DEPARTMENT OF THE INTERIOR
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U. S. GEOLOGICAL SURVEY
George Otis Smith, Director

Bulletin 788—C

TOPOGRAPHIC INSTRUCTIONS
OF THE
UNITED STATES GEOLOGICAL SURVEY

C. TRANSIT TRAVERSE

Compiled by E. M. DOUGLAS

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ILLUSTRATIONS

NOTE

It is desired that these instructions shall be complete so far as transit traverse for map control is concerned, in order to reduce to a minimum the necessity for personal instruction in such work. Notice of errors or omissions or suggestions for improvement will be welcomed.

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Chief Topographic Engineer.

Approved:
GEORGE OTIS SMITH, *Director.*

WASHINGTON, D. C., *May 15, 1925.*

SUGGESTIONS TO COMPUTERS

[NOTE.—The following suggestions, contained in the part of this bulletin relating to triangulation, apply also to traverse computations.]

Do not crowd your work; paper is comparatively cheap.

Do your work in a systematic manner. If it permits tabular arrangement, always use the forms approved by other computers unless you can convince them that yours are better. The Survey has printed forms for many purposes; these should be used whenever possible, for by their use the work is made more mechanical, and the more mechanically the work is done the less chance there is for error.

A computer who is inexperienced or out of practice should check his work in every way possible. He should check logarithms either of numbers or of circular functions by using first a tabular value for a quantity less than the given one and then a greater tabular value, so that the differences in one case may be added and in the other subtracted. This operation may be reversed when the logarithm is given and numbers or angles are required.

Many errors are made by taking out the first three figures of a logarithm from the wrong line of a seven-place table where a dash over the fourth figure indicates that the first three should come from a lower line.

As the algebraic signs of cosines and sines are so frequently required, the rules governing them should be firmly fixed in the mind; as an aid to this remember the general rule that distances measured upward or to the right on the conventional plat of the quadrants of the circle are considered positive, others negative. The wrong use of signs is a very common source of error.

Where the function of an angle over 90° is desired, instead of subtracting 90° or 270° from the angle to find the argument, add the figures in the tens and hundreds of degrees places together and prefix the sum to the unit degree figure, dropping the sum if it is 9. Thus 121° gives $1+2=3$, and 31° is the argument; 184° gives $1+8=9$, drop it, leaving 4° for the argument; 290° gives $9+2=11$, drop 9 from the 11 or add the two figures a second time, giving an argument of 20°.

Each step in a long computation, if it is not at once automatically checked, should be checked by repeating the computation.

Check the copying of angles, distances, etc., taken from adjusted results for use in new computations; also check figures carried from page to page.

Gross errors are sometimes made by using the sine when a cosine is required, or by writing a product in the wrong column, as east for west, in transit-traverse computations.

Placing the decimal point in the wrong place is a common mistake. This may in many cases be corrected by a mere inspection of the quantity to see whether it appears of proper value.

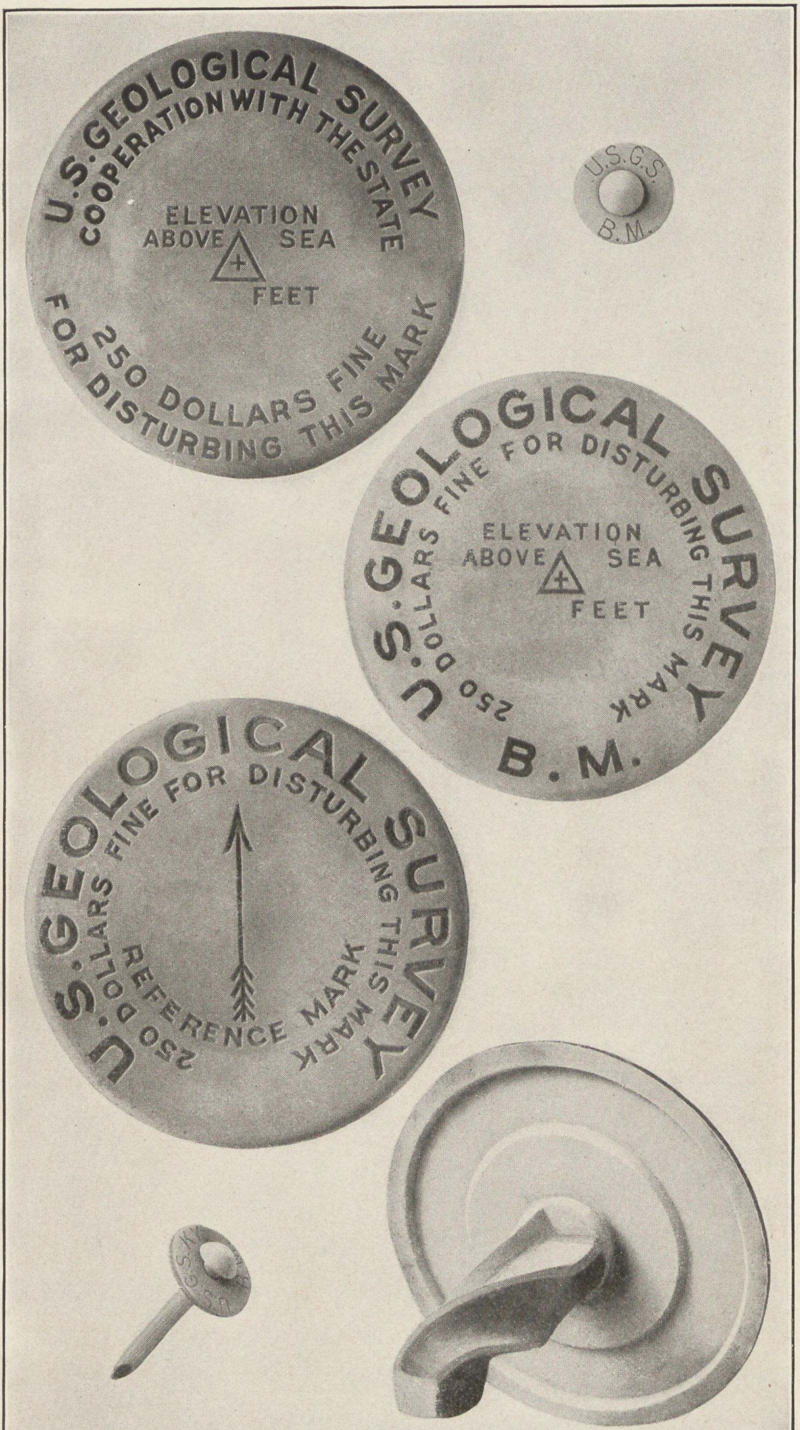
When a large closure error is found in a transit-traverse line look first for a compensating error of 1° or 10° in the azimuths or angles.

Good judgment should be exercised in the degree of accuracy sought for a given result. For the preliminary computation of geographic positions, for example, six-place logarithms will suffice; these can be taken from a seven-place table with only a rough interpolation. A four-place logarithm can often be used to advantage. The accuracy of the results obtained should equal the requirements; more than this involves a waste of time.

The foot, yard, and mile are the units adopted for all Geological Survey field work, but for geodetic computations meters are used. The best conversion tables for metric and English measures are those published by the Bureau of Standards. In using these all changes from one system to another should be checked by reversing the operation. The logarithms for the interchange of these measures are given in "Geographic tables and formulas," page 364.

When computers are duplicating work and a difference is found, each should recompute the result before correcting either, as errors have frequently been made by changing the correct figures.

When two persons are comparing a copy with the original, if the reader occasionally calls out a wrong figure or word intentionally and notes whether the error is caught up, it tends to keep the listener more intent on the work.



GEOLOGICAL SURVEY MARKS FOR TRIANGULATION, TRANSIT TRAVERSE, AND LEVELING

C. TRANSIT TRAVERSE

Compiled by E. M. Douglas

GENERAL CONDITIONS FOR MAP CONTROL

The boundary lines of all regular United States Geological Survey maps are parallels of latitude and meridians of longitude. In order that these shall be properly located and that intermediate points shall be placed in correct positions, some system of horizontal control is required. The method to be adopted for linear control should be fixed by the character of the country, one of the requirements being that all control work shall be so accurate that no errors will be apparent in maps several times as large in scale as those to be published. In mountainous regions or in hilly, partly timbered areas horizontal control is effected by a system of triangulation, the whole area being divided up into triangles whose apexes are represented by stations established on prominent points several miles apart.

In heavily timbered areas, where it is difficult to see from any point more than a mile or two in any direction, horizontal control is best obtained from distances measured on the ground with a 300-foot steel tape, a record being made of angles measured with a transit at each bend in the line. Such control must begin and end at points whose positions have been previously determined, and regardless of the character of the country such control must be carried around the edge of each quadrangle and once across its center east and west.

