frankstown to Rebecca Furnace.

4. Describe the character and location of the road from Spruce Creek to Hollidaysburg.

NOTE.—The student should be required to practice sketching, in contours, from plaster models, as giving him at once a better general view of the field, and revealing at a glance the relations of parts to the whole. It will be found to furnish the best kind of training both of hand and eye.

The models of Mr. Harden are not distorted, having the same vertical and horizontal scales, thus giving a perfectly natural representation.

CHAPTER XV.

FIELD SKETCHING.

235. It is only after considerable experience with the more reliable instruments of precision that the topographer can hope to make a comparatively accurate graphical projection of the field without their aid. The hand instruments which may be employed in this class of work have already been fully described, and the general method of proceeding does not differ materially from that of a reconnaissance which is filled in at the time it is made.

236. The quality most needed here is the ability to convert a perspective view, on a vertical plane, into a horizontal projection, without the geometrical and mechanical assistance available in an instrumental survey. The eye must be so trained as to measure the relative degrees of slope of a distant eminence, and the hand so skillful as to project the same in contours, showing the horizontal equivalents for the estimated degrees of inclination. The distances and directions to the details must be correctly adjudged and delineated, and so conventionalized as to be understood by any one familiar with such matters.

The converse of this qualification should also be cultivated, that, is the ability to convert the projection as given in the drawing or sketch into the perspective as it would exist were the reader placed at any particular point of sight. Thus on Sheet 4 is shown the relation between these two views, as revealed at the eastern end of the Panther Creek Basin at Mauch Chunk. As will be seen at once, the details of buildings, etc., may vary *ad libitum*, but the topography should be well defined and unmistakable.

The ability thus to interpret a chart is of great value, especially in military operations; but it is possessed by comparatively few persons. It may be cultivated by assuming a point of sight on a contour map, and making a sketch of the horizon, outlining the intermediate features. The vegetation, unless sketched in plan, will of necessity be imaginary; but in mountainous countries it may be assumed that the slopes are covered with timber.

237. In sketching, the topographer bases his drawing upon some line, known or measured, as a road, or the known distance between any two objects. He may even, in emergencies, assume this latter distance, and make his scale from it, in which case the relative position of the objects in the sketch will not be affected; but the actual distances cannot be relied upon until the assumed base has been measured, and the scale readjusted. The accuracy of his work will be greatly increased if he provide a very light tripod with a plane table or tablet attached, or a simple Jacob's staff, to support his sketch whilst he sights to the points to be located. By proceeding thus from point to point, a network of triangles will be formed by intersection, giving a large number of stations from which the contours may readily be sketched by a hand-level and scale of equivalents drawn on the tablet.

238. It is best to begin at the lower levels and work up, since the eye will more readily determine a level line than one of various degrees of elevation or depression.

239. In all survey work, whether run with instruments or merely sketched, the principal lines should be made as long as possible, and all secondary features be located by offsets, always when possible working from greater to lesser, that the errors may be reduced instead of being magnified. The scale of the sketch should therefore be as large as is necessary to show all important objects.

240. From these general remarks it will appear that there are several distinct operations required in sketching, viz.: the selection and measuring of a base, and fixing stations of the triangulation by intersection; traversing the roads and streams, and sketching in the details, and finally determining the elevations and filling in the contours. It is only after considerable practice that all these operations can be conducted simultaneously.

241. Should there not be time for this, the relative elevations may be represented on the finished sketch by horizontal or vertical hachures, as shown in Plate 5, roughly sketched with a pen, and having the heights marked on at the points where they may have been taken.

CHAPTER XVI.

APPLICATIONS.

242. A CORRECT contour survey being completed and the map made, the topographer's work may be assumed to be done; but it is not so, for the knowledge he has acquired of the country over which he has tramped, and with every foot of which he is thoroughly familiar, will render him more competent than any one else can possibly be, to make the application of his data to the engineering works proposed.

These may include such projects as the location of any of the lines of communication, such as roads, railroads, or canals; the laying of conduits, for the conveyance of water, oil, or other fluids, either by gravity or by pumping; the selection of the best route for pneumatic tubes; the determination of a system of drainage, sewerage, or irrigation; the selection of the proper site for cities, and the adaptation of their plans to the topography; the laying out and improvement of parks, the drainage of lakes, marshes, mines, and a variety of other problems involving the health and prosperity of large communities.

It is seldom, indeed, that the topographer possesses the qualifications necessary to make all these applications in the most skillful manner; and hence he should, when desired, associate with himself some specialist in the particular direction of his operations. Where this is impracticable, and in unimportant cases, he may undertake the work himself by attention to the few general outlines and principles which follow, in connection with special works of reference.

COMMON ROADS.

To Make a Map-Location of a Common Road, Between Two Given Points, Having Given the Maximum Gradient.

243. Without entering here into a consideration of the relations between traffic, motive power, surface-covering, friction, and all

other forces which go to determine the gradient, which are questions for the expert road-builder, let us assume at once that the limiting gradient on a portion of the line is to be five feet in one hundred, or a five per cent. grade.

Having the map before us with the terminal points marked, set a pair of dividers to the base corresponding to the vertical interval between the contours, and to the scale of the map, which is readily done by a simple proportion.

With the dividers so set, start at the given point, as P, SHEET 3, and describe an arc from it as a centre, cutting the next lower contour (27); from this intersection as a centre, with the same radius, describe an arc cutting (24), and so on. The line joining these centres will be a surface-line on the assumed grade (in this case $\frac{3}{100}$), and will be the cheapest road that can be built upon the given conditions. Crossing the stream at (TT′), upon a level 6′ above the water, to reach the top of the hill at V, the grade must be increased to $\frac{5}{100}$ or $\frac{1}{20}$; and the centre line is located in the same manner, but with a radius of 60′, as that will be the base for a rise of three feet. Descending from V to W, the grade is the same; but from W to X it is reduced to $\frac{5}{200}$ or $\frac{1}{40}$, to prevent cutting at X. From Z back to P two routes are shown, which are the shortest for the given grade $\frac{3}{100}$, although a third might be located following the stream to a point M, where it must be diverted to N, and thence zigzag up the hill, but it would be longer than the others. The two distances ZxyzSR and Zx′y′z′R are equal; but the first gives a more graceful curve, and will require less construction, the part SR being supposed to have been already built for the descending grade.

The centre line as thus determined, will be an irregular line, which may be greatly improved in plan by rounding off the angles; but at the same time increasing the cuts and fills, and adding to the cost of the work. If, however, by so doing distance is saved, and the expenses of maintenance and operation thereby reduced, the improvement would be economical and justifiable. The centre line having thus been rectified on the map, may be located in the field, by co-ordinates from known points, or as in railroad work, and the side stakes be put in ready for a final estimate. The preliminary estimate may be prepared from the sections taken from the contour map, when it is made with sufficient accuracy.

Should the Road Go Over or Around a Hill?

244. Were the hill hemispherical in shape, there could be but one answer, as the *distances* are the same; and as the power required to haul a load up one foot is found to be, on an average road, about twenty times that necessary to move it on a level, it follows that so far as *power* is concerned, the level road would have greatly the advantage. In *time* also, the query must be decided in favor of the level track.

When time is omitted from the question, and the load or road such that the horse must walk, the length may be increased twenty-fold without loss of power; but generally the roundabout way may be kept within this limit by adopting an easy grade.

245. The maximum and minimum limits of grades on common roads may be taken at $\frac{5}{100}$ (for ordinary traffic) to $\frac{1}{1000}$ (for drainage), although they frequently exceed these limits in both directions.

246. The nature of the surface-covering has also a very sensible effect upon the tractive power, being $\frac{1}{5}$ of the load for sand; $\frac{1}{10}$ for gravel; $\frac{1}{20}$ for hard clay; $\frac{1}{30}$ for good cobble stones; $\frac{1}{40}$ for ordinary Belgian blocks; $\frac{1}{50}$ for best French Macadam; $\frac{1}{60}$ for good Belgian blocks; $\frac{1}{133}$ for asphalt; $\frac{1}{166}$ for granite tramways, and $\frac{1}{200}$ for iron tramways; the pace, in all cases, being "at a walk."

247. An examination of the road, as indicated on SHEET 4, from Mauch Chunk to Summit Hill, shows a tortuous location with undulating grades which, in some instances, are descending in the directions mentioned, causing a waste of energy. The road also from Nesquehoning up Rhume Run Gap is still more objectionable for the same reasons, being very crooked and undulating, particularly near the Old Hacklebarney Tunnel.*

Other roads on this chart may be very much improved in both vertical and lateral adjustment.

248. On SHEET 9 (scale $\frac{1}{100000}$), will be found some very inter-

* The student should determine the total difference of level between termini in these cases, and make an improved location, when possible on a uniform grade, determining the distance saved.

esting pieces of road location through the San Gottardo pass of the Alps. The main road, winding up the valley of the Ticino, reveals an unusual development in climbing the spurs near Airolo and the Alpe di Sarescia. The rise from Airolo to the bridge over the Tremola is (1536—1179) 357 meters, or 1171 feet, in an air-line distance of about 3300 feet, whilst by the road it is more nearly 3½ times as far, or about two miles. A similar series of zigzags is required to overcome the (2114—1536) 578 meters rise to the summit just beyond the lakes at Ospizio. From this point, 6934 feet high, the road rapidly descends the Reuss River to the villages and lakes on the north. At Andermatt (1444 m.), a branch road winds up the Oberalp, crossing the divide just south of the Oberalp See, at an elevation of (2052 m.) 6730 feet, and passing thence, by frequent flexures, descends the Vorder Rhein to Sedrun, and other points on the tributaries of the Rhine.

From this map merely a general idea can be obtained of the topography, as the elevations are only given at particular points; and hence it is of but little practical use in the location of roads, other than to determine their general directions. It is of no use for estimates, the scale being too small, and the hachure method of representation being valueless for the purpose.

RAILROADS.

249. In the case of a railroad, the above principles are slightly modified to meet the altered conditions. After the grades have been adjusted to the profile, the paper location of the centre-line on the contour map may be made as follows: From a table of grades computed from the profile, the *intersecting or zero curve* is located on the plot. This curve is the line of intersection of the surface by the plane of the proposed road bed, through the assumed grade lines. It is, therefore, a surface line, rising and falling with the grades, and thus intersecting the contours; or it is the line of no cut or fill, hence called the zero curve, and it is evident that the nearer the centre line of the road bed conforms to this zero line, the less will be the amount of work in construction. As, however, this would make too sinuous a location, it is equalized, but conforming as nearly to it as is consistent with other conditions, especially those of cost of maintenance and operation, which are functions of distance.

250. The zero curve is thus found: Assume the cut at any station to be 6 feet, and the surface slope $\frac{12}{-1}$ to the left; then the zero point will be found 72 feet to the left of the centre; plot it by scale and mark it zero. If it were a fill in the above instance, the point would be on the right. If the surface of the ground were level, it could never intersect the road bed, and the distance to zero point would be infinite. Other points are found opposite each station in the same manner.

The centre line having been adjusted with reference to this zero line, and a due regard to distance and amount of work, the curves are drawn in by means of paper or metal templates, representing various degrees of curvature made to the scale in use, and the tangent points marked. If necessary, an approximate estimate may now be made from the contour map, taking the sections from the contours and the location be re-adjusted, to reduce cost or distance, or both.

The field location is made from notes taken from this paper plot, but frequent modifications may be made to "fit the line" more closely to the ground.

The cross-section to be given to the road bed will vary with the number of tracks and character of the work and material. The side slopes may be based upon those of the surface; for example, when the latter make a less angle than 20°, the side slopes in cuts should be 1½ to 1; between 20° and 35°, they should be 1 to 1; and when they exceed 35°, a retaining wall becomes a necessity for earth. The batter of the face of the wall is usually 5 on 1. Compact dry clay or gravel will stand vertically for a short time. The slope of earthen embankments is generally 1½ to 1; and when they rest on a steep surface, footings or steps should be cut in it, or a low retaining wall built to hold it in place. Brush and logs are sometimes employed for this purpose.

251. One of the earliest railroads in the United States, familiarly known as the Switchback or Gravity Railroad, is that built in 1827 by Josiah White and Erskine Hazard, to connect the Summit Hill coal quarries with the Lehigh river at Mauch Chunk. (SHEET 4.) Since the completion of the Nesquehoning tunnel, 4.000 feet long, early in 1875, the road has been devoted almost exclusively to pleasure travel. It rises from the river by an inclined

plane to the summit of Mt. Pisgah, thence crosses a gap on a trestle, and continues on a descending grade to "Foot of Plane" at White Bear, below Mt. Jefferson. Rising thence to the engine house, it again descends to Market street on the "Summit." From here trains may be run *via* No. 2 Slope, Centreville and Jamestown, or by way of No. 1 Engine House and Jamestown, to the mouth of the Nesquehoning tunnel, and thence through to the N. V. R. R.; or they may follow the windings of the old gravity road back to Mauch Chunk, without employing any other power than that furnished by the stationary engines on Mts. Pisgah and Jefferson.

A similar railroad has been suggested for Fairmount Park, Philadelphia.

The adaptation of a line of railroad to the mountainous district of Pennsylvania, is clearly shown in Plate 16, and has been sufficiently described under the chapter on Modelling, (xv) page 166.

252. It remains, however, to call attention to an ingenious device for overcoming topographical obstacles when the valley having a rapidly rising grade furnished no lateral ravines for the development of the line, as in the

APPROACHES TO THE ST. GOTHARD RAILROAD TUNNEL, SWITZERLAND, SHEET 9.

In the location of this important connecting link between Germany and Italy, the limiting gradients were $\frac{1}{37}$ or 142.56 feet per mile, and the minimum radius of curvature between Amsteg and Biasca 918 feet. The ordinary limit, on other parts of the line, was 984 feet.

But even with these high limits, a sufficient height could only be obtained by constructing helicoidal tunnels, curving around inside the mountains, and thus gaining height at the expense of distance. Seven out of the forty-three tunnels in the approaches are of this character. In one, No. 34 (near Fiesso), the line crosses itself in the mountain, making more than a complete turn underground. Three of these developments are shown within the limits of the chart on the northern slope, and two, of the four, on the southern.

They are numbered, respectively, 19, 22 and 26, on the Swiss, and 34, 37, 41 and 43, on the Italian side, and their lengths are: for 19, 4877 feet; 22, 3575 feet; 26, 3591.6 feet; 34, 5107 feet; 37, 5103.9 feet; 41, 5087 feet, and 43, 4901 feet.

The main tunnel through the summit, from Airolo to Geschenen, has a length of 48,887 feet, or 9¼ miles, and the total length of the remaining 42 tunnels is 67,269.8 feet, or 12.74 miles, making a total of 22 miles of tunneling in a length of 66.75 miles of line, being one-third of the entire distance.

253. The St. Gothard tunnel lies nearly on the meridian, the variation at the north end being 4° west, and passes through the mountain at the Geschenen end, at a height of 3639 feet, and at the Airolo end, of 3757 feet, having a rising grade from the north end of 31.26 feet per mile, and from the south end of 10.56 feet per mile, with a short level stretch of 590 feet at the centre.

The highest point over the line of the tunnel is 9513 feet above tide.

The surveys for this line were made between 1850 and 1860; but the organization of the company was not affected until 1871, after the close of the Franco-Prussian war, and on the 7th of August, 1872, a contract was made with M. Favre, for its construction.

Canals.

254. The same general principles apply to the location of artificial water channels as to those by land. The number and lift of locks, and the approximate amount of earthwork required to remove any barrier, can be readily determined from the map.

255. As a simple and historical illustration, let us cite the work now being carried on at the Isthmus of Corinth, in Greece (Plate 17.).

This neck of land lies between the Geranian Hills, which rise on the north to a height of 2900 feet, and Mount Oniens on the south, 2000 feet high. The divide is about 260 feet above sea-level, and is comparatively narrow, so that on the whole line the solid rock through which the canal cuts is only about 2½ miles long; the remainder of the distance being alluvium, easily dredged.

At the foot of the ruins of the ancient City of the Isthmus, a sinuous valley extends southwesterly into the body of the central mass. At the western side is a shallow valley, facing on the Bay of Corinth. These natural features led to the project marked Location No. 2, by which the length of the through cut would have been made somewhat less, but the total length greater than that in No. 1.

As early as the time of Periander, the Tyrant of Corinth, (628 B. C.,) this idea was suggested and discussed; but it was not undertaken until the second half of the 1st century, when Nero caused important explorations to be made. The work was subsequently abandoned, because of the supposed great difference ot level of the waters in the bay and gulf. The shafts and excavations then made, and which still remain, will be utilized on the present works, begun April 10, 1881, and which are expected to be completed in four years from that date.