The United States Board of Surveys and Maps has classified traverse control for geodetic or map use into four orders. The position check for the first order is 1 in 25,000; for the second order, 1 in 10,000; for the third order, 1 in 5,000. Control of the fourth order is based on tape, wheel, or stadia distance measurements. For transit-traverse control as executed by the Geological Survey for map use an accuracy of the third order only is necessary, but the limit of error of 1 in 5,000 must be maintained. The main or trunk-line traverses that supplement the first-order (precise) work of the United States Coast and Geodetic Survey must be of such an accuracy that a control point near the corner of each degree quadrangle shall be located with an error of not more than 1 in 7,500.

TRANSIT-TRAVERSE FIELD WORK

PERSONNEL AND OUTFIT OF PARTY

A transit-traverse party consists of an instrument man in charge, a recorder, two tapemen, and two rodmen; also a cook and a teamster when camping is necessary.

The following supplies (see pls. 5, 6) can be obtained on requisition:

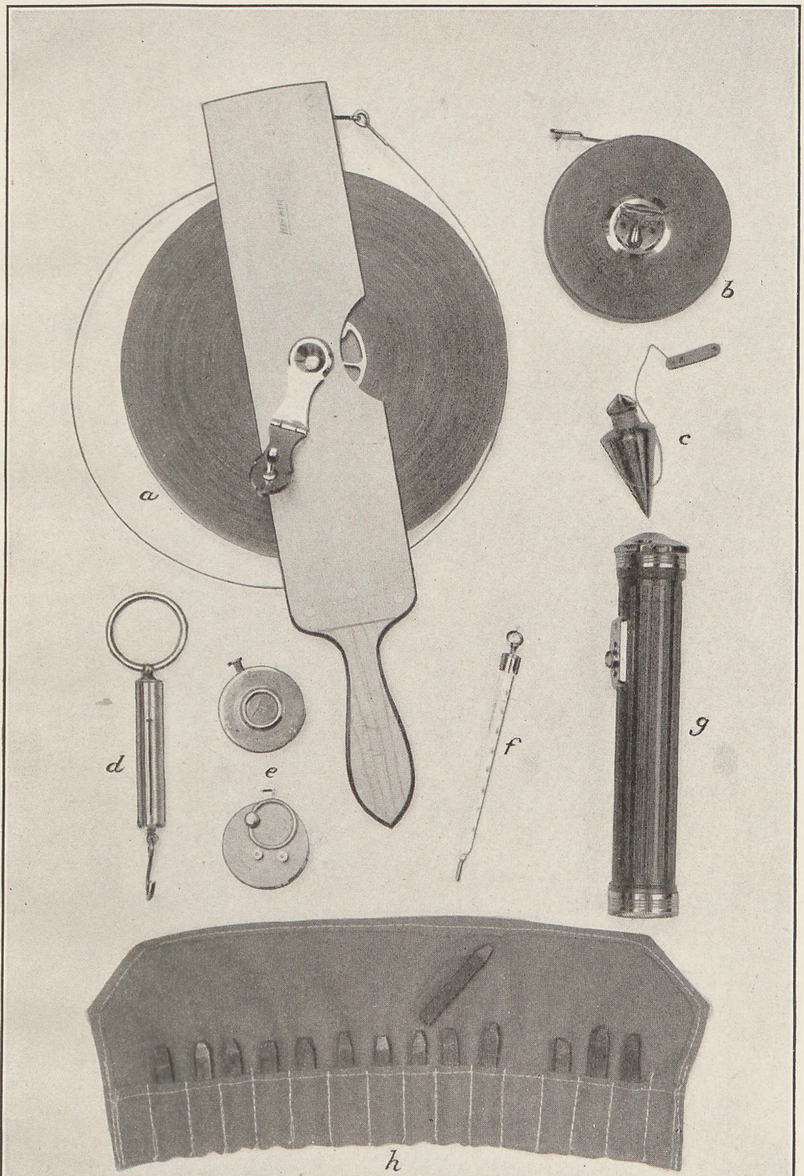
- One transit, graduated to 30 seconds and furnished with stadia wires.
- Two 300-foot steel tapes, graduated to feet throughout.
- One 100-foot steel tape.
- Two red and white transit rods.
- One stadia rod.
- Two plumb bobs.
- Eleven tally pins.
- Three hand recorders.
- Two electric hand lamps.
- One tape repair outfit, punch, and rivets.
- Three tape clips, temporary repairs.
- Two tape holders.
- One spring balance.
- One thermometer.
- One set steel dies, figures.
- One set steel dies, letters.
- Three large book bags.
- Standard bench-mark tablets.
- Canteens.
- Cement (in cans).
- Drills, hatchet, hammer, post-hole digger.
- Transit-traverse field notebooks 9–928.
- Tapemen's notebooks 9–929.
- Blank notebooks 9–896, or 3 by 5 inch pieces of manila paper.
- Book of instructions.
- Polaris and sun tables.

The instrument man must carry a reliable watch.

ADJUSTMENT OF INSTRUMENTS

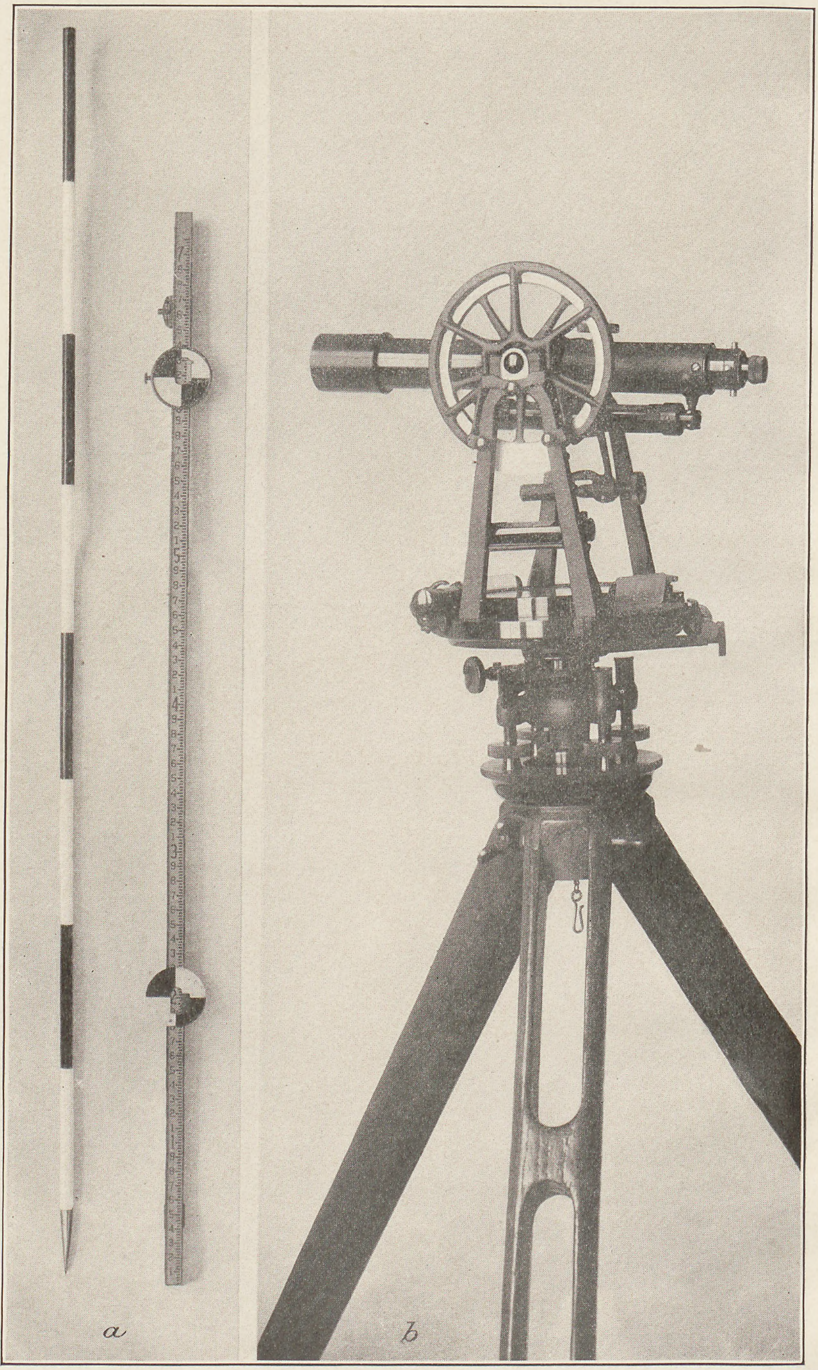
PRECAUTIONS

The object glasses and eyepieces of all instruments must be properly focused. The cross wires projected against a distant object should appear immovable when the eye only is moved. Before the adjustments are commenced the instruments must be firmly set up and leveled. An instrument may appear to be out of adjustment simply because some part is loose. The object glass may be partly unscrewed, or an adjusting screw may be only partly tightened; level bubbles or cross wires occasionally become loosened. Therefore, before commencing the adjustment of an instrument look out



APPARATUS USED IN TRANSIT TRAVERSE

a, 300-foot tape and reel; *b*, 100-foot tape; *c*, plumb bob; *d*, spring balance; *e*, hand counter; *f*, thermometer; *g*, flash light; *h*, steel dies



VERNIER TRANSIT (*b*), STADIA ROD (*a*, right), AND RANGE ROD (*a*, left) for such defects. When it is thought that an adjustment has been completed, always test it before using the instrument. All adjusting screws should be screwed tight enough to hold, yet not so tight as to injure the threads or put a severe strain on any other part. Especial care should be taken not to strain the cross-wire screws. Adjustments should be made in the order given under the following headings, for some adjustments depend on the accuracy of others previously made, and a change in any one may affect the others.

MINOR REPAIRS

Setting of bubbles.—For setting level bubbles a small supply of plaster of Paris should be kept on hand. For use the plaster should be mixed with water to the consistency of a thick paste. If plaster is lacking, strips of paper may be used, but these should never be jammed in very tight, as the pressure may distort the glass and thus vitiate the bubble reading by an appreciable amount. A reflecting surface of colored paper should be placed under the bubble in order to make the graduations more readable; a subdued green or blue tint is recommended.

Mounting of cross wires.—For mounting cross wires a small bottle containing shellac dissolved in alcohol, a pinch of beeswax, and a pair of dividers or a forked stick are needed. The best spider web is, of course, a freshly spun one from a small spider, for this will be both clean and elastic; but as spiders are not always available, it is well to keep on hand a spider cocoon. Such a cocoon will furnish webs enough to last for years, although with age the threads become stiff and brittle and therefore more liable to break from a jar to the instrument. Most webs taken from grass or bushes are rough, coarse, and dirty.

To draw the reticule from the instrument, unscrew and remove the eyepiece slide; then take out two opposite capstan-headed screws and loosen the other two. Using the latter two as handles, revolve the cross-wire ring 90°, insert a pointed stick through the end of the telescope tube into a screw hole in the ring, and, using it as a handle, remove the other capstan screws and draw out the ring. To replace it in the telescope, reverse this procedure. When in place the cross wires should be on the side of the ring toward the eyepiece.

Having pressed a bit of beeswax to each prong of the dividers or forked stick, let a small web fall from the end of one of the prongs, or pick with it from a cocoon a single thread, pressing the thread into the beeswax, stretch the thread moderately, and attach to the wax on the other prong. If an old web is used, it should first be dampened by dipping in water for a few seconds. In place of the dividers or forked stick, small sticks or lumps of wax may be attached to the web about 2 inches apart. Place the web across the reticule, using a magnifier to insure its coinciding exactly with the marked lines. Put a small drop of shellac on each end and leave until dry.

Instruments such as the prism level, dumpy level, and transit, which are not provided with Ys or similar devices for adjusting the cross wires, may be put in close adjustment by means of improvised wooden or metal Ys.

ADJUSTMENT OF TRANSIT

Plate levels.—With lower plate clamped and upper plate loose, level carefully; revolve the instrument 180° on its vertical axis and bring each level bubble halfway back to the center of the tube by means of the screw at one end.

Collimation.—Level carefully, sight on a point about 500 feet distant, raise or lower the telescope slightly, and note whether the vertical wire remains on the point; if not, loosen the capstan-headed screw and turn the cross-wire ring till the vertical wire will remain on the point when the telescope is raised or lowered. Clamp the instrument, set the vertical wire so that it cuts the point selected, transit the telescope by revolving it 180° on its horizontal axis, and select a second point 500 feet distant in the opposite direction from the first. Unclamp the upper plate, turn the transit 180° on the vertical axis, relevel if necessary, set it on the point first selected, and again clamp the plate. Transit the telescope, and if the vertical cross wire exactly bisects the second point its adjustment is perfect; if it does not, bring it one-quarter of the way back to the second point by turning the two capstan-headed screws on the sides of the telescope.

Standards.—Set up the transit near a tall building or other high object; after leveling carefully, point the telescope so that the vertical wire intersects a definite point about 60° above the horizontal, depress the telescope, and select a second point near the ground. Unclamp the upper plate, revolve the telescope and plate 180° on the vertical axis, clamp the plate with the vertical wire again cutting the upper point, and depress the telescope; if the cross wire intersects the lower point, the standards are in adjustment; if it does not, correct for one-half the error by the screw underneath one end of the telescope axis.

Object-glass slide.—If an adjustment for the telescope object-glass slide is possible, it is made as follows: First make the collimation adjustment for a point about 300 feet distant, then focus on a point 1,000 feet or more distant and again on a point only 10 or 15 feet distant, transit the telescope, unclamp the plate, turn it 180° on the vertical axis, and reclamp. If the cross wire still cuts the distant and near points, the slide is in perfect adjustment; if it does not, correct half the error by means of the side screws that hold the slide ring in place. Next repeat the regular collimation adjustment and again test for the slide error; repeat both adjustments until no errors appear.

Eyepiece tube.—The eyepiece may be put into position over the cross wires by turning the screws that hold the eyepiece ring until the cross wires appear in the center of the field; an exact centering is not required.

Telescope level.—If there is a level attached to the telescope, it may be adjusted by the "peg method" after all the other adjustments are made, as follows: Level the transit and bring the bubble to the center of the tube under the telescope. Take a reading on a leveling rod or pole 300 or 400 feet distant, which is held on a stake set firmly in the ground. Revolve the transit 180° on the vertical axis and after again bringing the bubble to the center set a second stake at the same distance as the first and at such an elevation that the rod or pole reading is the same as on the first stake. The tops of the two stakes will then be at the same elevation. Move the transit 25 or 50 feet back of one stake and on a line with the other. Make the telescope as nearly horizontal as possible by means of the attached level, clamp it, and then take a reading on the rod held on the near stake and another reading on the distant stake. If the two readings agree, the telescope is horizontal; if they do not agree, turn the tangent screw so as to bring the cross wire while set on the distant rod nearly to an agreement; repeat the operation until an agreement is reached. The telescope is then level, and the adjusting nuts at the end of the level tube should be turned until the bubble is brought to the center.

Vertical circle or arc.—The screws holding the vernier for the vertical arc should now be loosened and the vernier moved until the reading is 0° while the telescope is still level.

GENERAL REQUIREMENTS

Location of line.—Transit traverses should always be run in circuits or tied to points previously located. In a 15-minute quadrangle, in country where routes can be readily planned, traverse lines should follow as closely as possible the borders of the quadrangle to be controlled, not departing from them more than is necessary to keep on roads. If there is a choice of roads, select the one in an unmapped area. An additional east-west line should be run to bisect the quadrangle. In areas where the country will not permit this plan to be followed economically and where the selection of routes for the lines must be influenced by the location of highways, it will be necessary to plan the routes to meet the specific requirements.

Permanent marks.—In areas where topographic conditions permit a tablet (see pl. 4) in a concrete post must be placed as near as possible to each corner of each 15-minute quadrangle, one on each side halfway between the corners, one in the center of the quadrangle, and others at average intervals of 3 miles along other parts of the lines. All such marks must be stations on the lines and unless they have already been marked by a levelman should be stamped "Trav. Sta. No. —" (numbered consecutively) and also with the year of survey and the initial letter of the traverseman's surname. In areas that can not be traversed according to the regular plan permanent marks must be established at intervals not greater than 3 miles.

In cooperating States the appropriate tablet (*A*, pl. 4) must be used.

Where level bench marks have already been established along the route of survey, they should be tied to and stamped as above and thus made to serve as permanent marks on the traverse line.

It is desirable that every permanent point be tied to two or more witness or reference points, and the true azimuths, a sketch, and the approximate or exact distance to each, with description, should be duly recorded in the notebook.

Sites for marks.—The sites for permanent marks should be selected with great care and be at points where they may be used by levelmen as bench marks. It should be borne in mind that the value of the work depends largely on the permanence and the accuracy of the marks. Marks that are intended to be permanent must not be placed nearer than 15 feet to a wagon road or a railroad. They should not be placed on bridges, though these may be good places for temporary marks. A concrete post may be placed on the right of way line of a railroad or highway. The right of way line at the intersection of two roads is commonly an excellent site. The marks should not be placed near old buildings that may soon be torn down, enlarged, or rebuilt. The site selected should be a place where the mark will not be in the way of anyone and will probably not be disturbed for many years. Marks set in earth in exposed localities should be surrounded by mounds of earth or stone.