The length of Location No. 1 is 20,800 feet, or very nearly 4 miles, and the depth at the crest is 256 feet above sea-level, while on line No. 2, the length is 22,100 feet, and height 239 feet. A third line (not shown) was also surveyed, but abandoned as being much longer and more expensive.

Location No. 1 was selected, first, because it was straight; second, because the surface drainage could be more readily kept out of the cut; third, because the rock was softer than the sandstones found on the other routes, as shown by ancient quarries; fourth, because it was shorter and required less excavation.

As the tides in the Bay of Corinth never exceed fifteen inches, and in the Gulf four, no trouble is anticipated from this source. In cross section the canal will resemble that at Suez, having a width of 72 feet at bottom, and a uniform depth of 26.3 feet.

The maximum depth of the cut, as shown on the profile, is 284.7 feet to bottom, being the largest of its kind in Europe; but it is far surpassed by the drainage cut of the Desagüe de Huehuetoca in Mexico, which is 12½ miles long, and for a length of about half a mile has a depth varying from 160 to 200 feet.

The Corinth canal contains about 13,080,500 cubic yards of material. The cut will be spanned by two bridges and surmounted by a light-house.*

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* For a complete description, see "AMERICAN ENGINEER," Chicago, October 13 and 20, 1882, from which these extracts have been taken.

TRANSPORTATION OF FLUIDS—PIPE LINES.

256. Until recently, it was the custom to carry such valuable fluids as petroleum in casks or tank-cars, requiring the movement of a large percentage of "dead load." In 1876 the project of conducting it for long distances in pipes was successfully accomplished by the engineer* of the Tidewater Pipe Line Company (Limited). Amongst the various problems presenting themselves, were those of determining the *hydraulic gradient*, which would ensure a given discharge in a pipe of given diameter, working under a given head, and to so distribute the pumps over the route that the work of the several sections should be equal.

The practice in the oil regions to that date, had been to locate pumps at regular intervals, involving in some cases great waste of power. By a simple application of the hydraulic gradient to the profile, a very successful solution of the difficulty was obtained. To illustrate, let $h =$ the head, and $l =$ the length, both in feet; then $\frac{h}{l}$ is the expression for the hydraulic gradient, or the inclination at which the fluid will flow by gravity, giving the same velocity and discharge as if forced through a pipe of equal length under a pressure equal to the difference of level between the two ends of the inclined pipe, and the discharge would be constant if the pipe were indefinitely extended with this inclination. The general formula for the discharge is $D = C\sqrt{\frac{h}{l}}$, in which C is a constant, differing with the fluid, diameter of pipe, etc., etc., hence the discharge varies directly as the $\sqrt{\text{of the head}}$ or pressure and inversely as the $\sqrt{\text{of the length.}}$

If a head of oil be 2550 feet = to 900 pounds per square inch, and a length of pipe, equivalent to 15 miles horizontally, be assumed, then the hydraulic gradient becomes $\frac{1}{31}$ and gravity would overcome the resistance of the pipe, giving a constant discharge for a given value of C. By changing the inclination, the discharge would vary; hence if a vertical line be drawn to represent the head, and a horizontal line for the length, the hypothenuse will be the hydraulic gradient, and any elevation below it will not affect the discharge, but any elevation above it must be added

* General H. Haupt, C. E.

to the head. The work of the pump will be the same at whatever point of the hypothenuse the discharge may be made, so that wherever the profile of the ground is intersected by the hydraulic gradient, will be the place for a new pumping station.

257. It may follow, therefore, that sections of equal work might vary from six to sixty miles in length. Also, that an elevation of 2500 feet at the pump would require no additional pressure to overcome it, while at the extreme end of the section, such an elevation would double the resistance.

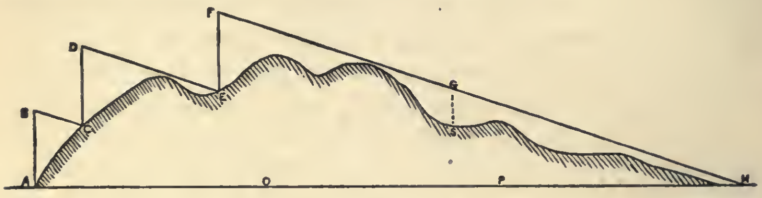

FIG. 41.

As an illustration, assume a profile, as in Fig. 41. Starting from a station A, lay off A B = 2550 feet, and draw the hydraulic gradient B C. The point C, at which it intersects the line of profile, would be the location of the second station. Lay off C D = 2550 feet, and draw a second gradient, which determines the position of the third station by its intersection at E.

The vertical distances, G S, between the line of profile and the hydraulic gradient, represent the pressures on the pipes at those points. And if they should exceed safe limits, a change of location will be required.

In Fig. 41 the distance A H, if straight and level, would require 3 pumping stations, at A, O and P. The line over the broken and irregular profile would also require but three stations, at A, C and E, and the resistance would be no greater than on the straight and level line, except from the slightly increased length of pipe.

The important problem of so locating the stations as to secure uniformity of work for each pump appears to be of very simple solution. It also appears that if stations are properly located, elevations, even high mountains, will have no influence in increasing resistances, and an air line across the country will be preferable to one following the water courses. The principles which control the location of a pipe line are, therefore, entirely different from those which are applicable to rail or common roads.

When the fluid passing through a *full* pipe is water, the formula for the discharge becomes $D = 39.27\sqrt{\frac{h}{l} \times d^5}$, in which $h =$ the head, l, the length, and $d =$ diameter in feet. $D =$ cubic feet per second.

In gallons per hour, the discharge under pressure becomes $D = 1022 \sqrt{\frac{d^5 h}{l}}$. These formulæ show how important a factor the diameter of the pipe becomes.

FLOW OF WATER IN OPEN CHANNELS, OR PIPES PARTIALLY FILLED.

258. In this case, which is that of an irrigation ditch, a feeder for a canal, an aqueduct, or a sewer, the general formula becomes

$$D = 100\, a \sqrt{\frac{h}{l} \times \frac{a}{c}} \text{ in which}$$

$D =$ the discharge, in cubic feet per second.
$a =$ the area of the current, in square feet.
$h =$ the head in feet.
$l =$ the length in feet (horizontally).
$c =$ the length of the wetted perimeter, in feet.
$\frac{a}{c}$ is called the hydraulic mean depth, or hydraulic radius.

In all such problems, therefore, the topographer has simply to find or assume the values for D, a, c, and either h or l to find l or h. Having thus determined the hydraulic gradient, he can easily make the proper paper location on his contour map, from which it is readily transferred to the field.

IRRIGATION

259. In conducting irrigation operations, a complete topographical survey becomes fundamentally necessary, and next to it, a knowledge of the character of the soils and the amount of precipitation, form important elements.

260. The plan of distribution, as used by the San Joaquin and King's River Irrigation Company in supplying the grain fields of those valleys with water, is shown in the sketch, Fig. 42, where the dotted lines represent the contours at vertical intervals of one

foot. The direction of flow is indicated by arrows. The main canal has an average elevation of 87 feet, and a fall of one foot to the mile. The primary ditches at right angles thereto have a fall of 8 feet, and the secondary or mitre ditches, of from 3 to 5 feet to the mile. From these latter, the water passes into the irrigating furrows, and thence to the catch-drain, to be used again in a lower series, or discharged into a natural water-way.

The primary ditches are here one mile apart; the secondaries one-fourth of a mile; the irrigating furrows, parallel to the former, and the "checks" to the latter, are 40 and 50 yards apart, respectively—the latter distance being measured along the furrow. One primary ditch, when full, will carry 50 feet per second, and supply

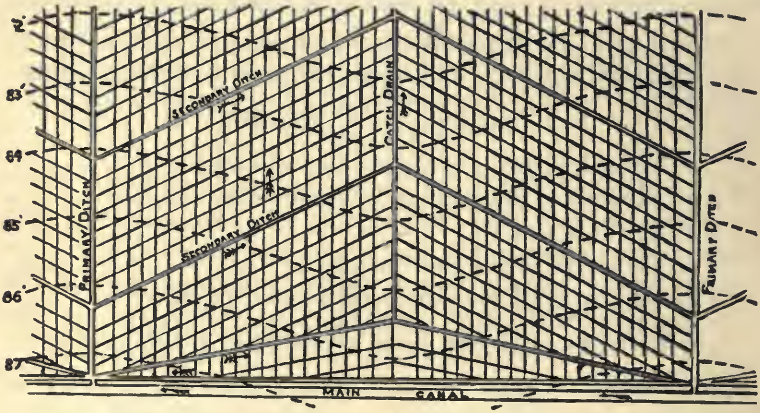

Fig. 42.

three secondaries. This is the simplest conceivable case; generally the problem is much more complicated, and will require the services of a competent hydraulic engineer.

AQUEDUCTS.

The Croton Water Shed for the Supply of New York City with Water.

261. In 1875 it was proposed to furnish the city with water taken from the Croton, Bronx and Bryam Rivers, by drawing the waters from impounding reservoirs constructed near their sources. An examination of the relative areas of the proposed basins (see Aqueduct, Enc. Brit.), shows at a glance the great

superiority of the Croton, as compared with the others, while the length of the aqueduct is less by 10 miles, thus giving a more abundant supply at less cost. The Croton water shed contains 361 square miles, and by the construction of a dam at Quaker Bridge, it is proposed to increase the storage capacity of the basin to 32,000,000,000 U. S. gallons, or a daily supply of 250,000,000 gallons for 160 days without any increase from the natural flow of the Croton. The present reservior contains 9,000,000,000 gallons, and its surface is $167\frac{17}{100}$ feet above mean tide. The new breast will be 200 feet above the same datum, making it the highest dam in the world. A new reservoir, to maintain the present supply until the completion of the large dam, will contain an additional 5,000,000,000, making the total capacity 46,000,000,000 gallons. The estimated cost of the work, including the aqueduct, 12′ diam., is $15,000,000. A complete topographical survey forms the basis for these estimates.

LOCATION OF CITIES.

262. All of the preceding applications are but means unto an end, that end being the selection of suitable sites for the establishment and maintenance, at the least possible expense, of large communities. This is the consummation of the topographer's skill, involving as it does a consideration of all the varied elements which combine to promote the health and general prosperity of a community. Towns and cities have generally originated by chance, and grown up around the forks of a road or the confluence of a stream; at a ford or near a mountain pass; over an ore-bank, or beside a water-fall. In time the facilities of transportation contributed to the growth of these centers, by building up manufacturing industries, supplying crude materials, and removing the completed products. This, in turn, created a demand for labor, thus increasing the population requiring the necessaries of life, attracting the wholesale merchant and retail dealer, with the host of professional and commission men, clerks, bankers and politicians, with their attendant servitors.

263. To all of these people, the cost of living and the health of their habitations, is largely dependent upon the topography of the immediate site of their city, as well as on that of the surrounding territory for many miles.

Thus, the facility for obtaining a supply of good water, of re moving sewage, of obtaining market products by rail or water, of procuring cheap fuel, suitable building material, good road-covering, etc., depend largely upon the topography.

Some cities are the outgrowth of political considerations, and are selected with reference to the social and legal necessities of a county, State or confederation of States, in which case the question of geographical position plays an important part in their growth and location.

264. It is, therefore, evident that the physical elements which enter into the problem of founding a city are, the *topography*, *hydrography*, *geology*, and *geography*, whilst the social elements are, the personal, political, industrial, agricultural, educational, religious, and others. It is only with the former that the topgraphical engineer has to deal directly.

265. In cities which have grown at hap-hazard, the municipal works are generally neglected until they become necessities. Then the much-needed improvements are introduced on a scale to meet immediate demands. Additions are made as the community increases, and the earlier works becoming too limited in capacity, must be torn out and replaced by larger conduits. Each system for gas, water, sewage, power, heat, etc., must be laid in its separate trench, with its corresponding house or mill connections, thus rendering it impossible to keep the streets in proper order. All this confusion may readily be prevented by the prescience of the topographer, backed by a wise policy on the part of the projectors of new towns and cities.

266. A careful survey and study of the physical elements above mentioned, will enable the founders to form some conception of the future magnitude of the place, just as the railroad engineer must estimate the future tonnage of his road before driving a stake for the location; and they should make provision for it by adapting the grades and plans of the streets, their widths and the size and form of the blocks and lots to those conditions, and by providing sub-ways, in which all the veins and arteries of a great city may be laid, and where they would readily be accessible without injury to the street surface. These sub-ways should be placed under the rear of the lots, be thoroughly drained and

well ventilated. For sanitary reasons, the houses should be placed with their angles facing the cardinal points; but this is secondary to the adaptation of the street lines to the topography for good drainage and easy traffic.

267. In illustration of these general principles may be cited the cities of New York, Philadelphia, Boston, Baltimore, and other seaports; Chicago, Detroit, Cleveland, Buffalo, Erie, and other lake ports; St. Paul, St. Louis, Cincinnati, New Orleans, and other river ports (all places of concentration and trans-shipment), and Minneapolis, Denver, Leadville, Lowell, Altoona, and others, important manufacturing, milling and mining centres. In all these instances the rapid growth was due to a combination of elements, and often in the face of a defective local topography. Thus at Chicago and New Orleans, the surface is so low and wet that it is generally impossible to build cellars, and very difficult to drain the streets and dwellings; but the surrounding county to a great distance is so productive, and the facility of access and trans-shipment so readily available, that the growth became rapid and permanent, notwithstanding these natural obstacles.

The presence of Chicago river was no doubt the determining feature in the selection of that particular point.

New York, Boston and Baltimore, are largely built upon rocks and swamps, making foundations difficult and expensive. Philadelphia upon alluvium, between two rivers, with sufficient elevation to furnish an admirable drainage and supply system, which has unfortunately not been fully improved, because of the pernicious system of making public improvements under a hydra-headed management. Minneapolis, one of the most beautiful of Western cities, has accumulated great wealth from its unrivalled water power; whilst its consort, St. Paul, at the head of navigation on the Mississippi, has developed a commercial activity which places it in the front rank as a center of distribution for the Northwest.

268. It will be found to be a law, almost without exception, that the largest towns of the West are on the remote banks of the navigable streams, forming centres of supplies for the divergent immigration.

CONCLUSION

269. From the above summary of the duties of the topographical engineer, it would appear that the qualifications mentioned in the introduction were none too stringent, and the importance of his work can hardly be over-estimated.

Whilst we have nought to do with the moral training of the topographer in the pages of a book, it may not come amiss for him to remember that a reputation for honesty, fidelity, temperance, affability, and other virtues, added to intelligence, energy, and skill, will undoubtedly conduce greatly to his success as an engineer, as well as to his usefulness as a man.

By diligently applying the principles embraced in these pages, it is hoped that he will, in a short time, find himself possessed of sufficient knowledge and tact to enable him successfully to engage in the practical work of the profession.

APPENDIX A.

TOPOGRAPHIC FEATURES PRODUCED BY PHYSICAL AGENCIES.

There is a universal tendency on the part of meteorologic agents to produce changes of form which are characteristic of such agencies, so that the form becomes typical of the force which produced it, and by which its character, direction, and relative intensity may be measured.

The ability to distinguish these elements from their resulting forms is one of great moment to the topographer and engineer in designing works intended to resist them. To this end considerable space is given to a consideration of the physical agencies which are continually modifying the face of nature, and for this purpose no more classic exposition of recent date is to be found than that of Mr. Grove K. Gilbert, Chief Geologist of the United States Geological Survey, as published in the Fifth Annual Report of the Director for 1883-4, from which the following pages are to a great extent reproduced.

EARTH SHAPING.

The moulding of the earth's details as determined by the circulation of the fluids which encircle it may be divided into three parts:—1. Subaërial shaping (land sculpture). 2. Subaqueous shaping (submerged formations). 3. Littoral (shore) shaping. In each case the process is threefold, comprising erosion, transportation and deposition.

In subaërial or land shaping the agents of erosion are meteoric —rain, acting both mechanically and chemically; streams, and frost. The agent of transportation is running water. The condition of deposition is diminishing velocity.

In subaqueous shaping, or the moulding of surface which takes place beneath lakes and oceans, currents constitute the agent of erosion. They constitute also the agent of transportation; and the condition of deposition is, as before, diminishing velocity.

In littoral shaping, or the modelling of shore features, waves constitute the agent of erosion. Transportation is performed by waves and currents acting conjointly, and the condition of deposition is increasing depth.

On the land the amount of erosion vastly exceeds the amount of deposition. Under standing water erosion is either nil or incomparably inferior in amount to deposition.

The products of littoral erosion undergo division, going partly to littoral deposition and partly to subaqueous deposition. The material for littoral deposition is derived partly from littoral erosion and partly from land erosion.

That is to say, the detritus worn from the land by meteoric agents is transported outward by streams. Normally it is all carried to the coast, but owing to the almost universal complication of erosion with local uplift, there is a certain share of detritus deposited upon the basins and lower slopes of the land. At the shore a second division takes place, the smaller portion being arrested and built into various shore structures, while the larger portion continues outward and is deposited in the sea or lake. The product of shore erosion is similarly divided. A part remains upon the shore, where it is combined with material derived from the land, and the remainder goes to swell the volume of subaqueous deposition.

The forms of the land are given chiefly by erosion.

Since the wear by streams keeps necessarily in advance of the waste of the intervening surfaces, and since, also, there is inequality of erosion dependent on diversity of texture, land forms are characterized by their variety.

The forms of sea beds and lake beds are given by deposition. The great currents by which subaqueous sediments are distributed sweep over the ridges and other prominences of the surface and leave the intervening depressions comparatively currentless. Deposition, depending on retardation of current, takes place chiefly in the depressions, so that they are eventually filled and a monotonous uniformity is the result.

The forms of the shore are intermediate in point of variety between those of the land and those of the sea bed; and since they alone claim parentage in waves, they constitute a distinct class.

Ocean shores are genetically distinguished from lake shores by the coöperation of tides, which modify the work accomplished by waves and wind currents.

The phenomena of ocean shores are therefore more complicated than those of lake shores, and an exhaustive treatment of the subject would include the discussion of their distinguishing characteristics. They fall, however, without the limits of the present investigation, and in the analysis which follows, the influence of tides is not considered.

The order of treatment is based on the threefold division of the process of shore shaping. Littoral erosion and the origin of the sea-cliff and wave-cut terrace will be first explained, then the process of littoral transportation with its dependent features the beach and the barrier, and finally the process of littoral deposition, resulting in the embankment, with all its varied phases, and the delta.

WAVE WORK.

LITTORAL EROSION.

In shore sculpture the agent of erosion is the wave. All varieties of wave motion which affect standing water are susceptible of producing erosive effect on the shore, but only those set in motion by wind need be considered here. They are of two kinds; the wind wave proper, which exists only during the continuance of the wind; and the swell, which continues after the wind has ceased. It is unnecessary to discriminate the effects of these upon the shore further than to say that the wind wave is the more efficient and therefore the better deserving of special consideration. In the wind wave two things move forward, the undulation and the water. The velocity of the undulation is relatively rapid; that of the water is slow and rhythmic.

A particle of water at or near the surface, as each undulation passes, describes an orbit in a vertical plane, but does not return to the starting point. While on the crest of the wave it moves forward, and while in the trough it moves less rapidly backward, so that there is a residual advance.*

This residual advance is the initiatory element of current. By virtue of it the upper layer of water is carried forward with reference to the layer below, being given a differential movement in the direction towards which the wind blows. This movement is gradually propagated to lower aqueous strata, and ultimately produces movement of the whole body, or a wind-wrought current. So long as the velocity of the wind remains constant, the velocity of the current is less than that of the wind; and there is always a differential movement of the water, each layer moving faster than the one beneath. The friction is thus distributed through the whole vertical column, and is even borne in part by the lake bottom. The greater the depth the smaller the share of friction apportioned to each layer of water, and the greater the velocity of current which can be communicated by a given wind.† The height of waves is likewise conditioned by depth of water, deep water permitting the formation of those that are relatively large.

When the wave approaches a shelving shore its habit is changed. The velocity of the undulation is diminished, while the velocity of the advancing particles of water in the crest is increased; the wave length, measured from trough to trough, is diminished, and the wave height is increased; the crest becomes acute, with the front steeper than the back; and these changes culminate in the breaking of the crest, when the undulation proper ceases. The return of the water thrown forward in the crest is accomplished by a current along the bottom called the *undertow*. The momentum of the advancing water contained in the wave crest

* The theory of wave motion involved in this and the following paragraphs is based partly on observation, but chiefly on the discussions of J. S. Russell, Airy, Cialdi and Rankine.

† This is a matter of observation rather than theory. It implies that the friction between contiguous films of water increases in more than simple ratio with the differential velocity of the films.

gives to it its power of erosion. The undertow is efficient in removing the products of erosion.

The retardation of the undulation by diminishing depth of water changes the direction of its axis or crest line—excepting when the axis is parallel to the contours of the shoaling bottom —and the phenomena are analogous to those of the refraction of light and sound. As a wave passes obliquely from deep water to a broad shoal of uniform depth, the end first entering shoal water is first retarded and the crest line is for the moment bent. When the entire crest has reached shoal water it is once more straight, but with a new trend, a trend making a narrower angle with the line of separation between deep and shallow water. The wave has been refracted. When a wave passes obliquely from deep water to shoal water whose bottom gradually rises to a shore, the end nearer the shore is the more retarded at all stages of progress, and the crest line is continuously curved. When the wave breaks and the undulation ceases, the crest line is nearly parallel to the shore. It results that for a wide range of wind direction there is but small range in the direction of wave trend at the shore. It results also, as has been often noted, that when the wind blows normally into a circling bay, the waves it brings are diversely turned, so as to beat angularly against both sides and normally against the head of the bay.

When the land at the margin of the water consists of unconsolidated material or of fragmental matter lightly cemented, the simple impact of the water is sufficient to displace or erode it. The same force is competent also to disintegrate and remove firmer rock that has been superficially weakened by frost, or is partially divided by cracks, but it may be doubted whether it has any power to wear rock that is thoroughly coherent. The impact of large waves has great force, and its statement in tons to the square foot is most impressive; but, so far as our observation has extended, the erosive action of waves of clear water beating upon firm rock without seams is practically nil. On the shores of Lake Bonneville, not only was there no erosion on the faces of cliffs at points where the waves carried no detrital fragments, but there was actually deposition of calcareous tufa; and this deposition was most rapid at points specially exposed to the violence of the waves.

The case is very different when the rock is divided by seams, for then the principle of the hydrostatic press finds application. Through the water forced into the seams, and sometimes through air imprisoned and compressed by the water, the blow struck by the wave is applied not merely to large surfaces but in directions favorable to the rending and dislocation of rock masses.

It rarely happens, however, that the impact of waves is not reinforced by the impact of mineral matter borne by them. The detritus worn from the shore is always at hand to be used by the waves in continuance of the attack; and to this is added other detritus carried along the shore by a process presently to be described.

The rock fragments which constitute the tool of erosion are themselves worn and comminuted by use until they become so fine that they no longer lie in the zone of breakers, but are carried away by the undertow.

The direct work of wave erosion is restricted to a horizontal zone dependent on the height of the waves. There is no impact of breakers at levels lower than the troughs of the waves; and the most efficient impact is limited upward by the level of the wave crests, although the dashing of the water produces feebler blows at higher levels. The indirect work has no superior limit, for as the excavation of the zone is carried landward, masses higher up on the slope are sapped so as to break away and fall by mere gravity. Being thus brought within reach of the waves, they are then broken up by them, retarding the zonal excavation for a time, but eventually adding to the tool of erosion in a way that partially compensates.

Let us now consider what goes on beneath the surface of the water. The agitation of which waves are the superficial manifestation is not restricted to their horizon, but is propagated indefinitely downward. Near the surface the amount of motion diminishes rapidly downward, but the rate of diminution itself diminishes, and there seems no theoretic reason for assigning any limit to the propagation of the oscillation. Indeed, the agitation must be carried to the bottom in all cases where the depth operates as a condition in determining the magnitude of waves, for that determination can be assigned only to a resistance opposed by the bottom to the undulation of the water.

During the passage of a wave each particle of water affected by it rises and falls, and moves forward and backward, describing an orbit. If the passing wave is a swell, the orbit of the particle is closed,* and it is either a circle or an ellipse; but in the case of a wind wave the orbit is not closed. The relative amounts of horizontal and vertical motion depend on the depth of the particle beneath the surface, and on the relation of the total depth of the water to the size of the wave. If the water is deep as compared to the wave-length, the horizontal and vertical movements are sensibly equal, and their amount diminishes rapidly from the surface downward. If the depth is small, the horizontal motion is greater than the vertical, but diminishes less rapidly with depth. Near the line of breakers, the vertical motion close to the bottom becomes inappreciable, while the horizontal oscillation is nearly as great as at the surface. This horizontal motion, affecting water which is at the same time under the influence of the undertow, gives to that current a pulsating character, and thus endows it with a higher transporting power than would pertain to its mean velocity. Near the breaker line, the oscillation communicated by the wave may even overcome and momentarily reverse the movement of the undertow. Inside the breaker line no oscillation proper is communicated. The broken wave crest, dashing forward, overcomes the undertow and throws it back; but the water returns without acceleration, as a simple current descending a slope.

It should be explained that the increment given by pulsation to the transporting power of the undertow depends upon the general law that the transporting power of a current is an increasing geometric function of its velocity. Doubling the velocity of a current more than doubles the amount it can carry, and more than doubles the size of the particles it is able to move.

* This is strictly true only while the swell traverses deep water. It is pointed out by Cialdi that in passing to shoal water the swell is converted into a wave of translation, and the particles no longer return to their points of starting.

The transporting power of the undertow diminishes rapidly from the breaker line outward. That part of its power which depends on its mean velocity diminishes as the prism of the undertow increases; that part which depends on the rhythmic accelerations of velocity diminishes as the depth of water increases.

The pulsating current of the undertow has an erosive as well as a transporting function. It carries to and fro the detritus of the shore, and dragging it over the bottom, continues downward the erosion initiated by the breakers. This downward erosion is the necessary concomitant of the shoreward progress of wave erosion; for if the land were merely planed away to the level of the wave troughs, the incoming waves would break where shoal water was first reached and become ineffective at the water margin. In fact, this spending of the force of the waves where the water is so shallow as to induce them to break, increases at that point the erosive power by pulsation, and thus brings about an interdependence of parts. What may be called a normal profile of the submerged terrace is produced, the parts of which are adjusted to an harmonious interrelation. If some exceptional temporary condition produces abnormal wearing of the outer margin of the terrace, the greater depth of water at that point permits the incoming waves to pass with little impediment and perform their work of erosion upon portions nearer the shore, thus restoring the equilibrium. If exceptional resistance is opposed by the material at the water margin, erosion is there retarded until the submerged terrace has been so reduced as to permit the incoming waves to attack the land with a greater share of unexpended energy.

THE SEA-CLIFF.

Wave erosion, acting along a definite zone, may be rudely compared to the operation of a horizontal saw, but the upper wall of the saw cut, being without support, is broken away by its own weight and falls in fragments, leaving a cliff at the shoreward margin of the cut.

One of the most noteworthy and constant characters of the sea-cliff is the horizontality of its base. Being determined by wave erosion, the base must always stand at about the level of

Plate 18.

the lake on which the waves are formed. The material of the cliff is the material of the land from which it is carved. Its declivity depends partly on the nature of that material and partly on the rate of erosion. If the material is unconsolidated, the inclination cannot exceed the normal earth slope; if it is thoroughly indurated, the cliff may be vertical or may even overhang. If the rate of wave erosion is exceedingly rapid, the cliff is as steep as the material will permit; if the rate is slow, the inclination is diminished by the atmospheric waste of the cliff face. (See Plate 18.)

It will appear in the sequel that the distribution of sea-cliffs is somewhat peculiar, but this cannot be described until the process of littoral transportation has been explained.

THE WAVE-CUT TERRACE.

The submerged plateau whose area records the landward progress of littoral erosion, becomes a terrace after the formative lake has disappeared, and, as such, requires a distinctive name. It will be called the *wave-cut terrace.*

Its prime characteristics are, first, that it is associated with a cliff; second, that its upper margin, where it joins the cliff, is horizontal; and third, that its surface has a gentle inclination away from the cliff. There is an exceptional case in which an island or a hill of the mainland has been completely pared away by wave action, so that no cliff remains as a companion for the wave-cut terrace; but this exception does not invalidate the rule. The lakeward inclination is somewhat variable, depending on the nature of the material and on the pristine acclivity of the land. It is greater where the material is loose than where it is coherent; and greater where the ratio of terrace width to cliff height is small. It is probably conditioned also by the direction of the current associated with the wind efficient in its production; but this has not been definitely ascertained.

The width of the terrace depends on the extent of the littoral erosion, and is not assignable. Its relative width in different parts of a given continuous coast depends entirely on the conditions determining the rapidity of erosion, and a discussion of these at this point would be premature.

LITTORAL TRANSPORTATION.

Littoral transportation is performed by the joint action of waves and currents. Usually, and especially when the wind blows, the water adjacent to the shore is stirred by a gentle current flowing parallel to the water margin. This carries along the particles of detritus agitated by the waves. The waves and undertow move the shallow water near the shore rapidly to and fro, and in so doing momentarily lift some particles, and roll others forward and back. The particles thus wholly or partially sustained by the water are at the same moment carried in a direction parallel to the shore by the shore current. The shore current is nearly always gentle and has of itself no power to move detritus.

When the play of the waves ceases, all shore action is arrested. When the play of the waves is unaccompanied by a current, shore action is nearly arrested, but not absolutely. If the incoming waves move in a direction normal to the shore, the advance and recoil of the water move particles toward and from the shore, and effect no transfer in the direction of the shore; but if the incoming waves move in an oblique direction the forward transfer of particles is in the direction of the waves, while the backward transfer, by means of the undertow, is sensibly normal to the shore, and there is thus a slow transportation along the shore. If there were no currents a great amount of transportation would undoubtedly be performed in this way, but it would be carried on at a slow rate. The transporting effect of waves alone is so slight that only a gentle current in the opposite direction is necessary to counteract it. The concurrence of waves and currents is so general a phenomenon, and the ability of waves alone is so small, that the latter may be disregarded. *The practical work of transportation is performed by the conjoint action of waves and shore currents.*

In the ocean the causes of currents are various. Besides wind currents there are daily currents caused by tides upon all coasts, and it is maintained by some physicists that the great currents are wholly or partly due to the unequal heating of the water in different regions. But in lakes there are no appreciable tides, but there are synchronous oscillations of considerable amplitude, due to a variety of disturbing causes which produce breakers. Currents due to unequal heating have never been discriminated. The motions of the lake waters are controlled largely by the wind.

With the shifting of the wind the direction of the littoral current on any lake shore is occasionally, or it may be frequently, reversed, and the shore drift under its influence travels sometimes in one direction and sometimes in the other. In most localities it has a prevailing direction, not necessarily determined by the prevailing direction of the shore current, but rather by the direction of that shore current which accompanies the greatest waves. This is frequently but not always the direction also of the shore current accompanying the most violent storms.

The source of shore drift is twofold. A large part is derived from the excavation of sea-cliffs, and is thus the product of littoral erosion. From every sea-cliff a stream of shore drift may be seen to follow the coast in one direction or the other.

Another part is contributed by streams depositing at their mouths the heavy part of their detritus, and is more remotely derived from the erosion of the land. The smallest streams merely reinforce the trains of shore drift flowing from sea-cliffs, and their tribute usually cannot be discriminated. Larger streams furnish bodies of shore drift easily referred to their sources. Streams of the first magnitude, as will be explained farther on, overwhelm the shore drift and produce structures of an entirely different nature, known as deltas.

THE BEACH.

The zone occupied by the shore drift in transit is called the *beach.* Its lower margin is beneath the water, a little beyond the line where the great storm waves break. Its upper margin is usually a few feet above the level of still water. Its profile is steeper upon some shores than others, but has a general feature consonant with its wave-wrought origin. At each point in the profile the slope represents an equilibrium in transporting power between the inrushing breaker and the outflowing undertow. Where the undertow is relatively potent its efficiency is diminished by a low declivity. Where the inward dash is relatively potent the undertow is favored by a high declivity. The result is a profile of gentle flexure, upwardly convex for a short space near its landward end, and concave beyond.

In horizontal contour the beach follows the original boundary between land and lake, but does not conform to its irregularities. Small indentations are filled with shore drift, small projections are cut away, and smooth, sweeping curves are given to the water margin and to the submerged contours within reach of the breakers. (See Plate 19.)

The beach graduates insensibly into the wave-cut terrace. A cut-terrace lying in the route of shore drift is alternately buried by drift and swept bare, as the conditions of wind and breaker vary. The cut-and-built terrace (Fig. 43), which owes its detrital extension to the agencies determining the beach profile, may be regarded as a form intermediate between the beach and the cut-terrace.

FIG. 43.—SECTION OF A CUT-AND-BUILT TERRACE.

THE BARRIER.

Where the bottom of the lake has an exceedingly gentle inclination the waves break at a considerable distance from the water margin. The most violent agitation of the water is along the line of breakers; and the shore drift, depending upon agitation for its transportation, follows the line of the breakers instead of the water margin. It is thus built into a continuous outlying ridge at some distance from the water's edge. It will be convenient to speak of this ridge as a *barrier*.