Concrete posts.—Where solid rock or large boulders are not available, the most durable objects in which to place tablets are concrete posts. These posts may be made by contract, or if made in place, proceed as follows: Provide two or three heavy reinforcing wires of nearly the length of the proposed post, with ends bent over an inch or two; also a piece of conical sheet-iron pipe 12 inches long, 6 inches in diameter at one end and 8 inches at the other. Dig a hole

12 inches in diameter and 24 to 36 inches deep. The deepest holes are required in cold regions; a 24-inch hole is deep enough in regions where the ground seldom freezes. Place the reinforcing wires in the hole, and fill within 6 inches of the surface of the ground with concrete consisting of one part cement, two parts sand, and three parts broken stone or gravel, well mixed and moderately wet; tamp well. Set the iron pipe, large end down, over the center of the concrete block so as to inclose the wires, and space them an inch or so from the outside. Fill the pipe with cement mortar, consisting of one part cement and two parts clean sand; tamp well. In the top of the post place a tablet flush with the rounded surface of the cement. Any marks to be added to the tablet should be stamped on it before it is placed in the wet mortar. The finished post should not project more than 6 inches above the original ground surface. The post when completed should be sheltered from the sun for several days. If a mark must be established in soft or wet ground proceed as follows: Drive a wooden stake 3 by 3 inches, or larger, as far in the ground as it will go without splitting. Saw off the top about 6 inches above the ground. Place a length of glazed drain tile 6 inches or more in diameter around the stake, with its flange end at least 12 inches below the surface of the water or ground. Fill the tile with cement mortar, round off the top slightly, and set a bench-mark tablet in the top flush with the surface of the cement.

Azimuth marks.—Whenever practicable two or more reference marks should be established for each permanent mark, from which azimuths can be found for future use. These may be church steeples, cupolas on schoolhouses, water tanks, corners of large buildings, or any other prominent objects. If no well-defined objects are visible, copper nails in large trees 50 to 100 feet distant will serve the purpose. The distances and the angles to near-by marks should be measured. A sketch helps the computer avoid errors in finished work. All reference marks and the azimuths to them must be described and reported, together with the computed results of the line.

Additional points.—Besides the permanently marked points, a number of other points should be carefully located along the traverse, and these points should be specifically designated in the field notes. Of special importance are the crossings of boundaries of States, counties, and civil townships, and the locations of the principal crossroads, railroad and highway crossings, railroad stations, and township and section corners. Note should also be made of less important landmarks, such as road forks, mileposts, railroad switches, and stream crossings. These points should be so completely described in the notebook as to be readily identified.

Control for airplane photographs.—In view of the extensive use of airplane photography for mapping, all points on a traverse line that can be easily identified from the air must be located.

Maps are most successfully compiled from aerial photographs when the control traverses are run after the photographs have been made. By this arrangement routes for traverses that will most effectively control the photographs may be selected. It is absolutely essential that traverse points be located near each end and the center of an area covered by a tri-lens photograph in order to control it properly, and the chance of getting such a combination of points is very much reduced if the arrangement of the areas to be photographed in the quadrangle is not first considered. This condition does not apply to single-lens photographs, for which the ordinary rules for the distribution of traverse lines may be followed.

Control points for aerial photographs should be selected with due regard to easy identification, and only such points as are clearly shown in the photographs should be chosen for computation. Gates, trees, wire fences, windmills, houses, and indefinite road intersections are unsuitable. Road forks, road intersections, well-defined angles in roads or streams, stream crossings that intersect roads at right angles, fence lines defined by a growth of trees or brush, sharp angles in woodland boundaries, and railroad crossings usually make good points for identification.

Level bench marks.—The work must if possible be so arranged that the levelman can determine an elevation for each traverse mark; therefore the party that precedes should endeavor to select sites for marks suitable for the other party, and the descriptions made by both parties should agree. Copies of the descriptions should be forwarded daily to the party following.

Land survey corners.—Diligent search and inquiry should be made for marks on the public-land surveys, and accurate connections should be made with each one that is found. It is very important that numerous corners be located for the topographer. In areas where unusual difficulty is experienced in finding corners the General Land Office will, on request through the Washington office, detail a cadastral engineer to assist in the search.

Accuracy.—For all circuit closures in new work or ties between located points of the same or a higher order an accuracy of not less than 1 in 5,000 (about 1 foot to the mile) must be maintained.

For main or trunk control traverses that follow routes near the borders of each full degree quadrangle an accuracy of 1 in 7,500 must be maintained—that is, the initial and computed positions of a tie point must not show a difference of more than 1 part in 7,500 of the length of the traverse line. To insure such a degree of accuracy especial care must be taken in making the measurements of distance. The front tapeman should be a man of experience and should be held responsible for proper procedure.

Highway surveys.—Highway surveys may often be substituted for or used as transit-traverse lines. The field notes for these surveys can usually be obtained from the office of the State highway department, which is generally at the State capitol.

The methods of surveying highways are similar to those used in transit traverse, except that the true azimuths of the lines are seldom given; but approximate azimuths may be based on a magnetic bearing of the first course, to which has been applied the deflection angle at each transit station. If no true azimuths are known, it will be necessary to tie to at least two adjacent stations near the beginning of each highway survey and to observe for the true azimuth of that course. Additional azimuths should be determined at stations not more than 10 miles apart.

Field notes of highway surveys should be copied in book 9–928. In these notes each station is usually referred to two or three points; the descriptions of these points should be copied from the field notes and used in tying to the stations at which azimuth observations are to be made.

The results of each azimuth observation should be computed in the field as soon as the observation is made, and the bearings from the highway surveys should be checked between observations.

In copying field notes of highway surveys all road forks, bridges, railroad crossings, civil boundary lines, and junctions with other highway surveys should be noted for computation.

Highway surveys must always be tied to triangulation or transit-traverse stations by running a traverse line from a station on the highway survey to a station of higher order.

FIELD METHODS

Duties of tape men.—The front tape man must carefully mark off each tape length, if on a wagon road, with tally pins; if on a railroad tangent, with keel on the rail. Each time he marks off a tape length he registers it on his hand recorder; each time the rear tape man reaches the mark left by the front tape man he does likewise. When a transit station is established the two tape men compare their hand records for check on the measurement. Should they differ, the course must be remeasured.

Transit stations should be made at even tape lengths or even 10-foot marks, wherever possible, in order to simplify the work of the computer. They should be selected at points affording not only an unobstructed view back to the transit but also a clear view forward. Each station is to be marked, if on a wagon road, by a 10-penny nail driven into the ground through a piece of paper on which the front tape man has written the number of the station and the distances; if on a railroad, by a keel cross on the rail with the number and distance on the nearest tie.

Stations on main lines are to be numbered consecutively, beginning with zero; those on short spur lines to section corners or other points to be computed are to be lettered instead of numbered. Station numbers should never be duplicated in a single locality.

The two tape men must keep in book 9–929 separate records of the number of stations and distances between them. At noon and at night these records must be compared with the recorder's notes, and should there be a difference it must be corrected before the line is carried forward, the line being retraversed if necessary.

In locating transit stations the front tape man should bear in mind that it is desirable for the instrument man to be able to sight the bottom of the rod in each direction. This is especially important on short sights, for errors due to sighting the upper part of a rod which may be out of plumb may appreciably affect the accuracy of the line.

Method of measuring.—When measuring along a wagon road the tape must be kept horizontal unless the grade is very slight; on short steep slopes a plumb bob must be used either to bring the tape end vertically over an established point or to establish a new point. Judgment should be used in selecting the proper length of tape on short slopes; no attempt should be made to use the full 300-foot length; about 150 feet is ordinarily all that a tape man can hold horizontal with the proper tension and plumb at the same time. On slopes that require "breaking" the tape into short sections, the entire tape should first be drawn forward its full length by the front rodman if convenient, or by the front tape man, who then returns to help "break" the tape at the proper places, until the end of the tape is reached. In this manner the distance is measured on the whole tape and does not depend on the sum of the separate horizontal measurements.

On long regular slopes the distance on the slope should be measured and recorded and the angle of slope measured with the transit. The corrections for slopes of 1° or 2° for short distances are negligible.

Test of tape.—A tested tape will be supplied to each party and should be kept in reserve; the tape used in measuring should be compared with the tested tape each week and the results made a part of the record. A tape when in use should always be stretched by means of a spring balance to a tension of 20 pounds.

Tape errors.—Tests of tapes by the Bureau of Standards seldom disclose errors as great as 0.01 foot in 300, but occasionally for a patched tape the error runs as high as 0.06 foot. Great care should be taken when a broken tape is patched to see that the length of the section is not changed. Before any tape is used in the field the length should be checked up by the chief of party, by comparison with an unbroken standardized tape.

A difference of 7¾ feet in the elevation of the ends of a 300-foot tape will shorten the horizontal distance 0.1 foot. A difference in elevation of 2½ feet will shorten the distance 0.01 foot.

Geological Survey 300-foot steel tapes are standardized at a temperature of 68° F. and a tension of 20 pounds. A variation of 10° above or below this temperature will change the length of the tape 0.02 foot. Differences of temperature of 20° or 30° above or below 68° are common and for such differences corrections should be made in the recorded figures for distance, which should be increased for temperatures above 68° and decreased for temperatures below 68°.

A change in tension of a Geological Survey 300-foot steel tape from 20 to 25 pounds increases its length 0.016 foot. A decrease in tension from 20 to 5 pounds shortens the tape 0.047 foot.

The correction for sag (always negative) for a 300-foot tape supported at 50 foot intervals under a tension of 20 pounds is 0.016 foot.

Errors in taping.—The errors that most seriously affect the accuracy of taped lines may be grouped in two classes.