The barrier is the functional equivalent of the beach. It is the road along which shore drift travels, and it is itself composed of shore drift. Its lakeward face has the typical beach profile, and its crest lies a few feet above the normal level of the water (Fig. 44).

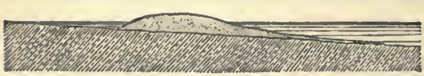

FIG. 44.—SECTION OF A BARRIER.

Plate 19.

BEACH OF LIMESTONE PEBBLES, MACKINAW ISLAND, MICH.

Between the barrier and the land a strip of water is inclosed, constituting a lagoon. This is frequently converted into a marsh by the accumulation of silt and vegetable matter, and eventually becomes completely filled, so as to bridge over the interval between land and barrier, and convert the latter into a normal beach.

The principal elements of the theory of shore-drift deposits here set forth are tacitly postulated by many writers on the construction of harbor and coast defenses. According to Cialdi* the potency of currents in connection with waves was first announced by Montanari; it has been concisely and, so far as appears, independently elucidated by Andrews.†

Still-water level is the datum with which all vertical elements of the profile of the beach and barrier are necessarily compared; and, referred to this standard, not only does the maximum height of the beach or barrier vary in different parts of the same shore, but the profile as a whole stands at different heights.

The explanation of these inequalities depends in part on a principle of wide application, which is on the one hand so important and on the other so frequently ignored that a paragraph may properly be devoted to it, by way of digression. There are numerous geologic processes in which quantitative variations of a causative factor work immensely greater quantitative variations of the effect. It is somewhat as though the effect was proportioned to an algebraic power of the cause, but the relation is never so simple. Take, for example, the transportation of detritus by a stream. The variable cause is the volume of water; the variable effect is the quantity of detritus transported. The effect is related to the cause in three different ways: First, increase of water volume augments the velocity of flow, and with increase of velocity the size of the maximum particle which can be moved increases rapidly. According to Hopkins, the size of the maxi-

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* *Loc. cit.*, p. 394, et seq. Cialdi himself maintains at great length that the work is performed by waves, and that the so-called shore current, a feeble peripheral circulation observed in the Mediterranean, is qualitatively and quantitatively incompetent to produce the observed results. Whether he would deny the efficiency of currents excited by the same winds which produce the waves is not clearly apparent.

† Trans. Chicago, Acad. Sci., vol. 2, p. 9.

mum fragment which can be moved varies as the sixth power of the velocity, or (roughly) as the $\frac{3}{2}$ power of the volume of water.* Second, the increase of velocity enlarges the capacity of the water to transport detritus of a given character; that is, the per cent. of load to the unit of water is increased. Third, increase in the number of unit volumes of water increases the load pro rata. The summation of these three tendencies gives to the flooded stream a transporting power scarcely to be compared with that of the same stream at its low stage, and it gives to the exceptional flood a power greatly in excess of the normal or annual flood. Not only is it true that the work accomplished in a few days during the height of the chief flood of the year is greater than all that is accomplished during the remainder of the year, but it may even be true that the effect of the maximum flood of the decade or generation or century surpasses the combined effects of all minor floods. It follows that the dimensions of the channel are established by the great flood and adjusted to its needs.

In littoral transportation the great storm bears the same relation to the minor storm and to the fair-weather breeze. The waves created by the great storm not only lift more detritus from each unit of the littoral zone, but they act upon a broader zone, and they are competent to move larger masses. The currents which accompany them are correspondingly rapid, and carry forward the augmented shore drift at an accelerated rate. It follows that the habit of the shore, including not only the maximum height of the beach line and the height of its profile, but the dimensions of the wave-cut terrace and of various other wave products presently to be described, is determined by and adjusted to the great storm.

It should be said by way of qualification that the low-tide stream and the breeze-lifted wave have a definite though subordinate influence on the topographic configuration. After the great flood has passed by, the shrunken stream works over the finer débris in the bed of the great channel, and by removing

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* The scouring capacity, however, or the ability to dislodge material from its bed, varies only as the square of the velocity. This distinction should be carefully observed.

at one place and adding at another shapes a small channel adjusted to its volume. After the great storm has passed from the lake and the storm swell has subsided, the smaller waves of fair weather construct a miniature beach profile adapted to their size, superposing it on the greater profile. This is done by excavating shore drift along a narrow zone under water and throwing it up on a narrow ridge above the still-water level. Thus as early perceived by De la Beche* and Beaumont,† it is only for a short time immediately after the passage of the great storm that the beach profile is a simple curve; it comes afterward to be interrupted by a series of superposed ridges produced by storms of different magnitude.

Reverting now to the special conditions controlling the profiles of beach or barrier at an individual locality, it is evident that the chief of these is the magnitude of the largest waves breaking there. The size of the waves at each locality depends on the force of the wind and on its direction. A wind blowing from the shore lakeward produces no waves on that shore. One from the opposite shore produces waves whose height is approximately proportional to the square root of the distance through which they are propagated, provided there are no shoals to check their augmentation. For a given force of wind, the greatest waves are produced when the direction is such as to command the broadest sweep of water before their incidence at the particular spot, or in the technical phrase, when the *fetch* is greatest.

A second factor is found in the configuration of the bottom. Where the off-shore depth is great the undertow rapidly returns the water driven forward by the wind, and there is little accumulation against the shore; but where the off-shore depth is small the wind piles the water against the shore, and produces all shore features at a relatively high level.

THE SUBAQUEOUS RIDGE.

Various writers have mentioned low ridges of sand or gravel running parallel to the shore and entirely submerged. As the origin of such ridges is not understood, they have no fixed

* Manual of Geology, Philadelphia, 1832, p. 72.

† Leçons, p. 226 and plate IV.

position in the present classification, and they are placed next to the barrier only because of similarity of form.

The subject is described by Russell, who visited the eastern shore of Lake Michigan in 1884. He says:

Bars of another character are also formed along lake margins, at some distance from the land, which agree in many ways with true barrier bars, but differ in being composed of homogeneous, fine material, usually sand, and in not reaching the lake surface.

The character of structures of this nature may be studied about the shores of Lake Michigan, where they can be traced continuously for hundreds of miles. There are usually two, but occasionally three, distinct sand ridges; the first being about 200 feet from the land, the second 75 or 100 feet beyond the first, and the third, when present, about as far from the second as the second is from the first. Soundings on these ridges show that the first has about 8 feet of water over it, and the second usually about 12; between, the depth is from 10 to 14 feet. From many commanding points, as the summit of Sleeping Bear Bluff, for example, these submerged ridges may be traced distinctly for many miles. They follow all the main curves of the shore, without changing their character or having their continuity broken. They occur in bays as well as about the bases of promontories, and are always composed of clean, homogeneous sand, although the adjacent beach may be composed of gravel and boulders. They are not shore ridges submerged by the rise of the lake, for the reason that they are in harmony with existing conditions, and are not being eroded or becoming covered with lacustral sediments.

In bars of this character the fine debris arising from the comminution of shore drift appears to be accumulated in ridges along the line where the undertow loses its force; the distance of these lines from the land being determined by the force of the storms that carried the waters shoreward. This is only a suggested explanation, however, as the complete history of these structures has not been determined.*

Bars similar to those described by Russell occur along the eastern coast of Lake Michigan wherever the bottom is sandy, being most frequently detectable at a depth of 13 feet, but ranging upward to 3 feet and downward to 18 feet. At the south end of the lake they are not restricted to the 5-foot zone, but range to 13 feet. A single locality of occurrence was found on the shore of Lake Erie, but none on Lake Ontario.

These ridges constitute an exception to the beach profile, and show that the theory of that profile givenabove is incomplete.

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* Geol. Hist. of Lake Lahontan, pp. 92, 93.

Under conditions not yet apparent, and in a manner equally obscure, there is a rhythmic action along a certain zone of the bottom. That zone lies lower than the trough between the greatest storm waves, but the water upon it is violently oscillated by the passing waves. The same water is translated lakeward by the undertow, and the surface water above it is translated landward by the wind, while both move with the shore current parallel to the beach. The rhythm may be assumed to arise from the interaction of the oscillation, the landward current, and the undertow.

LITTORAL DEPOSITION.

The material deposited by shore processes is, first, shore drift; second, stream drift, or the detritus delivered at the shore by tributary streams. Increasing depth of water is in each case the condition of littoral deposition. The structures produced by the deposit of shore drift, although somewhat varied, have certain common features. They will be treated under the generic title of *embankments*. The structures produced by the deposit of stream drift are *deltas*.

EMBANKMENTS.*

The current occupying the zone of the shore drift and acting as the coagent of littoral transportation has been described as slow, but it is inseparably connected with a movement that is relatively rapid. This latter, which may be called the off-shore current, occupies deeper water and is less impeded by friction. It may in some sense be said to drag the littoral current along with it. The momentum of the off-shore current does not permit it to follow the sinuosities of the water margin, and it sweeps from point to point, carrying the littoral current with it. There is even a tendency to generate eddies or return currents in embayments of the coast. The off-shore current is moreover controlled in part by the configuration of the bottom and by the necessity of a return current. The littoral current, being controlled in large part by the movements of the off-shore current, separates from the water margin in three ways: first, it continues its direction unchanged at points where the shore-line turns landward, as at the entrances of bays; second, it sometimes turns

* Plate VII, Beach, etc.

from the land as a surface current; third, it sometimes descends and leaves the water margin as a bottom current.

In each of these three cases deposition of shore drift takes place by reason of the divorce of shore currents and wave action. The depth to which wave agitation sufficient for the transportation of shore drift extends is small, and when the littoral current by leaving the shore passes into deeper waters the shore drift, unable to follow, is thrown down.

When the current holds its direction and the shore-line diverges, the embankment takes the form of a *spit*, a *hook*, a *bar*, or a *loop*. When the shore-line holds its course and the current diverges, whether superficially or by descent, the embankment usually takes the form of a *terrace*.

THE SPIT.

When a coast line followed by a littoral current turns abruptly landward, as at the entrance of a bay, the current does not turn with it, but holds its course and passes from shallow to deeper water. The water between the diverging current and coast is relatively still, although there is communicated to the portion adjacent to the current a slow motion in the same direction. The waves are propagated indifferently through the flowing and the standing water, and reach the coast at all points. The shore drift cannot follow the deflected coast line, because the waves that beat against it are unaccompanied by a littoral current. It cannot follow the littoral current into deep water, because at the bottom of the deep water there is not sufficient agitation to move it. It therefore stops. But the supply of shore drift brought to this point by the littoral current does not cease, and the necessary result is accumulation. The particles are carried forward to the edge of the deep water and there let fall.

In this way an embankment is constructed, and so far as it is built it serves as a road for the transportation of more shore drift. The direction in which it is built is that of the littoral current. It takes the form of a ridge following the boundary between the current and the still water. Its initial height brings it just near enough to the surface of the water to enable the wave agitation to move the particles of which it is constructed; and it is narrow. But these characters are not long maintained. The causes which lead to the construction of the beach and the barrier are here equally efficient, and cause the embankment to grow in breadth and in height until the cross-profile of its upper surface is identical with that of the beach.

The history of its growth is readily deduced from the configuration of its terminus, for the process of growth is there in progress. If the material is coarse the distant portion is very slightly submerged, and is terminated in the direction of growth by a steep slope, the subaqueous "earth-slope" of the particular material. If the material is fine the distant portion is more deeply submerged, and is not so abruptly terminated. The portion above water is usually narrow throughout, and terminates without reaching the extremity of the embankment. It is flanked on the lakeward side by a submerged plateau, at the outer edge of which the descent is somewhat steep. The profile of the plateau is that normal to the beach, and its contours are confluent with those of the beach or barrier on the main shore. Toward the end of the embankment its width diminishes, its outer and limiting contour turning toward the crest line of the spit and finally joining it at the submerged extremity.

The process of construction is similar to that of a railroad embankment the material for which is derived from an adjacent cutting, carted forward along the crest of the embankment and dumped off at the end; and the symmetry of form is often more perfect than the railway engineer ever accomplishes. The resemblance to railway structures is very striking in the case of the shores of extinct lakes.

As the embankment is carried forward and completed, contact between the current and the inshore water is at first obstructed and finally cut off, so that there is practically no communication of movement from one to the other at the extremity of the spit. At the point of construction the moving and the standing water are sharply differentiated, and there is hence no uncertainty as to the direction of construction. The spit not only follows the line between the current and still water, but aids in giving definition to that line, and eventually walls in the current by contours adjusted to its natural flow.

THE BAR.

If the current determining the formation of a spit again touches the shore, the construction of the embankment is continued until it spans the entire interval. So long as one end remains free the vernacular of the coast calls it a *spit;* but when it is completed it becomes a *bar.* Figure 45 gives an ideal cross-section of a completed embankment.

The bar has all the characters of the spit except those of the terminal end. Its cross-profile shows a plateau bounded on either hand by a steep slope. The surface of the plateau is not level, but has the beach profile, is slightly submerged on the windward side and rises somewhat above the ordinary water level at the leeward margin. At each end it is continuous with a beach or barrier. It receives shore drift at one end and delivers it at the other.

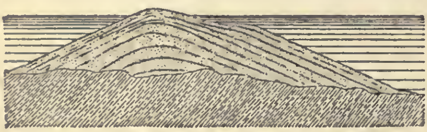

FIG. 45.—SECTION OF A LINEAR EMBANKMENT.

The bar may connect an island with the shore or with another island, or it may connect two portions of the same shore. In the last case it crosses the mouth either of a bay or of a river. If maintained entire across the entrance to a bay it converts the water between it and the shore into a lagoon.* At the mouth of a river its maintenance is antagonized by the outflowing current, and if its integrity is established at all it is only on rare occasions and for a short time. That is to say, its full height is not maintained; there is no continuous exposed ridge. The shore drift is, however, thrown into the river current, and unless that current is sufficient to sweep it into deep water a submerged bar is thrown across it, and maintains itself as a partial obstruction to the flow. The site of this submerged bar is usually also the point at which the current of the stream, meeting the standing water of the lake, loses its velocity and deposits the coarser part of its load of detritus. If the contribution of river drift greatly exceeds that of shore drift, a delta is formed at the river mouth, and this, by changing the configuration of the coast, modifies the

* See Plate 20, Bar, etc.

Plate 20.

BAR JOINING EMPIRE AND SLEEPING BLUFFS, LAKE MICHIGAN.

littoral current and usually determines the shore drift to some other course. If the contribution of river drift is comparatively small it becomes a simple addition to the shore drift, and does not interrupt the continuity of its transportation. The bars at the mouths of small streams are constituted chiefly of shore drift, and all their characters are determined by their origin. The bars at the mouths of large streams are constituted chiefly of stream drift, and belong to the phenomena of deltas.

FIG. 46.—MAP OF BRADDOCK'S BAY AND VICINITY, N. Y., SHOWING HEADLANDS CONNECTED BY BARS.

On a preceding page the fact was noted that the horizontal contours of a beach are more regular than those of the original surface against which it rests, small depressions being filled. It is now evident that the process of filling these is identical with that of bar construction. There is no trenchant line of demarkation between the beach and the bar. Each is a carrier of shore drift, and each employs its first load in the construction of a suitable road.

Figure 46 is copied from the U. S. Engineers' map of a portion of the south shore of Lake Ontario west of the mouth of the Genesee River. The original contour of the shore was there irregular, consisting of a series of salient and reëntrant angles. The waves have truncated some of the salients and have united them all by a continuous bar, behind which several bays or ponds are inclosed. The movement of the shore drift is in this case from northwest to southeast, and the principal source of the material is a point of land at the extreme west, where a low cliff shows that the land is being eaten by the waves.

FIG. 47.—MAP OF THE HEAD OF LAKE SUPERIOR, SHOWING BAY BARS.

The map in Figure 47 is also copied from one of the sheets published by the U. S. Engineers, and represents the bars at the head of Lake Superior. These illustrate several elements of the preceding discussion. In the first place they are not formed by the predominant winds, but by those which bring the greatest waves. The predominant winds are westerly, and produce no waves on this coast. The shore drift is derived from the south coast, and its motion is first westerly and then northerly. Two bars are exhibited, the western of which is now protected from the lake waves, and must have been completed before the eastern was begun. The place of deposition of shore drift was probably shifted from the western to the eastern by reason of the shoaling of the head of the lake. The converging shores should theoretically produce during easterly storms a powerful undertow, by which a large share of the shore drift would be carried lakeward and distributed over the bottom. The manner in which the bars terminate against the northern shore without inflection is explicable likewise by the theory of a strong undertow. If the return current were superficial the bars would be curved at their junctions with both shores.

Similar formations will be found at the western ends of Lakes Ontario and Erie, and a shoaling is in process at the head of Lake Michigan, due to the littoral translation of drift from the wider portions of the lakes in the same direction along the opposite shores, towards the ends, this being the direction of the wave and current movements resulting from atmospheric disturbance. (L. M. H.)