The errors of one class are due to failure to keep the tape horizontal and to careless plumbing. The instrument man should impress the tape man with the fact that the accuracy of traverse depends on the taping more than on the instrumental work, for the latter is checked at every azimuth observation, whereas there is no check on the taping until the circuit is closed.

The errors of the other class are gross mistakes, arising generally from carelessness in counting tape lengths. They may be eliminated by checking the count of tape lenghs by independent measurements. To do this, the instrument man should measure each distance by stadia, using the red and white transit rod or a special stadia rod carried for this purpose. In case the distance is too great to be read by a single sight, he should set up the transit between stations and read both front and rear rods. Stations should under no circumstances be more than 2,600 feet apart, which is about the limit of visibility of the rod. On a railroad an additional check on the taping may be had by counting rail lengths, but it should be remembered that rails may be 26, 28, 30, or 33 feet long. The counting should be done by both rodmen and the recorder, or by the instrument man while moving from one station to the next. In other places a check may be had by pacing. The distance to a plus point should be checked, as well as the distance to the next station.

Temperature record.—The transit man should carry a thermometer and record the temperature every hour.

Stadia control.—Under certain conditions it is allowable to substitute stadia distances for tape-line measures in transit traverses for "fourth order" control of maps. Such lines should not exceed 20 miles in length and should be well checked, either by tying to a previously determined point or by closing on an azimuth station. Points on stadia lines should not be used as initial points for the extension of transit traverses.

For work of this class a Philadelphia rod with two targets should be used, one target to be fixed at the 2-foot mark, the other target to be set from signals by the transit man.

The value of the stadia interval must be accurately determined for each transit by the following method: With a steel tape measure a base line on nearly level ground and mark stations at intervals of 100, 200, 300, 500, 700, and 900 feet from the center of the transit. With the transit at station 0 read and record the rod interval at least five times for each station, setting the upper target carefully for each reading and recording intercepts to three places of decimals. Repeat the observation at intervals of two hours from 8 a. m. to 4 p. m. The means of the differences between the steel-tape distances and those found by stadia will be the corrections to apply to stadia readings before recording them. Only the corrected stadia distances are to be recorded.

Stadia stations should not be more than 900 feet apart.

OBSERVING AND RECORDING

Deflection angles.—At each station, in reading deflection angles, the instrument man should proceed as follows: Sight rear rod with transit circle set at last reading at previous station, transit telescope, sight front rod, and read both verniers. Turn instrument with the two plates clamped, the vernier remaining undisturbed; sight rear rod again and remeasure the angle. If the two results thus obtained differ more than 60 seconds, repeat the operation. Opposite vernier readings will not always give the same minutes and seconds; both must be read and recorded to the nearest second.

When the transit is carried from one station to the next, keep the upper plate clamped so as to retain the last vernier reading; after setting up the instrument verify the reading and record it as the first back-sight reading at the new station, but both verniers must be read twice at each station. By following this plan a useful check on the readings is procured without trouble, and it also permits easy and quick computation of an azimuth at any station. The approximate azimuth of a line must be known at a station where daylight observations are to be made on Polaris, in order to determine the proper pointing for the star.

Computing azimuth.—If the foregoing rule has been adhered to, the azimuth of a line at any station at which the deflection angle is read twice only may be found as follows:

Find the difference between the A vernier reading for the last foresight along a preceding course the azimuth for which is known and the A vernier reading for the last foresight along any following course the azimuth of which is desired; subtract the smaller reading from the larger and divide the difference by 2. Adding the quotient to the known azimuth when the later A vernier reading is greater or subtracting it from the known azimuth when the later A vernier reading is less will give the azimuth desired.

Example:

At station 10 the last A vernier reading of foresight from station 10 to 11 is 120° 42′ 00″.

At station 72 the last A vernier reading of foresight from station 72 to 73 is 94° 20′ 00″.

The azimuth of line 10 to 11 is 167° 25′ 00″.
120° 42′ 00″—94° 20′ 00″=26° 22′ 00″.
½ of 26° 22′ 00″=13° 11′ 00″.

Known azimuth 10 to 11	=167°	25′	00″
	— 13	11	00
Azimuth of line station 72 to 73	=154	14	00

The half angle is subtracted in this example because the second vernier reading is less than the first.

Tangents.—At a railroad or highway crossing where there is a long tangent the distance to the farther end of the tangent should be assumed or estimated and the deflection angle to it recorded. In the computed results the record should be made according to the following model: "Position of a point 3 miles distant, on line with R. & N. Railway tangent, latitude 47° 10′ 20″, longitude 110° 14′ 07″." This record will afford data by which the topographer can accurately plot the tangent.

Azimuth observations.—Observations on Polaris or the sun for azimuth must be made each day if the weather permits. On a crooked line with many short courses azimuth observations should be made at points not more than 100 stations apart; on a traverse with long tangents they should fall not more than 10 miles apart. When practicable an azimuth station should be placed at each decided change in the direction of the line and where an abrupt change occurs between long and short sights. These requirements may necessitate going back over the line in order to make the essential observations. If conditions are favorable it is possible to make azimuth observations on Polaris in broad daylight.

Both the transit and the azimuth mark must be at stations in the traverse preferably not less than 500 nor more than 1,500 feet apart. Each point should be marked by a stake with a tack or, if on a railroad, by a nail in a tie. The azimuth mark for night observations may consist of a vertical slit one-eighth inch wide and 6 inches long cut in the side of a box or tin can containing a candle or lantern, the slit to be carefully centered over the tack in the stake, or of a nail on the marked point illuminated by a lantern or flashlight shaded from direct observation from the transit.

In pointing the telescope for night observations use the electric hand lamp to illuminate the cross wires, holding it nearly in front of the object glass, or allow it to shine on a piece of paper fastened with a rubber band in front of the object glass and having in it a half-inch hole.

In clear weather Polaris can be seen with a good transit telescope several hours before sunset, but it is necessary to know the star's altitude within about 10 minutes of arc and its bearing within about 1° in order to get the star into the field of the telescope when it is not visible to the naked eye. The finding of Polaris in daylight may be facilitated by preparing a table of positions of the star for a month in advance. The table should give the hour angle for a selected hour of local time, also the altitude and azimuth of the star for the same time. Corrections easily applied may be found for other hour angles and for changes in latitude or longitude.

To find the altitude and azimuth with sufficient accuracy for this purpose proceed as follows:

Assume that an observation is to be made at 3^h 25^m p. m., ninetieth meridian (central) standard time, January 10, 1925, at a place whose latitude is 40° 10′ and longitude 85° west from Greenwich, as scaled from a good map. As 85° is 5° east of the ninetieth meridian the watch is five-fifteenths hour, or 20 minutes, slower than local time. The observation is therefore to be made at 3^h 45^m local mean time.

The ephemeris (p. 1) shows that the nearest upper culmination of Polaris, which is then on the meridian above the pole, occurs at 6^h 15.6^m p. m. January 10, 1925, Greenwich mean time. The correction to reduce this culmination time to 85° west longitude time is -0.9^m.

Local time of upper culmination $=6^h\ 15.6^m-0.9^m$	6^h	14.7^m
Assumed observation time	3	45
Hour angle of Polaris	2	29.7

Always take the nearest upper-culmination time, whether it is before or after the observation time.

From the table on page 22 of United States Geological Survey Bulletin 650 the bearing of Polaris for latitude 40° 10′ and an hour angle of 2^h 29.7^m (before upper culmination) was found to be 0° 53′ 07″. Polaris was therefore about 53′ east of true north at the time and place of observation. This is not the exact bearing, but it is near enough for the purpose. When this table is not at hand the bearing can be computed from the table on page 10 of the ephemeris.

The altitude of Polaris may be found from the tables on page 26 of Bulletin 650. It may also be found by reversing the operation called for by the tables on page 12 of the General Land Office ephemeris or by means of the following formula:

$$\text{Sine of altitude} = \sin \phi \sin \delta + \cos \phi \cos \delta \cos t$$

where ϕ=the latitude of the place, δ the declination of the star, and t its hour angle east or west of upper culmination.

With the transit in good adjustment set off on the vertical arc an angle of 41° 03′ (the altitude); next focus the telescope very carefully for a distant pointing. It is well to focus the telescope on a star at night and then mark the focusing slide so that it can be set at the same place at any time, for unless the telescope is properly focused the star can not be found in the daytime.

If an approximate true north bearing is not known, obtain it by compass, making proper allowance for declination. Point the telescope 0° 53′ east of true north, as found by computation or by the needle. If the air is clear and the star can not be seen in the field of the telescope, turn the transit on its vertical axis slowly, without disturbing the vertical-circle setting, for a degree or two to the right or left to correct any imperfect pointing in azimuth. When the star is seen turn the tangent screws of both the vertical and the horizontal axis so that the cross-wire intersection will cover it, and then proceed with the observation for azimuth in the manner described below, which is applicable to observations at any hour of the day or night when the star is visible.