THE HOOK.

It may occur also that a spit at a certain stage of its growth becomes especially subject to some conflicting current, so that its normal growth ceases, and all the shore drift transported along it goes to the construction of an inner branch. The bent embankment thus produced is called a *hook.*

The currents efficient in the formation of a hook do not cooperate simultaneously, but exercise their functions in alternation. The one, during the prevalence of certain forces, brings the shore drift to the angle and accumulates it there; the other, during the prevalence of other forces, demolishes the new structure and redeposits the material upon the other limb of the hook.

In case the land on which it is based is a slender peninsula or a small island, past which the currents incited by various winds sweep with little modification of direction by the local configuration, the hook no longer has the sharp angle due to the action of two currents only, but receives a curved form.

Hooks are of comparatively rare occurrence on lake shores, but abound at the mouths of marine estuaries, where littoral and tidal currents conflict.

Plate 21 represents a recurved spit on the shore of Lake Michigan, seen from a neighboring bluff. The general direction of its construction is from left to right, but storms from the right have from time to time turned its end toward the land and the successive recurvements are clearly discernible near the apex.

The mole enclosing Toronto harbor on the shore of Lake Ontario is a hook of unusual complexity, and the fact that its growth threatens to close the entrance to the harbor has led to its thorough study by engineers. Especially has its history been developed by Fleming in a classic essay to which reference has already been made. A hill of drift projects as a cape from the north shore of the lake. The greatest waves reaching it, those having the greatest fetch, are from the east (see Fig. 48), and the coöperating current flows from east to west. As the hill gradually yields to the waves, its coarser material trails westward, building a spit. The waves and currents set in motion by southwesterly winds carry the spit end northward, producing a hook. In the past the westward movement has been the more powerful and the spit has continued to grow in that direction, its northern edge being fringed with the sand ridges due to successive recurvements, but the shape of the bottom has introduced a change of conditions. The water at the west end of the spit is now deep, and the extension of the embankment is correspondingly slow. The northward drift, being no longer subject to frequent shifting of position, has a cumulative effect on the terminal hook and gives it a greater length than the others. In the chart of the harbor (Fig. 49) the composite character of the mole is readily traced. It may also be seen that the ends of the successive hooks are connected by a beach, the work of waves gener-

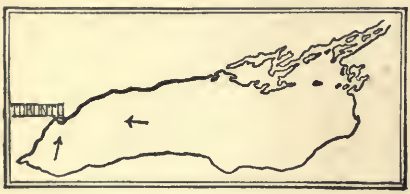

FIG. 48.—DIAGRAM OF LAKE ONTARIO, TO SHOW THE FETCH OF WAVES REACHING TORONTO FROM DIFFERENT DIRECTIONS.

Plate 21.

DUTCH POINT, A RECURVED SPIT, GRAND TRAVERSE BAY, LAKE MICHIGAN.

ated within the harbor by northerly winds.* It will be observed furthermore that while the west end of the spit is continuously fringed by recurved ridges its eastern part is quite free from them. This does not indicate that the spit was simple and unhooked in the early stages of growth, but that its initial ridge has disappeared. As the cliff is eroded, its position constantly shifts landward, the shore current follows, and the lakeward face of the spit is carried away so that the waves break over it, and then a new crest is built by the waves just back of the line of the old one.†

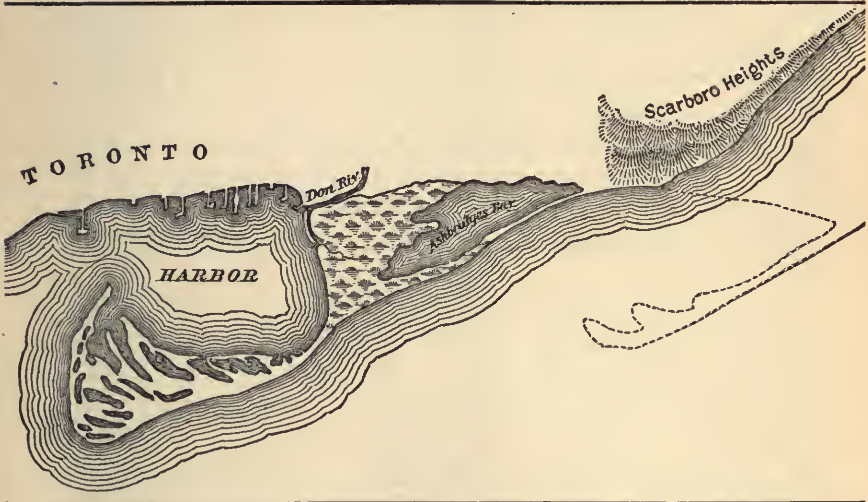

FIG. 49.—MAP OF THE HARBOR AND PENINSULA (HOOK) AT TORONTO. FROM CHARTS PUBLISHED BY H. Y. HIND, IN 1854.

By this process of partial destruction and renewal the spit retreats, keeping pace with the retreating cliff. At an earlier stage of the process the spit may have had the position and form

* The marsh occupying part of the space between the spit and the mainland (Fig. 49) is only incidentally connected with the feature under discussion. A small stream, the Don, reaches the shore of the lake within the tract protected from waves by the hook, and is thus enabled to construct a delta with its sediment.

† Report on the preservation and improvement of Toronto Harbor. In supplement to *Canadian Journal*, 1854. At the present time the spit is divided near the middle, a natural breach having been artificially prevented from healing. The portion of the peninsula fringed by successive hooks stands as an island.

indicated by the dotted outline, but whatever hooks fringed its inner margin have disappeared in the process of retreat.

THE LOOP.

Just as the spit, by advancing until it rejoins the shore, becomes a bar, so the completed hook may with propriety be called a *loop* or a *looped bar*. There is, however, a somewhat different feature to which the name is more strikingly applicable. A small island standing near the mainland is usually furnished on each side with a spit streaming toward the land. These spits are composed of detritus eroded from the lakeward face of the island, against which beat the waves generated through the broad expanse. The currents accompanying the waves are not uniform in direction, but vary with the wind through a wide angle; and the spits, in sympathy with the varying direction of currents, are curved inward toward the island. If their extremities coalesce, they constitute together a perfect loop, resembling, when mapped, a festoon pendent from the sides of the island. (See Plate 22.)

THE WAVE-BUILT TERRACE.

It has already been pointed out that when a separation of the littoral current from the coast line is brought about by a divergence of the current rather than of the coast line, there are two cases, in the first of which the current continues at the surface, while in the second it dives beneath the surface. It is now necessary to make a further distinction. The current departing from the shore, but remaining at the surface, may continue with its original velocity or it may assume a greater cross-section and a diminished velocity. In the first case the shore drift is built into a spit or other linear embankment. In the second case it is built into a terrace. The quantity of shore drift moved depends on the magnitude of the waves; but the speed of transit depends on the velocity of the current, and wherever that velocity diminishes, the accession of the shore drift must exceed the transmission, causing accumulation to take place. This accumulation occurs, not at the end of the beach, but on its face, carrying its entire profile lakeward and producing by the expansion of its crest a tract of new-made land. If afterward the water disappears, as

BAR, JOINING ISLAND TO MAINLAND, LAKE SUPERIOR, NEAR MARQUETTE.

in the case of an extinct lake, the new-made land has the character of a terrace. A current which leaves the shore by descending, practically produces at the shore a diminution of flow, and the resulting embankment is nearly identical with that of a slackening superficial current.

The wave-built terrace is distinct from the wave-cut terrace in that it is a work of construction, being composed entirely of shore drift, while the wave-cut terrace is the result of excavation, and consists of the pre-existent terrene of the locality. The wave-built terrace is an advancing embankment, and its internal structure is characterized by a lakeward dip (Fig. 51). It is thus contrasted with the retreating embankment (Fig. 50).

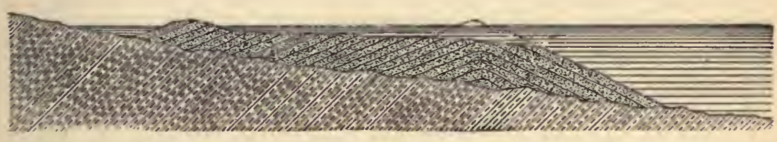

FIG. 50.—SECTION OF A LINEAR EMBANKMENT RETREATING LANDWARD. THE DOTTED LINE SHOWS THE ORIGINAL POSITION OF THE CREST.

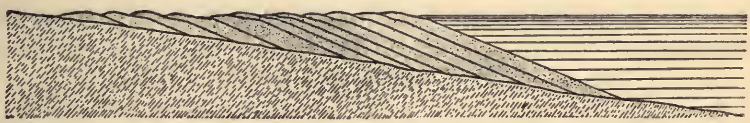

FIG. 51.—SECTION OF A WAVE-BUILT TERRACE.

The surface of the wave-built terrace, considered as a whole, is level, but in detail it is uneven, consisting of parallel ridges, usually curved. Each of these is referable to some exceptional storm, the waves of which threw the shore drift to an unusual height.

Where the shore drift consists wholly or in large part of sand, and the prevailing winds are toward the shore, the wave-built terrace gives origin to dunes, which are apt to mask its normal ribbed structure.

The locality most favorable for the formation of a wave-built terrace is the head of a triangular bay, up which the waves from a large body of water are rolled without obstruction. The wind sweeping up such a bay carries the surface of the water before it, and the only return current is an undertow originating near the head of the bay. The superficial advance of the water constitutes on each shore a littoral current conveying shore drift toward the head of the bay, and as these littoral currents are diminished and finally entirely dissipated by absorption in the undertow, the shore drift taken up along the sides of the bay is deposited. If the head of the bay is acute, the first embankment built is a curved bar tangent to the sides and concave toward the open water. To the face of this successive additions are made, and a terrace is gradually produced, the component ridges of which are approximately parallel. The sharpest curvature is usually at the extreme head of the bay.

The converging currents of such a bay give rise to an undertow which is of exceptional velocity, so that it transports with it not only the finest detritus but also coarser matter, such as elsewhere is usually retained in the zone of wave action. In effect there is a resorting of the material. The shore drift that has travelled along the sides of the bay toward its head, is divided into two portions, the finer of which passes out with the reinforced undertow, while the coarser only is built into the terrace.

THE V-TERRACE AND V-BAR.

It remains to describe a type of terrace for which no satisfactory explanation has been reached. The shores of the ancient Pleistocene lakes afford numerous examples, but those of recent lakes are nearly devoid of them, and the writer has never had opportunity to examine one in process of formation. They are triangular in ground plan, and would claim the title of delta were it not appropriated, for they simulate the Greek letter more strikingly than do the river-mouth structures. They are built against coasts of even outline, and usually, but not always, upon slight salients, and they occur most frequently in the long, narrow arms of old lakes.

There seems no reason to doubt that these embankments, like the others, were built by currents and waves, and such being the case the formative currents must have diverged from the shore at one or both the landward angles of the terrace, but the condition determining this divergence does not appear.

In some cases the two margins appear to have been determined by currents approaching the terrace (doubtless at different times) from opposite directions; and then the terrace margins are concave outward, and their confluence is prolonged in a more or less irregular point. In most cases, however, the shore drift appears to have been carried by one current from the mainland along one margin of the terrace to the apex, and by another current along the remaining side of the terrace back to the mainland. The contours are then either straight or convex.

DRIFTING SAND; DUNES.

The dune is not an essential shore feature, but is an accessory of frequent occurrence.

Dunes are formed wherever the wind drifts sand across the land. The conditions essential to their production are wind, a supply of sand, and sterility or the absence of a protective vegetal growth. In arid regions sterility is afforded by the climatic conditions, and the sand furnished by river bars laid bare at low water, and by the disintegration of sand rocks, is taken up by the wind and built into dunes; but where rain is abundant, accumulations of such sort are protected by vegetation, and the only sources of supply are shores, either modern or ancient.

Shore drift nearly always contains some sand, and is frequently composed exclusively thereof. The undertow carries off the clay, which might otherwise hold the sand particles together and prevent their removal by the wind; and pebbles and bowlders, which, by their superior weight oppose wind action, are less able to withstand the attrition of littoral transportation, and disappear by disintegration from any train of shore drift which travels a considerable distance. Embankments are therefore apt to be composed largely of sand; and the crests of embankments, being exposed to the air during the intervals between great storms, yield dry sand to the gentler winds.

The sand drifted from the crests of free embankments, such as barriers, spits, and bars, quickly reaches the water on one side or the other. What is blown to the lakeward side falls within the zone of wave action, and is again worked over as shore drift. What is blown to the landward side extends the area of the embankment, correspondingly encroaching on the lagoon or bay.

Sand blown from the crests of embankments resting against the land, such as beaches and terraces, will spread over the land if the prevailing wind is favorable. In cases where the prevailing wind is toward the lake the general movement of sand is, of course, in that direction, and it is merely returned to the zone of the waves and readded to the shore drift; but where the prevailing winds are toward the land, dunes are formed and slowly rolled forward by the wind. The supply of dry sand afforded by beaches is comparatively small, and dunes of magnitude are not often formed from it. The great sand magazines are wave-built terraces, and it is from these that the trains of sand so formidable to agriculture have originated.

THE DISTRIBUTION OF WAVE-WROUGHT SHORE FEATURES.

Upon every coast there are certain tracts undergoing erosion; certain others receive the products of erosion, and the intervals are occupied by the structures peculiar to transportation. Let us now inquire what are the conditions determining these three phases of shore shaping. (See Plate 23.)

It will be convenient to consider first the conditions of transportation. In order that a particular portion of shore shall be the scene of littoral transportation, it is essential, first, that there be a supply of shore drift; second, that there be shore action by waves and currents; and in order that the local process be transportation simply, and involve neither erosion nor deposition, a certain equilibrium must exist between the quantity of the shore drift on the one hand and the power of the waves and currents on the other. On the whole this equilibrium is a delicate one, but within certain narrow limits it is stable. That is to say, there are certain slight variations of the individual equilibrium, which disturb the equilibrium only in a manner tending to its immediate readjustment. For example, if the shore drift receives locally a small increment from stream drift, this increment, by adding to the shore contour, encroaches on the margin of the littoral cur-

Plate 23.

SPIT OF SHINGLE, ANTRAIN ISLAND, LAKE SUPERIOR.

rent and produces a local acceleration, which acceleration leads to the removal of the obstruction. Similarly, if from some temporary cause there is a local defect of shore drift, the resulting indentation of the shore contour slackens the littoral current and causes deposition, whereby the equilibrium is restored. Or if the force of the waves is broken at some point by a temporary obstruction outside the line of breakers, as for example by a wreck, the local diminution of wave agitation produces an accumulation of shore drift whereby the littoral current is narrowed and thus accelerated until an adjustment is reached.

Outside the limits thus indicated everything which disturbs the adjustment between quantity of shore drift and capacity of shore agents leads either to progressive local erosion or else to progressive local deposition. The stretches of coast which either lose or gain ground are decidedly in excess of those which merely hold their own.

An excessive supply of shore drift over and above what the associated current and waves are competent to transport leads to deposition. This occurs where a stream of some magnitude adds its quota of debris. A moderate excess of this nature is disposed of by the formation of a wave-built terrace on the lee side of the mouth of the stream, that is, on the side toward which flows the littoral current accompanying the greatest waves. A great excess leads to the formation of a delta, in which the stream itself is the constructing agent and the influence of waves is subordinate.

On the other hand, there is a constant loss of shore drift by attrition, the particles in transit being gradually reduced in size until they are removed from the littoral zone by the undertow. As a result of the defect thus occasioned, a part of the energy of the waves is expended on the subjacent terrene, and the work of transportation is locally accompanied by a sufficient amount of erosion to replenish the wasting shore drift. For the maintenance of a continuous beach in a permanent position, it appears to be necessary that small streams shall contribute enough debris to compensate for the waste by attrition.

Theoretically, transportation must be exchanged for erosion wherever there is a local increase in the magnitude of waves, and for deposition where there is a local decrease of waves; but practically the proportions of waves are so closely associated with the velocities of the accompanying currents that their effects have not been distinguished.

The factor which most frequently, by its variation, disturbs the equilibrium of shore action is the littoral current. It has already been pointed out that wherever it leaves the shore, shore drift is deposited; and it is equally true that wherever it comes into existence by the impinging of an open-water current on the shore, shore drift is taken up and the terrene is eroded. It has been shown also that the retardation of the littoral current produces deposition, and it is equally true that its acceleration causes erosion. Every variation, therefore, in the direction or velocity of the current at the shore has a definite effect in the determination of the local shore process.

Reëntrant angles of the coast are always, and reëntrant curves are usually, places of deposition.