Angles may be read as follows: Set on azimuth mark, then on star; reverse telescope; set on star, then on azimuth mark. Each set of observations should consist of not less than three direct and three reverse measurements, the circle being shifted for each set by about 60°. Observations may be made at any time the star is visible but preferably when it is at or near elongation. The time of setting the cross wires on the star should be recorded to the nearest second. Observations should be made rapidly; not more than 15 minutes need be taken to complete a set. The notes should be kept in the form which follows:

Date: January 10, 1925.

Azimuth observation at station 332, mark at station 333.

Latitude 40° 10′, longitude 85° west of Greenwich.

Watch 35 seconds fast of ninetieth meridian standard time (not daylight-saving time).

	Vernier A	Vernier B	Mean	Angle mark to star	Watch time
	° ′ ″	° ′ ″	° ′ ″	° ′ ″	*H. m. s.*
Mark	279 06 30	99 06 00	99 06 15		
Star	333 02 30	153 03 00	153 02 45	53 56 30	3 40 18
Star	153 01 30	333 01 00	153 01 15	53 55 45	3 41 20
Mark	99 06 00	279 05 00	99 05 30		
Mark	172 02 00	352 02 30	172 02 15		
Star	225 56 00	45 56 00	225 56 00	53 53 45	3 45 00
Star	45 55 00	225 54 30	225 54 45	53 52 30	3 46 45
Mark	352 02 30	172 02 00	172 02 15		
Mark	40 56 00	220 56 00	40 56 00		
Star	94 46 30	274 46 30	94 46 30	53 50 30	3 50 19
Star	274 46 00	94 45 30	94 45 45	53 49 30	3 52 36
Mark	220 56 00	40 56 30	40 56 15		
Mean				53 53 05	3 46 03
Watch fast					35
					3 45 28 3 45.5

Because of the difficulty of finding Polaris for daylight observations it is often advantageous to record the reading on the star first, then on the mark, and last on the star.

For daylight observations when the star is only dimly seen it is not advisable to shift the horizontal circle between readings, as to do so would make it more difficult to find the star again.

On the same page with the other records the latitude and longitude of each azimuth station, scaled to the nearest minute from the best map available, should be recorded, together with the date of observation, the watch error, and a statement as to the time zone used and whether or not the watch was set for daylight-saving time.

An example of computation for either daylight or night observations on Polaris is here given:

January 10, 1925, ninetieth meridian time. Latitude 40° 10′, longitude 85° 00′. Instrument on station 332; mark on station 333.

	H.	m.	s.
January 10, 1925, ninetieth meridian standard time of observation (correction having been made for watch error)	3	45	28
Correction for 5° east of longitude 90°	+	20	00
Local mean time of observation	4	05	28
	(4	05.5)	

The nearest upper culmination of Polaris as given in tables is 6^h 15.6^m p. m., January 10, 1925, Greenwich mean time, civil date. The correction (always negative) to reduce to local meridian is $\frac{8.5}{360}$ of daily change $(3.9^m)=0.9^m$.

	H.	m.
Local mean time of upper culmination, January 10, 1925, p. m. $(6^h\ 15.4^m-0.9^m)$	6	14.7

	H.	m.
Hour angle, being the interval between time of observation (4^{h} 05.5^{m}) and time of culmination	2	09.2
With this hour angle as an argument and the declination for the given date (88° 54′ 25″), find by double interpolation from the table of azimuths of Polaris of the Land Office tables (p. 10) the azimuth angle for the latitude and time	0°	46.9′
As the star has not reached culmination it is east of north (180°) or, 180° being added, has an azimuth of	180°	46.9′
Subtract from this angle the measured angle between mark and star	53	53.1
The star being east of the mark, the remainder is the true azimuth of the mark on station 333 from station 332	126	53.8

A rough check of this azimuth may be obtained by comparing it with the observed magnetic bearing, allowance being made for declination.

Sun observations.—When it is impracticable to take observations on Polaris for azimuth, observations on the sun may be taken instead, but such observations should not be taken within two hours before or after noon, or when the vertical angle of the sun is less than 15°.

Set up the transit at a station in the line of survey, adjust and carefully level it, read the verniers and record the readings for first pointing on the rod. Point the telescope to the sun and allow the image to fall on a piece of white paper held 3 or 4 inches from the eyepiece. Focus the cross wires on this image. By means of the two tangent screws move the telescope till the vertical and horizontal wires bisect the sun's image, taking care to use the middle horizontal wire and not the upper or lower stadia wire. Read and record the horizontal and vertical angles. Repeat the pointing and reading at least five times, and after the last pointing read again on the rod. Should the reading on the rod not agree within 1 minute of the first reading, discard the entire set and make new observations.

Reverse the telescope and repeat the readings at least five times as before. This time should be recorded to the nearest minute at the first and last pointing, and the mean time should be computed.

An example of field notes for afternoon observations is given on the next page.

Instrument, station 624; rod, station 625.

Latitude 38° 53′ 46″ (as scaled from any good map).

Date, November 10, 1925. Ninetieth meridian time (standard time).

	Vernier readings						Vertical angles to sun		
Rod	0°	00′	00″	180°	00′	00″			
Sun	90	36	00	270	36	00	17°	01′	Time of first pointing at sun 3^h 16^m p.m.
Sun	90	45	30	270	45	30	16	54	
Sun	90	55	00	270	55	00	16	46	
Sun	91	02	00	271	02	00	16	40	
Sun	91	09	00	271	09	00	16	35	
Rod	00	00	00	180	00	00			
Reverse telescope (relevel if necessary).									
Rod	0°	00′	00″	180°	00′	00″			
Sun	91	30	30	271	30	30	16°	15′	
Sun	91	38	00	271	38	00	16	10	
Sun	91	45	00	271	45	00	16	04	
Sun	91	54	00	271	54	00	15	59	
Sun	92	00	30	272	00	30	15	52	Time of last pointing at sun 3 20 p.m.
Rod	00	00	00	180	00	00			
									6 36
	913	15	30				164	16	Mean time of observation 3^h 18^m

Mean angle, rod to sun, +91° 19′ 33″.

Mean of vertical angles	16° 25′ 36″
Correction for refraction (always minus)	03 14
Correct altitude of sun	16 22 22

Refraction tables are given in Bulletin 650, page 334, but if no tables are available the approximate value of the refraction in seconds may be taken as 58 times the natural cotangent of the sun's observed altitude.

To compute the azimuth from the field notes use the formula

$$\mathrm{Cot}^2\frac{\text{azimuth angle}}{2}=\frac{\sin \text{ of } (S-\text{latitude})\times\sin(S-\text{altitude corrected for refraction})}{\cos S\times\cos(S-\text{polar distance})}$$

in which $S = \frac{1}{2}$ (latitude + altitude + polar distance).

It is necessary to obtain from tables, for the hour, day, and year, the declination of the sun—that is, the angular distance of the sun north or south of the Equator. The declination at Greenwich noon, for each day in the year, is given in a publication of the General Land Office entitled "Ephemeris of the sun and Polaris." This ephemeris is issued about December 1 of each year for the following year.

The polar distance is the angular distance between the sun and the north pole. In winter, when the sun is south of the Equator, the polar distance is 90° plus the declination; in summer, when the sun is north of the Equator, it is 90° minus the declination. Twice a year, September 23 and March 21, it is 90°, the declination being 0 when the sun crosses the line.

The procedure to find the declination of the sun in the example given is as follows:

Observations for November 10, 1925, 3^h 18^m p. m., ninetieth meridian time. When it is noon at Greenwich it is 6 a. m. on the ninetieth meridian (90°÷15=6; 12 noon—6 hours=6 a. m.). The mean of the times of observation is 3^h 18^m p. m., 9 hours and 18 minutes after 6 a. m. local time or Greenwich noon. In the tables showing the position of the sun for the year 1925 the apparent declination at Greenwich noon on November 10 is given as 17° 04′ 43″ south. The south declination is increasing at the rate of 42.37 seconds for each hour after Greenwich noon. The tables give declination for apparent (sun) time. The change from apparent to mean noon can generally be disregarded, as it will never be more than 15 seconds of arc.

The observation was made 9 hours and 18 minutes (=9.3 hours) after Greenwich noon; therefore the change in the declination of the sun since the preceding Greenwich noon was 42.37×9.3=394 seconds=6 minutes and 34 seconds.

Declination (south) November 10, 1925, at Greenwich noon	17° 04′ 43″
Correction to be added for 9.3 hours	6 34
Declination at 3.18 p. m	17 11 17

To find the polar distance, add the declination as above found to 90°:

Declination	17° 11′ 17″
	90 00 00
North polar distance, November 10, 1925, 3^h 18^m p. m	107 11 17

To find the value of S in the formula:

Latitude	38° 53′ 46″	
Altitude of sun	16 22 22	
Polar distance	107 11 17	
	162 27 25	
½ of sum	81 13 42	=S
S	81° 13′ 42″	
Latitude	38 53 46	
	42 19 56	=S—latitude
S	81° 13′ 42″	
Altitude	16 22 22	
	64 51 20	=S—altitude of sun
S	81° 13′ 42″	
Polar distance	107 11 17	
	25 57 35	=S—polar distance

There are times when the polar distance is less than S, but always subtract the lesser quantity from the greater.