Salient angles are usually eroded, and salient curves nearly always, the reasons being, first, that a current following the shore is relatively swift opposite a salient, and, second, that a current directed toward the shore is apt to be divided by a salient, its halves being converted into littoral currents transporting shore drift in opposite directions *away* from the salient.

Some salient angles, on the contrary, grow by deposition. This occurs where the most important current approaches by following the shore and is thrown off to deep water by a salient. The most notable instances are found on the sides of narrow lakes or arms of lakes, in which case currents approaching from the direction of the length are accompanied by greater waves than those blown from the direction of the opposite shore, and therefore dominate in the determination of the local action.

It thus appears that there is a general tendency to the erosion of salients and the filling of embayments, or to the simplification of coast outlines. This tendency is illustrated not only by the shores of all lakes, but by the coasts of all oceans. In the latter case it is slightly diminished by the action of tides, which occasion currents tending to keep open the mouths of estuaries, but it is nevertheless the prevailing tendency.

It is now understood that the diversities of land topography are wrought by stream erosion.

The simplification of a coast line is a work involving time, and the amount of work accomplished on a particular coast affords a relative measure of the time consumed. There are many modifying conditions—the fetch of the waves, the off-shore depth, the material of the land, the original configuration, etc.—and these leave no hope of an absolute measure; but it is possible to distinguish the young coast from the mature.

Low but nearly continuous sea-cliffs mark the adolescent coast; simple contours and a cordon of sand, interspered with high cliffs, mark the mature coast. As a result of the inconstancy of the relations of land and water, it is probable that all coasts fall under these heads, but Richthofen has sketched the features of the theoretic senile coast.* As sea-cliffs retreat and terraces grow broader the energy of the waves is distributed over a wider zone and its erosive work is diminished. The resulting defect of shore drift permits the erosion of embankments, and the withdrawal of their protection extends the line of cliff; but eventually the whole line is driven back to its limit and erosion ceases. The cliffs, no longer sapped by the waves, yield to atmospheric agencies and blend with the general topography of the land. Shore drift is still supplied by the streams and is spread over the broad littoral shoal, where it lies until so comminuted by the waves that it can float away.

STREAM WORK; THE DELTA.

The detritus brought to lakes by small streams is overwhelmed by shore drift and merges with it. The tribute of large streams, on the contrary, overwhelms the shore drift and accumulates in deltas. In the formation of a normal delta the stream is the active agent, the lake is the passive recipient, and waves play no essential part.

The process of delta formation depends almost wholly on the following law: *The capacity and competence of a stream for the*

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* Führer für Forschungsreisende, p. 338.

transportation of detritus are increased and diminished by the increase and diminution of the velocity. The capacity of a stream is measured by the total load of debris of a given fineness which it can carry. Its competence is measured by the maximum size of the particles it can move. A swift current is able to transport both more matter and coarser matter than a slow current. The competence depends on the velocity of the water at the bottom of the channel, for the largest particles the stream can move are merely rolled along the bottom. Finer particles are lifted from the bottom by threads of current tending more or less upward, and before they sink again are carried forward by the general flow. Their suspension is initiated by the bottom current, but the length and speed of their excursion depend on the general velocity of the current. Capacity is therefore a function of the velocity of the more superficial threads of current as well as of those which follow the bottom.

Suppose that a river freighted with the waste of the land is newly made tributary to a lake. Its water flows to the shore, and shoots out thence over* the relatively still lake water until its momentum has been communicated by friction to so large a body of water as to practically dissipate its velocity. From the shore outward the velocity at the bottom is the velocity of the lake water and not that of the river water, and is inconsiderable. The entire load consequently sinks to a final resting place and becomes a deposit. The coarse particles go down in immediate contiguity to the shore. The finest are carried far out before they escape from the superficial stratum of river water.

The sinking of the coarse material at the shore has the effect of building out a platform at the level of the bottom of the river channel. Postulate the construction of this platform for some distance from the shore without any modification of the longitudinal profile of the river, the river surface descending to the shore and then becoming horizontal. Evidently, the horizontal portion has no energy of descent to propel it, and yet is opposed by friction; its velocity is, therefore, retarded, its capacity and com-

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* It is said that some glacier-fed streams on entering lakes pass under instead of over the lake water and that peculiar delta features result, but these are not fully described.

petence are consequently diminished, and it drops some of its load. The fall of detritus builds up the bottom at the point where it takes place, and causes a checking of the current immediately above (up stream). This in turn causes a deposit; and a reciprocation of retardation and deposition continues until the profile of the stream has acquired a continuous grade from its mouth at the extremity of the new platform backward to some steeper part of its channel—a continuous grade sufficient to give it a velocity adequate to its load. The postulate is, of course, ideal. The river does not in fact build a level bed and afterward change it to a slope, but carries forward the whole work at once, maintaining continuously an adjustment between its grade and its work. Moreover, since the deposition begins at some distance from the mouth, the lessening load does not require a uniform grade and does not produce it. The grade diminishes gradually lakeward to the foot of the deposit slope, so that the longitudinal profile is slightly concave upward. At the head of the deposit slope there is often an abrupt change of grade. At its foot, where the maximum deposit is made, there is an abrupt change of a double character; the incline of the river surface is exchanged for the horizontal plane of the lake surface; the incline of the river bottom is exchanged for the steeper incline of the delta front.

The river current is swifter in the middle than at the sides, and on a deposit slope, where velocity is nicely adjusted to load, the slight retardation at the sides leads to deposition of suspended matter. A bank is thus produced at either hand, so that the water flows down an elevated sluice of its own construction. The sides are built up pari passu with the bottom, but inasmuch as they can be increased only by overflow, they never quite reach the flood level of the water surface. A river thus contained, and a river channel thus constructed, constitute an unstable combination. So long as the bank approximates closely to the level of the surface at flood stage, the current across the bank is slower than the current of the stream, and deposits silt instead of excavating; but whenever an accidental cause so far lowers the bank at some point that the current across it during flood no longer makes a deposit, there begins an erosion of the bank which increases rapidly as the volume of escaping water is augmented. A side channel is thus produced, which eventually becomes deeper than the main or original channel and draws in the greater part or perhaps all of the water. The ability of the new channel to drain the old one depends on two things: first, the outer slope of the bank, from the circumstances of its construction, is steeper than the descent of the bottom of the channel; second, the first-made channel, although originally following the shortest route to the lake, has so far increased its length by the extension of its mouth that the water escaping over its bank may find a shorter route. The river channel is thus shifted, and its mouth is transferred to a new point on the lake shore.

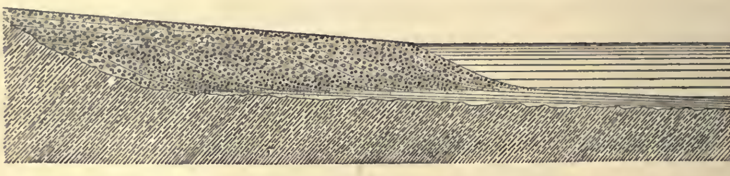


FIG. 52.—SECTION OF A DELTA.

At the lake shore the manner of deposition is different. The heavier and coarser part of the river's detrital load, that which it pushes and rolls along the bottom instead of carrying by suspension, is emptied into the lake and slides down the face of the delta with no impulse but that given by its own weight. The slope of the delta face is the angle of repose of this coarse material, subject to such modification as may result from agitation by waves. The finer part of the detritus, that which is transported by suspension, is carried beyond the delta face, and sinks more or less slowly to the bottom. Its distribution depends on its relative fineness, the extremely fine material being widely diffused, and the coarser falling near the foot of the delta face. The depth of the deposit formed from suspended material is greatest near the delta and diminishes gradually outward, so that the slope of the delta face merges by a curve with the slope of the bottom beyond.

As the delta is built lakeward, the steeply inclined layers of the delta face are superposed over the more level strata of the lake bottom, and in turn come to support the gently inclined layers of the delta plain, so that any vertical section of a normal delta exhibits at the top a zone of coarse material, bedded with a gentle lakeward inclination, then a zone of similar coarse material, the laminations of which incline at a high angle, and at bottom a zone of fine material, the laminations of which are gently inclined and unite by curves with those of the middle zone.

The characters of the fossil delta, or the delta as it exists after the desiccation of the lake concerned in its formation, are as follows: the upper surface is a terrace with the form of an alluvial fan. The lower slope or face is steep, ranging from 10° to 25°; it joins the upper slope by an angle and the plain below by a curve. The line separating the upper surface from the outer slope or face is horizontal, and in common with all other horizontal contours of the structure, is approximately a circular arc. The upper or landward limit of the upper surface is a line horizontally uneven, depending on the contours of the antecedent topography. The lower limit of the face is a vertically uneven line, depending on the antecedent topography as modified by lake sediments. The material is detrital and well rounded; it exhibits well-marked lines of deposition, rarely taking the character of bedding.

The fossil delta is invariably divided into two parts by a channel running from its apex to some part of its periphery and occupied by a stream, the agent of its construction becoming, under changed conditions of base level, the agent of demolition.

The fan-like outline of the normal delta is modified wherever wave action has an importance comparable with that of stream action. Among the great variety of forms resulting from the combination of the two agencies, there is one which repeats itself with sufficient frequency to deserve special mention. It occurs where the force of the waves is considerable and the amount of shore drift brought by them to the delta is inconsiderable. In such case the shore current from either direction is deflected by the mass of the delta, and wave action adjusts the contour of the delta to conformity with the deflected shore current. If the wave influences from opposite directions are equal, the delta takes the form of a symmetric triangle similar to that of the V-terrace.

Numerous illustrations are to be seen on the shores of Seneca and Cayuga Lakes, where the conditions are peculiarly favorable. The lake is long and narrow, so that all the efficient wave action is associated with strong shore currents, and these alternate in direction. The predominant rock of the sides is a soft shale, so easily triturated by the waves that the entire product of its erosion escapes with the undertow, and no shore drift remains. The sides are straight, and each tributary stream builds out a little promontory at its mouth, to which the waves give form. Some of these triangular deltas embody perfectly the Greek letter, but they turn the apex toward the water instead of toward the land.

ICE WORK; THE RAMPART.

This feature does not belong to lakes in general, but is of local and exceptional occurrence. It was named the "Lake Rampart" by Hitchcock, who gave the first satisfactory account of its origin.* Earlier observations, containing the germ of the explanation of the phenomenon, were made by Lee † and Adams.‡ A later and independent explanation was given by White.§

The ice on the surface of a lake expands while forming, so as to crowd its edge against the shore. A further lowering of temperature produces contraction, and this ordinarily results in the opening of vertical fissures. These admit the water from below, and by the freezing of all that water they are filled, so that when expansion follows a subsequent rise of temperature the ice cannot assume its original position. It consequently increases its total area and exerts a second thrust upon the shore. Where the shore is abrupt, the ice itself yields, either by crushing at the margin or by the formation of anticlinals elsewhere; but

* Lake Ramparts in Vermont. By Chas. H. Hitchcock. In Proc. Am. Ass. Adv. Sci., vol. 13, 1860, p. 335.

† C. A. Lee. Am. Jour. Sci., vol. 5, 1822, pp. 34-37, and vol. 9, 1825, pp. 239-241.

‡ J. Adams. Am. Jour. Sci., vol. 9, 1825, pp. 136-144.

§ C. A. White. Am. Naturalist, vol. 2, 1869, pp. 146-149.

if the shore is generally shelving, the margin of the ice is forced up the acclivity, and carries with it any bowlders or other loose material about which it may have frozen. A second lowering of temperature does not withdraw the protruded ice margin, but initiates other cracks and leads to a repetition of the shoreward thrust. The process is repeated from time to time during the winter, but ceases with the melting of the ice in the spring. The ice formed the ensuing winter extends only to the water margin, and by the winter's oscillations of temperature can be thrust landward only to a certain distance, determined by the size of the lake and the local climate. There is thus for each locality a definite limit, beyond which the projection of bowlders cannot be carried, so that all are deposited along a common line, where they constitute a wall or rampart.

The base of a rampart stands somewhat above and beyond the ordinary margin of the water. It is parallel to the water margin, following its inflections. Its size is probably determined in fact by the supply of material, but there must also be a limit dependent on the strength of the ice formed in the given locality. Its material is usually coarse, containing bowlders such as the waves generated on the same lake would be unable to move. These may be either smooth or angular, heavy or light, the process of accumulation involving no discrimination.

Ramparts are not found on the margins of large lakes, for whatever record the ice of winter may make is obliterated by the storm waves of summer. Neither do they occur on the shores of very deep lakes, for such do not admit of a heavy coating of ice; and for the same reason they are not found in warm climates. So far as the writer is aware, they have never been found in the fossil condition, except that in a single instance a series of them serves to record very recent changes of level.

SUBMERGENCE AND EMERGENCE.

In the preceding discussion the general relation of the water surface to the land has been assumed to be constant. In point of fact it is subject to almost continuous change, and its mutations modify the products of littoral shaping.

Lakes with outlets lower their water surfaces by corrading the channel of outflow. Lakes without outlets continually oscillate up and down with changes of climate; and finally, all large lakes, as well as the ocean, are affected by differential movements of the land. The series of displacements which in the geologic past has so many times revolutionized the distribution of land and water, has not ceased; and earth movements are so nearly universal at the present time that there are few coasts which betray no symptoms of recent elevation or subsidence. In this place it is unnecessary to consider whether the relation of water surface to land is affected by mutations of the one or of the other; and the terms emergence and submergence will be used with the understanding that they apply to changes in the relation without reference to causes of change.

The general effect of submergence or emergence is to change the horizon at which shore processes are carried on; and if a considerable change of level is effected abruptly, the nature of the processes and the character of their products are not materially modified. A submerged shore-line retains its configuration until it is gradually buried by sediments. An emerged shore-line is subjected to slow destruction by atmospheric agencies. Only the delta is rapidly attacked, and that is merely divided into two parts by the stream which formed it. In the case of submergence the new shore constructed at a higher horizon is essentially similar to the one submerged. In the case of emergence the new shore constructed at a lower horizon rests upon the smooth contours wrought by lacustrine sedimentation, and, finding in the configuration little that is incongruous with its shore currents, carves few cliffs and builds few embankments. The barrier is usually one of its characteristic elements.

A slow and gradual submergence modifies the products of littoral action. The erosion of sea-cliffs is exceptionally rapid, because the gradually deepening water upon the wave-cut terraces relieves the waves from the task of carving the terraces and enables them to spend their full force against the cliffs. The cliffs are thus beaten back before the advancing tide, and their precipitous character is maintained with constant change of position.

A rhythm is introduced in the construction of embankments. For each level of the water surface there is a set of positions appropriate to the initiation of embankments, and with an advancing tide these positions are successively nearer and nearer the land; but with the gradual advance of water the position of embankments is not correspondingly shifted. The embankment constructed at a low stage controls the local direction of the shore current, even when its crest is somewhat submerged, and by this control it determines the shore drift to follow its original course. It is only when the submergence is sufficiently rapid to produce a considerable depth of water over the crest of the embankment that a new embankment is initiated behind it. The new embankment in turn controls the shore current, and by a repetition of the process a series of embankments is produced whose crests differ in height by considerable intervals.

A slow and gradual emergence causes the waves, at points of excavation, to expend their energies upon the terraces rather than the cliffs. No great cliffs are produced, but a wave-cut terrace is carried downward with the receding tide. There is now no rhythm in the construction of embankments. At each successive lower level the shore drift takes a course a little farther lakeward, and is built into a lower embankment resting against the outer face of the one just formed.

The delta is very sensitive to emergence. As soon as the lake water falls from its edge, the formative stream, having now a lower point of discharge, ceases to throw down detritus and begins the corrasion of its channel. It ceases at the same time to shift its course over the surface of the original delta, but retains whatever position it happened to hold when the emergence was initiated. Coincidently it begins the construction of a new or secondary delta, the apex of which is at the outer margin of the original structure. With continuous emergence a series of new deltas are initiated at points successively farther lakeward, and there is produced a continuous descending ridge divided by the channel of the stream.

THE DISCRIMINATION OF SHORE FEATURES.

A shore is the common margin of dry land and a body of water. The elements of its peculiar topography are little liable to confusion so long as they are actually associated with land on one side and water on the other; but after the water has been withdrawn, their recognition is less easy. They consist merely of certain cliffs, terraces, and ridges; and cliffs, terraces, and ridges abound in the topography of land surfaces. In the following pages the topographic features characteristic of ancient shores will be compared and contrasted with other topographic elements likely to create confusion.

Such a discrimination as this has not before been attempted, although the principal distinctions upon which it is based have been the common property of geologists for many years.

CLIFFS.

THE CLIFF OF DIFFERENTIAL DEGRADATION.