All the quantities required in the formula are now known except cot azimuth angle. To find that quantity proceed as follows:

S—latitude	42° 19′ 56″	log sin	9.82829
S—altitude	64 51 20	log sin	9.95676
S—polar distance	25 57 35	colog cos	0.04619
S	81 13 42	colog cos	0.81674

Log cot^2 ½ azimuth 0.64798

Divide log by 2 to get square root.

Log cot ½ azimuth 0.32399

(The cologs of cosines are the log cosines subtracted from 10.)

Angle corresponding to log cot 0.32399=25° 22′ 22″=½ azimuth.

Azimuth of the sun 50° 44′ 44″
Angle between rod and sun +91 19 33

Azimuth at station 624
to station 625 319 25 11=S. 40° 34′ 49″ E.

If the angle between the rod and the sun is plus, subtract it from the azimuth of the sun; if minus, add it.

An example of field notes for morning observations is given below.

Instrument, station 426; rod, station 427.
Latitude, 42° 36′ 24″.
Date, August 14, 1925. 75th meridian time.

	Vernier readings		Vertical angles to sun	
Rod	0°00′00″	180°00′00″		
Sun	312 40 00	132 40 00	38°55′00″	Time of first pointing at sun 8^h 40^m a.m.
Sun	312 50 30	132 50 30	39 04 00	
Sun	312 58 30	132 58 30	39 11 00	
Sun	313 07 00	133 07 00	39 17 30	
Sun	313 14 00	133 14 00	39 22 30	
Rod	0 00 00	180 00 00		
Reverse telescope.				
Rod	0°00′00″	180°00′00″		
Sun	313 39 00	133 39 00	39°40′30″	
Sun	313 48 30	133 48 30	39 49 30	
Sun	313 58 00	133 58 00	39 57 00	
Sun	314 08 30	134 08 30	40 03 00	
Sun	314 16 00	134 16 00	40 10 00	Time of last pointing at sun 8 44 a.m.
Rod	00 00 00	180 00 00		
	3124 40 00		395 30 00	1724

Mean of readings 313° 28′ 00″. Mean time of observation 8^h 42^m

Subtracting mean from 360° gives mean angle, rod to sun, 46° 32′ 00″ east of south.

Mean of vertical angles 39° 33′ 00″
Correction for refraction 01 10

Correct altitude of sun 39 31 50

The azimuth is computed from the field notes according to the formula given on page 106.

Observations for August 14, 1925, 8^h 42^m a. m., seventy-fifth meridian time. When it is noon at Greenwich it is 7 a. m. on the seventy-fifth meridian (75÷15=5; 12 noon—5 hours=7 a. m.). The mean of the times of observation is 8^h 42^m a. m., 1 hour and 42 minutes (=1.7 hours) after 7 a. m. local time or Greenwich noon. In the tables showing the position of the sun for the year 1925 the sun's apparent declination at Greenwich noon on August 14 is given as 14° 27′ 08″ north. The declination is decreasing at the rate of 46.12 seconds for each hour after Greenwich noon. The observation was made 1.7 hours after Greenwich noon; therefore the change in the declination of the sun since the preceding Greenwich noon is 46.12×1.7=74 seconds=1 minute and 14 seconds.

Declination (north) August 14, 1925, at Greenwich noon	14° 27′ 08″
Correction to be subtracted for 1.7 hours	1 14
Declination at 8^h 42^m a. m	14 25 54

Subtracting the declination from 90° gives the polar distance:

	90° 00′ 00″
Declination	14 25 54
Polar distance, August 14, 1925, 8^h 42^m a. m	75 34 06

To find the value of S:

Latitude	42° 36′ 24″	
Altitude of Sun	39 31 50	
Polar distance	75 34 06	
	157 42 20	
½ of sum	78 51 10	=S
S	=78° 51′ 10″	
Latitude	=42 36 24	
	36 14 46	=S—latitude
S	=78° 51′ 10″	
Altitude	=39 31 50	
	39 19 20	=S—altitude
S	78° 51′ 10″	
Polar distance	75 34 06	
	3° 17′ 04″	=S—polar distance

To find the azimuth angle of the sun from the data given, proceed as follows:

S—latitude	=36° 14′ 46″	log sin	9.77177
S—altitude	=39 19 20	log sin	9.80187
S—polar distance	= 3 17 04	colog cos	0.00071
S	=78 51 10	colog cos	0.71370
Log cot² ½ azimuth			0.28805
Log cot ½ azimuth			0.14402

Angle corresponding to log cot 0.14402=35° 40′ 10″=½ azimuth.
Bearing of sun, 71° 20′ 20″ (east of south).

	360°	00′	00″	
	—71	20	20	
Geographic azimuth of sun	288	39	40	
Observed angle between rod and sun	+46	32	00	
Azimuth at station 426 to station 427	335	11	40	=S. 24° 48′ 20″ E.

Geographic azimuths are counted clockwise from the south (0° or 360°; west, 90°; north, 180°; east, 270°).

In case unfavorable weather prevents the taking of azimuth observations leave adequate marks at a point selected, before proceeding with the line, and return later to make the observations.

Watch error.—The instrument man must carry a reliable watch and keep it in good condition. He should ascertain its error daily by comparison with telegraphic time, which is sent over Western Union lines once a day. In case he has no opportunity to make this comparison daily while running the line, he should do so as often as possible, figure the rate of error per day, and record the proper correction for each azimuth observation made. A watch error of 20 seconds or less will not appreciably affect the accuracy of the determination.

Magnetic declination.—A careful reading of the needle for magnetic declination should be made at frequent intervals and recorded opposite the proper station number in the notebook. Such determinations should be made at each azimuth station and at favorable points along the line where the needle is not likely to be affected by rails, electric wires, or similar disturbing elements. At azimuth stations determine the magnetic bearing of the azimuth mark at the time it is established. If the line follows a railroad, magnetic determinations should be obtained from a parallel line at a distance of 25 yards from the rails or wires.

Field record.—Complete notes must be kept by the recorder in book 9–928, to be written in a plain, neat hand with a No. 4 pencil. The blanks in the title-page should be filled in the first day the book is used.

The recorder must take down the vernier readings as they are called off by the transit man and compute the mean pointings and deflection angles, giving proper signs to the angles. He must keep up with the instrument man in these computations, as they enable him to note by inspection whether the instrument man has made errors in his readings and to call attention to them before the instrument is removed from the station. He should take special pains to see that the degree and minute numbers for the two verniers are consistent and are recorded in the proper columns. A single line should be drawn through erroneous records, which must never be erased.

The notes are to be kept in the following form:

Date, September 9, 1925. Line from Pikeville to Dayton, Mo.

Station No.	Distance (feet)	Vernier A	Vernier B	Mean	Deflection angle	Azimuth	Stadia	Vertical angle
		° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″		
326		316 51 30	136 52 30	316 52 00		[a] 123 35 00		
		275 06 00	95 07 00	275 06 45	41 45 15			
		233 21 00	53 22 00	233 21 30	41 45 15	[b] 81 49 45	Stadia 905	
	900				−41 45 15	[a] 81 49 47		
327		[c] 233 21 00	53 22 00	233 21 30			Sta. 327–328 N. 59° 30′ W	
		279 04 00	99 05 00	279 04 45	45 43 15			
		324 48 30	144 49 30	324 49 00	45 44 15	[b] 127 33 30	Stadia 1,330	
	1,320				+45 43 45	[a] 127 33 34		
327+	90	Stream crossing.						
327+	430	Crossroad at Tanbark.						
328		[c] 324 48 30	144 49 30	324 49 00				
		342 08 00	162 09 00	342 08 30	17 19 30			
		359 27 00	179 28 00	359 27 30	17 19 00	[b] 144 52 37	Stadia 260	
	260				+17 19 15	[a] 144 52 43		

[a] Written in red ink.
[b] Written with black pencil.
[c] From actual readings; not copied from the preceding record.

The record must contain also a description of the starting and ending points of the line, of each permanent mark established along the line, of each point which is to be computed for the use of the topographer, and of all crossings and other landmarks that may be of value to him. Such descriptions should be concise, yet full enough to leave no possible doubt as to the identity of the points described. Each should be supplemented by an explanatory sketch, if necessary, showing the deflection angles to the reference marks, as the true azimuths to these marks are required. The description should begin on the next line after the angle record.

Example of description of permanent mark:

Station 1025, bench-mark tablet stamped "Trav. Sta. No. 4, 1912," set in sandstone ledge, top of Walden Ridge, 3 miles northwest of Dayton, Mo., at junction of Dayton, Pikeville, and Morgan Springs roads, 325 feet west of residence of John Neilson. Reference marks: Cross cut in ledge 60.25 feet N. 25° 30′ E.; spike in root of white-oak tree 14 inches in diameter, 75.60 feet N. 45° 15′ W.

Examples of description of points to be computed and other landmarks:

Station 625+730 feet, center of crossroads at Antioch Church.
Station 720+320 feet, east abutment of bridge over Glade Creek.
Station 732, road fork at Johnson blacksmith shop.
Station 926+210 feet, center of track opposite semaphore, Lee station.
Station 936+300 feet, road crossing half a mile east of Sequatchie railroad bridge.

Each point to be computed should be marked with brackets in ink immediately upon its selection by the instrument man.

As soon as the records in a field book are completed, it should, if not needed for reference, be sent at once to the Survey office in Washington by registered mail. Tape man's books should be sent separate from other notes and on another day.

TRUNK-LINE TRAVERSES

The foregoing instructions apply also to trunk-line traverses, for which an accuracy of 1 in 7,500 is required. The only difference in methods between the two grades of work is that much greater care will be required for each operation, in both the field and the office, for the trunk lines. Temperature corrections must be made, and computations carried to tenths of a foot.

TRANSIT-TRAVERSE COMPUTATIONS

The steps in traverse computations are set forth below. The computations are made in books 9–928 and 9–931. The abstracts of results are placed on long sheets of paper. Each azimuth computation is to be made in the field notebook on the same page with the observations, and the results written in red ink in the azimuth column of notebook (see pp. 101, 111) on the line with the station occupied.

Computers should read carefully the " Suggestions to computers " on pages III–IV.

Field computation of azimuth.—Azimuth notes must be computed as soon as possible after observations are made and the results applied to the deflection angles. These computations must be made at odd times, when they will not interfere with other work. Errors of closure in azimuth should not be distributed until checked by a second computer either in the field or in the office. Allowance must always be made for convergence of meridians.

Computation of deflection angles.—The mean deflection angle is combined according to its sign with the azimuth from the preceding station, and the result placed in pencil opposite the deflection angle used. This process is repeated until the next computed azimuth, written in red ink, is reached.

The last azimuth in pencil will probably not agree with the observed azimuth. For any line not running due north or south there will be a discrepancy between observed and computed azimuths, due solely to convergence of meridians, which for latitude 30° will be 0.5 minute for each mile run east or west. For latitude 49° the amount will be 1 minute. For any latitude the convergence in minutes of arc will be the difference in minutes of longitude between the ends of the line multiplied by the sine of the middle latitude. For lines running east the computed azimuth should be less than the observed. For lines running west it should be greater.

Adjustment of closing errors.—If no large errors appear in the results, the discrepancy between computed and observed azimuths at the closing station is to be divided by the number of stations and a proportional correction applied to each penciled azimuth, the corrected figures being written in red ink. When a large closing error is found in a transit-traverse line look first for a compensating error of 1° or 10° in the azimuths or angles.

Computation of latitudes and departures.—Latitudes and departures are to be computed in book 9–931, as shown below:

Line from Pikeville to Dayton, Mo.

Station	Azimuth	Distance	Sine	Cosine	North	South	East	West
	° ′ ″	*Feet*			*Feet*	*Feet*	*Feet*	*Feet*
326 to 327	81 49 47	900	0.990	0.142	--------	128	--------	891
327+430 feet	127 33 34	430	.793	.610	262	--------	--------	341
					262			1,232
					128			
					134			
327+430 feet to 328	127 33 34	890	.793	.610	543	--------	--------	706

Natural sines and cosines for the azimuths given are written in the appropriate columns. By means of Crelle's tables the products of these quantities by distances are found and placed in the proper columns. The sines multiplied by the distance give departures east or west. When the sine is positive, the new point is west; when negative it is east. Cosines multiplied by distances give latitudes north or south. When the cosine is negative, the new point is north; when positive it is south. The direction of the new point can readily be determined by noting the azimuth, remembering that 0° azimuth is for a line running due south, 90° for a line due west, 180° for a line north, and 270° for a line east. In the example given in the above table the azimuth 81° 49′ 47″, being between due south and due west, will be to a point southwest. Four decimal places in sines and cosines should be used when distances are greater than 1,000 feet.

When the Gurden traverse tables for distances 1 to 100 for single minutes of arc are available, the latitudes and departures may be written in the north, south, east, and west columns direct for each azimuth and distance.

Whenever a point is reached for which the latitude and longitude are desired, as at 327+430 feet in the example, leave six blank spaces for the computation. The data for the computation for such a point are found from the record on page 111 as follows: For the crossroad at Tanbark post office, which is on the line between stations 327 and 328, the azimuth is the same as to station 328. The distance by measurement is that given, 430 feet from station 327. In order to make the computations continuous, station 328 is taken as 1,320−430=890 feet from the intermediate point used, the azimuth being the same for both points.

Computation of latitude and longitude.—The next step in this work is the computation of latitude and longitude. These should be determined for important points a mile or less apart. Assume, for illustration, that for station 326 (p. 111) the coordinates have been completed, and that 327+430 feet is the next location desired. Each of the four columns—north, south, east, and west—is summed; the difference between the sums of the north and south columns is placed in the column of the greater, and the difference between the east and west columns is placed in the column of the greater. The computations of latitude and longitude and the descriptions of the points are placed on the right-hand page of the book opposite the group of stations.

The logarithms of the geodetic constants for metric measures, called "the A, B, C factors," are on pages 219–290 of "Geographic tables and formulas."[1] Factors A and B are used to five decimal places only. These will be practically constant for a distance of 10 or 15 miles north and south, the value for the middle latitude being used.

For the example on page 113:

Log distance 134 (north)	2. 12710
Log to reduce feet to meters	9. 48402
Log B for latitude 39° 00′	8. 51093
	0. 12205

The sum, 0. 12205, is the logarithm of change in latitude in seconds between station 326 and 327+430 feet=1.32″ (north).

For change in longitude:

Log distance 1,232 (west)	3. 09061
Log to reduce feet to meters	9. 48402
Log A for latitude 39° 00′ 00″	8. 50914
Log secant of middle latitude	0. 10950
Log of change in longitude in seconds	1. 19327
New point west	15. 61″

These differences are to be added to the latitude and longitude of station 326.

When the Survey tables of M and P factors, prepared by D. H. Baldwin, are available the computation of changes in latitude and longitude may be materially shortened by adding log M to the log of distance north or south for change in latitude and by adding log P to the corresponding distance east and west for the change of longitude.

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[1] U. S. Geol. Survey Bull. 650.

The foregoing computation would then be written as follows:
For the latitude change:

Log distance 134 (north)	2.12710
Log M for latitude 39° 00′	7.99495
Log of change in latitude in seconds	[2]0.12204

For the longitude change:

Log distance 1,232 (west)	3.09061
Log P for middle latitude	8.10266
Log of change in longitude in seconds	1.19327

To check the plotting of positions on topographer's field sheets the distance between successive positions must be computed. As few lines are as much as 1 mile in length and none over 2 miles, the latitude and departure can with sufficient accuracy be taken as the base and perpendicular of a plane triangle. The distance sought will then be the hypothenuse, and its square will be equal to the sum of the squares of the base and altitude. For distances less than 10,000 feet Barlow's tables should be used in finding squares or square roots. The distance should be written in red ink, inclosed in a circle, on the right-hand page of the computation book in the blank space between the entries for the two stations referred to. After the record is complete its accuracy may be tested by computing a side from the given distance (hypothenuse) and the other side.

Adjustment of closures.—These operations are repeated for each selected point until the traverse line closes back on itself or ties to another point previously determined. The errors of closure for a 15-minute quadrangle, if not in excess of 1 second in latitude or 1¼ seconds in longitude, may be distributed proportionately between initial and closing points, provided the error is not greater than 1 in 5,000 parts of the distance between them for ordinary lines or 1 in 7,500 for trunk lines.

Errors.—Where so many operations are involved, errors are likely to creep into the computations. Therefore each step of the work should be checked as well as possible. The azimuth computation may be compared with the observed magnetic bearings, but because of the possibility of local variation little dependence can be placed on this comparison as a check. If the computed and observed azimuths for a line differ about 10 minutes, look for an error of that amount in the deflection angle or in the adding and subtracting of deflection

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[2] The difference in the fifth place is the result of carrying forward decimals from the sixth place in the first computation.

angles to azimuths. If the difference is larger, it is very likely that a wrong sign has been used for a deflection angle. To find the error, divide the difference by 2 and look for a deflection angle with an incorrect sign equal to the quotient. Errors of about 180° result if the recorder places the vernier readings in the wrong columns. By a careful inspection of the records it is sometimes possible to detect such an error. Many errors are due to incorrect multiplication by the distance, to the decimal point being in the wrong place, or to the product being written in the wrong column—in the north column when it should be in the south column, etc. The latitudes and departures, as well as the other steps in the work, should be computed by two persons working independently of each other; after each has completed each step of the work the results should be compared and differences corrected and verified.

A plat must be made by the computer on an approximate scale of 5 miles to 1 inch, on one or more pages of book 9–931, for each group of traverse notes. In the center of the plat of each circuit write the length of the circuit and the closing error.

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