It is a familiar fact that certain rocks, mainly soft, yield more rapidly to the agents of erosion than certain other rocks, mainly hard. It results from this, that in the progressive degradation of country by subaerial erosion the minor reliefs are generally occupied by hard rocks while the minor depressions mark the positions of soft rocks. Where a hard rock overlies one much softer, the erosion of the latter proceeds so rapidly that the former is sapped, and being deprived of its support falls away in blocks, and is thus wrought at its margin into a cliff. In regions undergoing rapid degradation such cliffs are exceedingly abundant.

THE STREAM CLIFF.

The most powerful agent of land erosion is the running stream, and, in regions undergoing rapid degradation, corrasion by streams so far exceeds the general waste of the surface that their channels are cut down vertically, forming cliffs on either hand. These cliffs are afterward maintained by lateral corrasion, which opens out the valley of the stream after the establishment of a base level has checked the vertical corrasion. Such cliffs are in a measure independent of the nature of the rock, and are closely associated with the stream. They stand as a rule in pairs facing each other and separated only by the stream and its flood plain. The base of each is a line inclined in the direction of the stream channel and in the same degree. The crest is not parallel thereto, but is an uneven line conforming to no simple law.

THE COULÉE EDGE.

The viscosity of a lava stream is so great, and this viscosity is so augmented as its motion is checked by gradual cooling, that its margin after congelation is usually marked by a cliff of some height. The distinguishing characters of such a cliff are that the rock is volcanic, with the superficial features of a subaerial flow. It has probably never been mistaken for a sea-cliff, and receives mention here only for the sake of giving generality to the classification of cliffs.

THE FAULT SCARP.

The faulting of rocks consists in the relative displacement of two masses separated by a fissure. The plane of the fissure is usually more or less vertical, and by virtue of the displacement one mass is made to project somewhat above the other. The portion of the fissure wall thus brought to view constitutes a variety of cliff or escarpment, and has been called a fault scarp.

In the Great Basin such scarps are associated with a great number of mountain ranges, appearing generally at their bases, just where the solid rock of the mountain mass is adjoined by the detrital foot slope. They occasionally encroach upon the latter, and it is in such case they are most conspicuous as well as most likely to be mistaken for sea-cliffs. Although in following the mountain bases they do not vary greatly in altitude, yet they never describe exact contours, but ascend and descend the slopes of the foot hills. The crest of such a cliff is usually closely parallel to the base for long distances, but this parallelism is not absolute. The two lines gradually converge at either end of the displacement. In exceptional instances they converge rapidly, giving the cliff a somewhat abrupt termination, and in such case a new cliff appears en échelon, continuing the displacement with a slight offset.

THE LAND-SLIP CLIFF.

The land-slip differs from the fault chiefly in the fact that it is a purely superficial phenomenon, having its whole history upon a visible external slope. It occurs usually in unconsolidated material, masses of which break loose and move downward short distances. The cliffs produced by their separation from the general or parent mass, are never of great horizontal extent, and have no common element of form except that they are concave outward. They frequently occur in groups, and are apt to contain at their bases little basins due to the backward canting which forms part of the motion of the sliding mass.

COMPARISON.

The sea-cliff differs from all others, first, in that its base is horizontal, and, second, in that there is associated with it at one end or other a beach, a barrier, or an embankment. A third valuable diagnostic feature is its uniform association with the terrace at its base; but in this respect it is not unique, for the cliff of differential degradation often springs from a terrace. Often, too, the latter is nearly horizontal at base, and in such case the readiest comparative test is found in the fact that the sea-cliff is independent of the texture and structure of the rocks from which it is carved, while the other is closely dependent thereon.

The sea-cliff is distinguished from the stream-cliff by the fact that it faces an open valley broad enough and deep enough to permit the generation of efficient waves if occupied by a lake. It is distinguished from the coulée edge by its independence of rock structure and by its associated terrace. It differs from the fault scarp in all those peculiarities which result from the attitude of its antecedent; the water surface concerned in the formation of the sea-cliff is a horizontal plane; the fissure concerned in the formation of the fault scarp is a less regular but essentially vertical plane. The former crosses the inequalities of the preëxistent topography as a contour, the latter as a traverse line.

The land-slip cliff is distinguished by the marked concavity of its face in horizontal contour. The sea-cliff is usually convex, or, if concave, its contours are long and sweeping. The former is distinguished also by its discontinuity.

TERRACES.

A terrace is a horizontal or nearly horizontal topographic facet interrupting a steeper slope. It is a limited plain, from one edge of which the ground rises more or less steeply, while from the opposite edge it descends more or less steeply. It is the "tread" of a topographic step.

Among the features peculiar to shores are three terraces: the wave-cut, the wave-built, and the delta.

THE TERRACE BY DIFFERENTIAL DEGRADATION.

The same general circumstances of rock texture which under erosion give rise to cliffs produce also terraces, but the terraces are of less frequent occurrence. The only case in which they are at all abundant, and the only case in which they need be discriminated from littoral terraces, is that in which a system of strata, heterogeneous in texture and lying nearly horizontal, is truncated, either by a fault or by some erosive action, and is afterwards subjected on the truncated section to atmospheric waste. The alternation of hard and soft strata gives rise under such circumstances to a series of alternating cliffs and terraces, the outcrop of each hard stratum appearing in a more or less vertical cliff, and the outcrop of each soft stratum being represented by a gently sloping terrace, united to the cliff above by a curve, and, in typical examples, separated from the cliff below by an angle.

The length of such terraces in the direction of the strike is usually great as compared with their width from cliff to cliff. They are never level in cross profile, but (1) rise with gradually increasing slope from the crest of one cliff to the base of the next, or (2) descend from the crest of one cliff to a medial depression, and thence rise with gradually increasing slope to the base of the next. The first case arises where the terrace is narrow or the dip of the strata is toward the lower cliff, the second case where the terrace is broad *and* the dip of the rocks is toward the upper cliff. In the first case the drainage is outward to the edge of the lower cliff; in the second it is toward the medial depression, whence it escapes by the narrow channels carved through the rock of the lower cliff.

THE STREAM TERRACE.

The condition of rapid erosion in any region is uplift. In a tract which has recently been elevated, the rate of degradation is unequal, the waste of the water channels being more rapid than that of the surface in general, so that they are deeply incised. Eventually, however, the corrasion of the water channels so reduces their declivities that the velocities of current suffice merely for the transportation outward of the detritus disengaged by the general waste of surface. In other words, a base level is reached. Then the process of lateral corrasion, always carried on to a certain extent, assumes prominence, and its results are rendered conspicuous. Each stream wears its banks, swinging from side to side in its valley, always cutting at one side, and at the other building a shallow deposit of alluvium, which constitutes its flood plain. The valley, having before consisted of the river channel margined on either side by a cliff, now consists of a plain bounded at the sides by cliffs and traversed by the river channel.

Acceleration of downward corrasion is brought about in many ways. It is brought about, within a certain range of conditions, by increase of rainfall; and it always ensues sooner or later from the defect of transported material. The general waste of the originally uplifted tract undergoes, after a long period, a diminution in rapidity. The streams have therefore less detritus to transport. Their channels are less clogged, and they are enabled to lower them by corrasion. Perhaps it would be better to say that after the immediate consequences of uplift have so far passed away that an equilibrium of erosive action is established, the degradation of the entire tract proceeds at a slow continuous rate, the slight variations of which are in a sense accidental.

In a great number of stream valleys, not one but many ancient flood plains find record in terraces, so that the stream terrace is a familiar topographic feature. (See Plate 24.)

When a stream meandering in a flood plain encroaches on a

Plate 24.

BIRD'SEYE VIEW OF MADISON VALLEY, MONTANA—SHOWING STREAM TERRACES.

wall of the valley and corrades laterally, it carries its work of excavation down to the level of the bottom of its channel; and afterward, when its course is shifted to some other part of the valley, it leaves a deposit of alluvium, the upper surface of which is barely submerged at the flood stage of the stream. The depth of alluvium on the flood plain is therefore measured by the extreme depth of the current at high water. It constitutes a practically even sheet, resting on the undisturbed terrene beneath. When the stream finally abandons it, and by carving a deeper channel, converts it into a terrace, the terrace is necessarily bipartite. Above, it consists of an even layer of alluvial material, fine at top and coarse at bottom; below, it consists of the pre-existent formation, whatever that may be. Where the lower portion is so constituted as to resist erosion, it loses after a long period its alluvial blanket, and then the terrace consists simply of the floor of hard rock as pared away by the meandering stream. The coarse basal portion of the alluvium is the last to disappear; and if it contains hard bowlders some of these will survive as long as the form of the terrace is recognizable.

THE MORAINE TERRACE.

When an alluvial plain or alluvial cone is built against the side or front of a glacier and the glacier is afterward melted away, the alluvial surface becomes a terrace overlooking the valley that contained the ice. The constructing stream may flow from the ice and gather its alluvium from the glacial debris, but it usually flows from the land. The slope of the alluvial plain is determined by the direction and other accidents of the stream. Where the plain adjoins the glacier, it receives whatever debris falls from the ice, and it may be said to coalesce initially with a morainic ridge. Its internal constitution is partly alluvial and partly morainic. If the morainic ridge is large, the plain does not become a moraine terrace. If it is small, it falls away when the removal of the ice permits the margin of the plain to assume the "angle of repose."

THE FAULT TERRACE.

It sometimes occurs that two or more fault scarps with throw in the same direction, run parallel with each other on the same slope, thus dividing the surface into zones or tracts at various heights. Each of these tracts contained between two scarps is a terrace. It is a dissevered section of the once continuous general surface divided by one fault from that which lies above on the slope and by another from that which lies below.

In the direction of its length, which always coincides with the strike of the faults, the terrace is not horizontal, but undulates in sympathy with the general surface from which it has been cut.

THE LAND-SLIP TERRACE.

This is closely related in cross-profile to the fault terrace, but is less regular and is of less longitudinal extent. Its length is frequently no greater than its width. The surface on which motion takes place has a cross section outwardly concave, so that the sliding mass moves on an arc, and its upper surface, constituting the terrace, has a less inclination than in its original position.

COMPARISON.

The only feature by which shore terraces are distinguished from all terraces of other origin, is the element of horizontality. The wave-cut terrace is bounded by a horizontal line at its upper edge; the delta is bounded by a horizontal line about its lower edge; and the wave-built terrace is a horizontal plain. But the application of this criterion is rendered difficult by the fact that the terrace of differential degradation is not infrequently margined by horizontal lines; while the inclinations of the stream terrace and the moraine terrace, though universal and essential characters, are often so small in amount as to be difficult of recognition. The fault terrace and land-slip terrace are normally so uneven that this character sufficiently contrasts them with all shore features.

The wave-cut terrace agrees with all the non-shore terraces in that it is overlooked by a cliff rising from its upper margin, and usually differs in that it merges at one end or both with a beach, barrier, or embankment. It is further distinguished from the terrace of differential degradation by the fact that its configuration is independent of the structure of the rocks from which it is carved, while the latter is closely dependent thereon. In freshly formed examples, a further distinction may be recognized in the mode of junction of terrace and cliff. As viewed in profile, the wave-cut terrace joins the associated sea-cliff by an angle, while in the profile wrought by differential degradation, the terrace curves upward to meet the overlooking cliff.

The wave-cut terrace is distinguished from the stream terrace by the fact that it appears only on the margin of an open basin broad enough for the propagation of efficient waves, whereas the latter usually margins a narrow or restricted basin. In the case of broad terraces a further distinction is found in the fact that the shore terrace descends gently from its cliff to its outer margin, whereas the stream terrace is normally level in cross section. In fresh examples the alluvial capping of the stream terrace affords additional means of discrimination.

The wave-cut terrace is distinguished from the moraine terrace by the fact that its floor consists of the preëxistent terrene in situ, the moraine terrace being a work of construction. The wave-cut terrace occurs most frequently on salients of the topography; its inner margin is a simpler curve than its outer. The moraine terrace is found most frequently in reëntrants; its outer margin is a simpler curve than its inner.

There are certain cases in which the wave-formed and stream terraces merge with each other and are difficult of separation. These occur in the estuaries of ancient lakes, where the terraces referable to wave action are confluent with those produced contemporaneously by the lateral corrasion of streams. The stream being then tributary to the lake, it could not carry its erosion to a lower level, and its zone of lateral corrasion was at its mouth continuous with the zone of wave erosion in the lake.

The wave-built terrace may be distinguished from all others by the character of its surface, which is corrugated with parallel, curved ribs. It differs from all except stream and moraine terraces in its material, which is wave-rolled and wave-sorted. It differs from the stream terrace in that it stands on a slope facing an open basin suitable for the generation of waves.

The delta differs from all except the stream terrace and the moraine terrace in its material and in its constant relation to a water way. Its material is that known as stream drift. Its mass is always divided by a stream channel so as to lie partly on each bank; its terminal contour is a convex arc centering on some point of the channel; and it is usually confluent in the ascending direction with the normal stream terrace. Indeed, when considered with reference to the dividing channel, it is a stream terrace; and it is only with reference to the lakeward margin that it is a shore terrace. It is distinguished from the normal stream terrace by its internal structure. The high inclination of the lamination of its middle member—formed by the discharge of coarse detritus into standing water—is not shared by the stream terrace, while its horizontal alluvium does not, as in the case of the stream terrace, rest on the preëxistent terrene. It is distinguished from simulating phases of the moraine terrace by its outer contour, which is outwardly convex and more or less irregular, while that of the moraine terrace is straight or simply curved. The frontal moraine terrace often affords a further distinction by the hummocky character of its outer face.

As the formation of the delta is independent of wave action, it may and does take place in sheltered estuaries and in small basins. A small lake interrupting the course of the stream may be completely filled by the extension of the delta built at its upper extremity; and when this has occurred, there is nothing in the superficial phenomena to distinguish the formation from the normal flood plain.

The terrace of differential degradation is further distinguished from all shore terraces by the fact that, without great variations in width, it follows the turnings of the associated cliff, conforming to it in all its salients and reëntrants. Where the shore follows an irregular contour, wave-cut terraces appear only on the salients, and in the reëntrants only wave-built terraces and deltas.

RIDGES.

Ridges are linear topographic reliefs. They may be broadly classed into (1) those produced by the erosion or dislocation of the earth's surface, and (2) those built upon it by superficial transfer of matter. In the first class, the substance of the ridge is continuous with that of the adjacent plain or valley; in the second, it is not; and this difference is so obvious that shore ridges, which fall within the second class, are not in the least liable to be confused with ridges of the first class. They will therefore be compared in this place only with other imposed ridges. Of shore phenomena, the barrier, the embankment, and the rampart are ridges. They will be contrasted with the moraine and the osar.

THE MORAINE.

The detritus deposited by glaciers at their lateral and terminal margins is usually built into ridges. The material of these is fragmental, heterogeneous, and unconsolidated. It includes large blocks, often many tons in weight, and these are angular or subangular in form. Sometimes their surfaces are striated. The crest of the moraine is not horizontal, but descends with the general descent of the land on which it rests.

Moraines are found associated with mountain valleys, and also upon open plains. In the first case their crests are narrow, and their contours are in general regular. The lateral moraines follow the sides of the valleys, often standing at a considerable height above their bottoms, and are united by the frontals or terminals, which cross from side to side with curved courses whose convexities are directed down stream. The moraines of plains have broad, billowy crests abounding in conical hills and in small basins.

THE OSAR OR KAME.

These names are applied to an indirect product of glacial action. It is multifarious in form, being sometimes a hill, sometimes a ridge, and often of more complicated form. It doubtless embraces types that need to be separated; but it is here sufficient to consider only the linear form. As a ridge, its trend is usually in the direction of glacial motion. Its material is waterworn gravel, sand and silt, with occasional bowlders. Its contours are characteristically, but not invariably, irregular. Its crest is usually, but not invariably, uneven; when even, it is parallel to the base or to that upon which the base rests. In other words, the ridge tends to equality of height rather than to horizontality.

COMPARISON.

The shore ridges are primarily distinguished from the glacial ridges by the element of horizontality. The barrier and the embankment are level-topped, while the rampart has a level base and is so low that the inequality of its crest is inconsiderable. It is only in exceptional cases and for short distances that moraines and osars exhibit horizontality. Shore ridges are further distinguished by their regularity. Barriers and embankments are especially characterized by their smoothness, while smooth osars are rare, and the only moraine with even contours is the lateral moraine associated with a narrow valley.

Other means of discrimination are afforded by the component materials, and the moraine is thus clearly differentiated. The barrier and the embankment consist usually of sand or fine gravel, from which both clay and larger bowlders have been eliminated. Except in immediate proximity to the sea-cliff whose erosion affords the detritus, the pebbles and bowlders are well rounded. The material of the rampart has no special qualities, but is of local derivation, the ridge being formed simply by the scraping together of superficial debris. The moraine contains heterogeneous material ranging from fine clay to very large, angular blocks. The materials of the osar are normally less rounded than those of normal shore ridges.

Certain osars of great length, even figure, and uniform height are distinguished from barriers by the greater declivity of their flanks, and by the fact that they do not describe contours on the margins of basins.

THE RECOGNITION OF ANCIENT SHORES.

The facility and certainty with which the vestiges of ancient water margins are recognized and traced depend on local conditions. The small waves engendered in ponds and in sheltered estuaries are far less efficient in the carving of cliffs and the construction of embankments than are the great waves of larger water bodies; and the faint outlines they produce are afterward more difficult to trace than those strongly drawn.

The element of time, too, is an important factor, and this in a double sense. A water surface long maintained scores its shore mark more deeply than one of brief duration, and its history is by so much the more easily read. On the other hand, a system of shore topography from which the parent lake has receded, is immediately exposed to the obliterating influence of land erosion, and gradually, though very slowly, loses its character and definition. The strength of the record is directly proportioned to the duration of the lake and inversely to its antiquity.

It will be recalled that in the preceding description the character of horizontality has been ascribed to every shore feature. The base of the sea-cliff and the coincident margin of the wave-cut terrace are horizontal; and so is the crest of each beach, barrier, embankment, and wave-built terrace; and they not merely agree in the fact of horizontality, but fall essentially into a common plane—a plane intimately related to the horizon of the maximum force of the breakers during storms. The outer margin of the delta is likewise horizontal, but at a slightly lower level—the level of the lake surface in repose. This difference is so small that for the purpose of identification it does not affect the practical coincidence of all the horizontal lines of the shore in a single contour. In a region where forests afford no obstruction, the observer has merely to bring his eye into the plane once occupied by the water surface, and all the horizontal elements of shore topography are projected in a single line. This line is exhibited to him, not merely by the distinctions of light and shade, but by distinctions of color, due to the fact that the changes of inclination and of soil at the line influence the distribution of many kinds of vegetation. In this manner it is often possible to obtain from the general view evidence of the existence of a faint shore tracing, which could be satisfactorily determined in no other way. The ensemble of a faintly scored shore mark is usually easier to recognize than any of its details.

It is proper to add that this consistent horizontality, which appeals so forcibly and effectually to the eye, cannot usually be verified by instrumental test. The surface of the "solid earth" is in a state of change, whereby the vertical relations of all its parts are continually modified. Wherever the surveyor's level has been applied to a fossil shore, it has been found that the "horizon" of the latter departs notably from horizontality, being warped in company with the general surface on which it rests. The level, therefore, is of little service in the correlation of shore lines seen at different places and not continuously traced; but when an ancient shore-line has been faithfully traced through a basin, the determination by level of its variations in height discovers the nature of displacements occurring since its formation. It might appear that the value of horizontality as an aid to the recognition of shores is constantly vitiated, but such is not the case. It is, indeed, true that the accumulated warping and faulting of a long period of time will so incline and disjoint a system of shore features that they can no longer be traced; but it is also true that the processes of land erosion will in the same time obliterate the shore features themselves. The minute elements of orographic displacement are often paroxysmal, but so far as observation informs us, the general progress of such changes is slow and gradual, so that, during the period for which shore tracings can withstand atmospheric and pluvial waste, their deformation is not sufficient to interfere materially with their recognition.

APPENDIX B.

PHOTOGRAPHIC SURVEYING.

The first scientific application of the principles of photography to surveying was made by Col. Laussedat, of the French Engineer Corps, in the year 1854; although the method had been used previously for hydrographic work by Beautemps-Beaupré, and also for surveys made by the French Abyssinian Commission, which were reported to the *Académie des Sciences*, by M. Arago, in 1846.

Col. Laussedat adopted the photographic method, after observing the extreme slowness and tediousness of the ordinary modes, during an extensive survey of the Pyrenees. In large topographical surveys of this kind the applicability of the method was especially evident. In Savoy a survey of 30,000 acres gave eighteen days' field and five months' office work, the contours being mapped fifteen feet apart. In another case 110 views sufficed to plot 20,000 acres, the field work occupying only fifteen days. The entire time required by this method is stated by Col. Laussedat not to exceed one-third that by the ordinary method, and it may be much less. The economy of time in the field is clearly evident.

The instrument used may be an ordinary landscape camera with the usual photographic equipment, including a level and hand compass. Such an apparatus may, with care, be used satisfactorily for the complete determination of points horizontally and vertically, where the scale used does not exceed $\frac{1}{5000}$, and even to determine the *horizontal location* of points where the scale of the plan is as large as $\frac{1}{2000}$. The accuracy attainable varies directly as the length of the principal focus of the objective used. A focal length much less than 15″ could not be used for satisfactory results with the scales above mentioned. For precise topographical work, however, where the scale may be as large as $\frac{1}{2000}$, a special combination of camera and transit is necessary. Without describing in detail, it is sufficient to state that the instrument must be of such construction as to allow of the revolution, in truly horizontal planes, of the optic axis of the camera objective and the line of collimation of the transit telescope. The sensitive plate, on which the exposure is made, must be perpendicular to the optic axis and at a constant distance equal to the principal focus of the lens. There should be also a fixed horizontal limb, with a minute reading vernier, attached to the camera to measure the angles between different views from the same station. There must, moreover, be a means for determining the true horizon of each view. Several French instruments have been devised, notably Moessard's and Chevalier's, that substantially fulfill the above conditions. With these it is possible to do work which is more than sufficiently accurate for ordinary graphic reproduction.

FUNDAMENTAL PRINCIPLES.

A perspective drawing or photograph is a simple conic projection on a plane, the visual rays all passing through a fixed point, called the point of sight. If the picture is revolved about its horizon line until it falls into the plane of the horizon, the relative position of picture and point of sight would be as indicated in the diagram, View No. 1, with its corresponding point of sight, S. The line, SP, is the constant principal focal length, of the objective, and the point P is the optic centre of the picture. If now points, a, b, c, etc., are projected to the horizon $h\,h'$, the true horizontal angles between these points will be obtained by drawing lines through S to the projections a', b', c', etc. To locate points then, it is only necessary to triangulate by means of at least two views of the same points, taken from the ends of a measured base line, thus locating their horizontal projections by intersections. In the figure, SS' is the base line plotted to scale. From S, View No. 1 is oriented by the compass bearing of its centre line SP. View No. 2 is similarly adjusted in position and the true location of points $a\,b\,c$ is found by the intersection of the lines Sa' and $S'a'$; Sb' and $S'b'$; Sc' and $S'c'$. A check is afforded by a view from a third section S'', whose location is known.

To find the height of a point above or below the horizon of any view, we take its horizontal and vertical coördinates with reference to the point of sight as an origin. These give the tangent of its vertical angle which, when multiplied by its true distance from S, measured on the plot, will be the height required. For example: to find the height of point A, in View 1, above its horizon hh', we have the proportion:

$$aa' : a'S :: X \text{ (true height in feet)} : AS \text{ (true distance in feet)}.$$

From which, $X = \pm AS \frac{aa'}{a'S}$. Denoting X by H; A S by D; $\frac{aa'}{a'S}$ by tan Θ we have the general formula

$$H = \pm D \tan \Theta$$

When the scale of the map is not large the ordinary landscape camera can be used satisfactorily, as explained by Lieut. Reed, U. S. A., in his work on "Photography Applied to Surveying."* The camera for use as a surveying instrument requires the following important TESTS AND ADJUSTMENTS :—

I. Measurement of the principal focal distance of the objective.

II. The placing of needle points in the rear frame of the camera, so that when the camera is levelled and an exposure made, the lines joining the images of these points will be truly horizontal, and pass through the optic centre of the picture.

To make these adjustments: In the first place draw two diagonals on the ground glass screen. Their intersection is the approximate optic centre. Also, place two fine needles opposite each other in the rear frame of the camera, so that the line joining them will pass through this optic centre. The instrument should now be set up in an open space, and carefully levelled. Then place three rods in a row, about 150 yards off, and at right angles to the line of sight of the camera, the image of the centre rod falling on the centre of the focussing plate, and those of the other rods near its edges. These end

* John Wiley & Sons, New York.

rods should have targets, which should be adjusted by means of a transit or level to the same height as the optic centre on the ground glass. The rods are now carefully focussed. The sliding focussing frame is then marked, so that the same focus may be used for all pictures taken for surveying purposes; as usually the points are distant ones, and the focus for all such is constant. The height of the lens if it have a vertical motion, should also be fixed by a mark. The exposure is then made, care being taken that the levelling of the camera is not disturbed. The camera is removed; and the transit set up in its place, over a point which was under the centre of the objective tube. The angles θ or θ' between the rods are then read carefully.

On the negative, the distance d or d' between either end rod and the middle one is measured, and the focal distance, PS, determined from the formula—

$$PS = \cot \theta \; d.$$

On the negative, moreover, we have the position of a true horizon line between the targets, also the images of the needles which may not fall exactly on this line. If not, they should be readjusted so that in future they will give the true horizon, remembering in making the adjustment that the negative was taken reversed as well as inverted. A second pair of points should also be put in at right angles to the horizon, so as to give a vertical line through the optic centre.

FIELD WORK.

The photographic method is best adapted to filling in the details of large primary or secondary triangles, though the entire survey could be made with the camera alone. The photographic stations are usually in groups of three, and occupy commanding positions near the borders of the survey, if possible. Several views (the number depending on the position of the station) are taken from each point of observation.* Angles to prominent points in the picture, as well as the angle made by the line of sight through the optic centre, with the base line, are read from the horizontal limb and vernier; or, in its absence, their bearings by a hand compass will answer. The camera must be carefully levelled in all its positions, and the height of the horizon line from the ground noted.

FORM OF FIELD NOTES FOR A PHOTOGRAPHIC SURVEY.

STATION.	VIEW.				REMARKS.
	No.	Index Number.*	Height of Centre of Plate above Ground.	Bearing.	
A	1	0	4.6′	$105\frac{3}{4}°$	
	2	+ .1		$140\frac{1}{2}$	
...	...	...	...	...	...
B	1	0	4.2′	208°	...
...	...	...	...	...	...

The distance at which a point can be located accurately from a photograph, depends on the focal length and the scale of the map. For example: If the focal length is 1.25 feet, and the scale $\frac{1}{2000}$, the limit of accuracy would be $1.25' \times 2000 = 2500'$. That is if the point is much more than 2500′ from the observing station, it would fall outside the horizon of each view (horizontally projected), and would, therefore, not give the intersection with sufficient exactness. If the scale were $\frac{1}{5000}$, the operations could be carried on at a distance of 6250′. For scales between $\frac{1}{2000}$ and $\frac{1}{5000}$, it is found by experience that the results are most satisfactory if the focal length is about 15″. Between $\frac{1}{5000}$ and $\frac{1}{10000}$ a focal length of 12″ may be used.

OFFICE WORK.

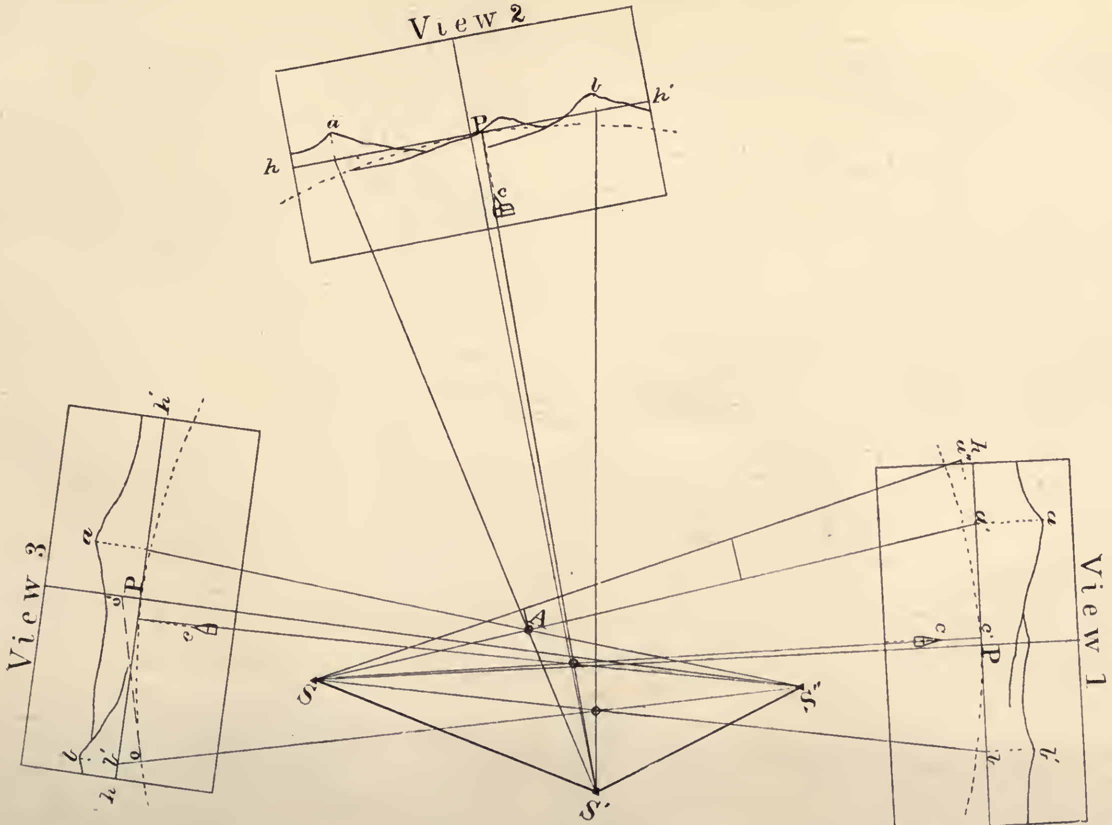
For exact work, plotting from the negative is to be preferred to using a print; but the print is much more convenient to handle. The negatives are prepared for plotting by drawing fine lines between the needle points indicating the horizon, and middle vertical. If these lines are scratched on the negative film with a fine needle point, they will appear as distant black lines on all subsequent prints.

* When the lens has a vertical motion its position when hh' is determined is 0. When the lens is raised or lowered the amount in inches is to be noted and placed in this column.

After plotting the base line, or the complete triangulation (if the photographic method is used merely for filling in), it will be found convenient to describe from each station a circle or an arc with a radius equal to the focal distance. The views from any station are then oriented tangentially to this arc, their lines of sight making the observed angles with the base or other fixed line (see diagram). If it is found preferable to orient a view, not from its principal line of sight, but from some point in the picture whose location is known, the method illustrated in the diagram, View 3, is used. The horizontal angle of point b is known with respect to the line $S'S''$. It is laid off in the direction $S''O$, and at O a tangent line, OO', is drawn. On it the length, OO', is measured, equal to the distance of the horizontal projection, b' from P. Through O' is drawn the true line of sight of the view.

MEASUREMENT OF HEIGHTS.

The most exact method is to calculate the tangent of the vertical angle of each point, as before explained, and multiply by the distance of the point taken from the plot. A much quicker graphic mode is entirely satisfactory when proper care and delicate instruments are used. It is the following:—Referring to the diagram, View 1, suppose at a' the perpendicular, $a'a''$, be drawn to the line $S\ a'$. Connect S with a'', and at the point A draw another perpendicular to $S\ a'$, till it meets $S\ a''$. The length of this perpendicular measured to the scale of the map is the height required. Greater accuracy is attained by measuring the perpendicular at a point two or three times the distance of A from S, and dividing the height thus gotten by the number taken, or the whole construction may be made on a much larger scale on a separate sheet. The heights thus found are only relative. To find them with respect to a fixed datum, it is necessary to know, first, the reference of the horizon to this datum, from which the absolute height can readily be obtained. The accuracy with which heights may be measured depends almost entirely on the amount of care and skill employed. With a 15″ objective, at a distance 1500′, the error should not exceed ± 1′. The picture should be taken, however, as near as possible to the object, when exact heights



PLOT OF PHOTOGRAPHIC SURVEY.

are to be determined, as the error is directly proportional to the distance, and inversely to the focal length.

In extended surveys, where the contours are ten or more feet apart, all desirable accuracy is obtained in the contouring, while the location of points is exact, agreeing with maps made by the most approved methods, as tested in a recent survey of the Schuylkill river and vicinity, near Fairmount. In conclusion, to quote from Prof. Hardy: "In proportion as the survey is small, and the greatest possible accuracy requisite, the photographic method loses its superiority. But for large surveys its advantages are unquestionable; and in all cases may be made a valuable source of contribution to those details which would otherwise demand a long and tedious direct observation."

In the preparation of this article I am especially indebted to the works of Col. A. Laussedat, Prof. A. S. Hardy, and Lieut. Henry A. Reed, U. S. A.

CHAS. HERMAN HAUPT.

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Haupt, Lewis Muhlenberg
The topographer, his instruments and methods. Ed.2.

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