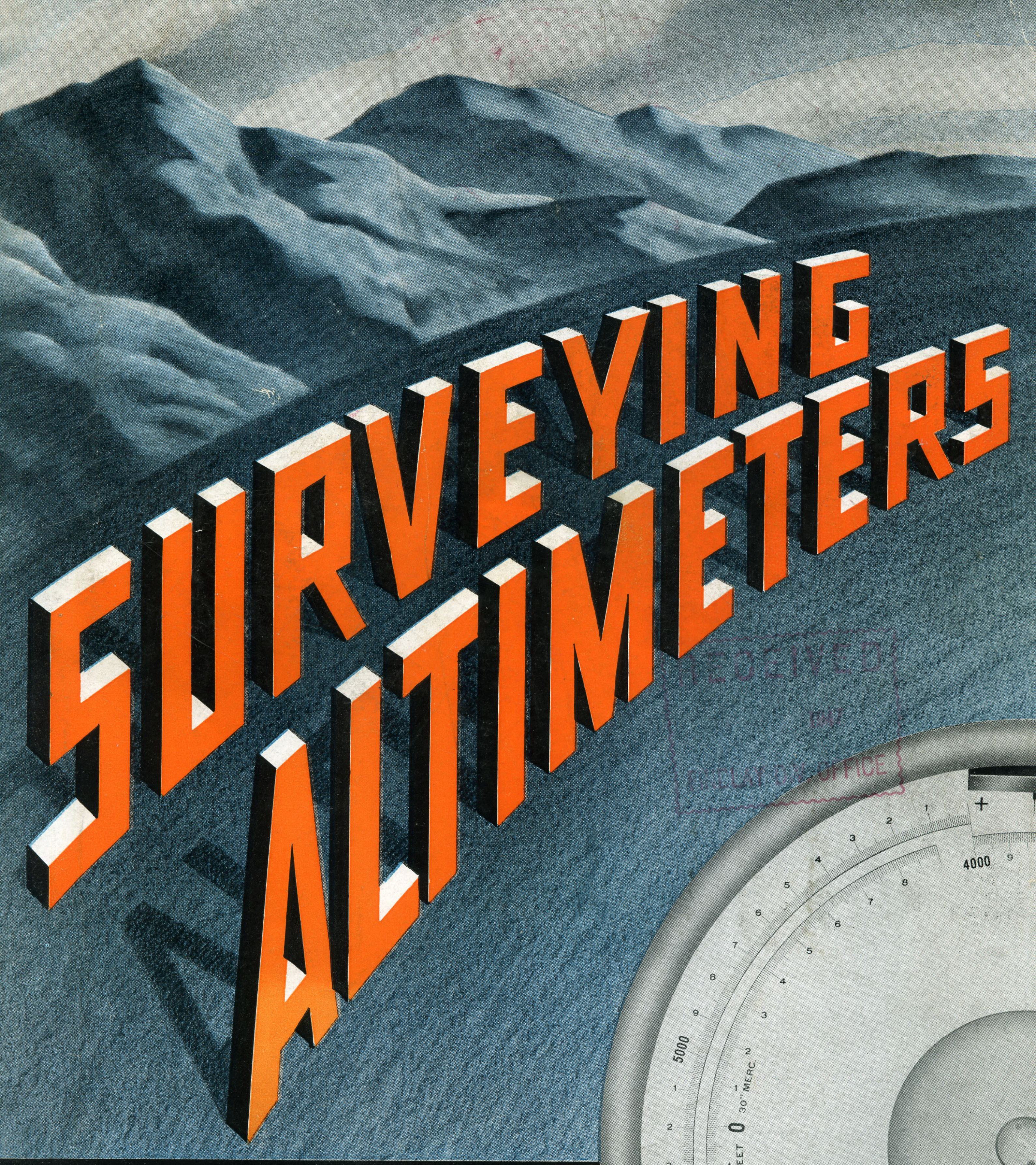
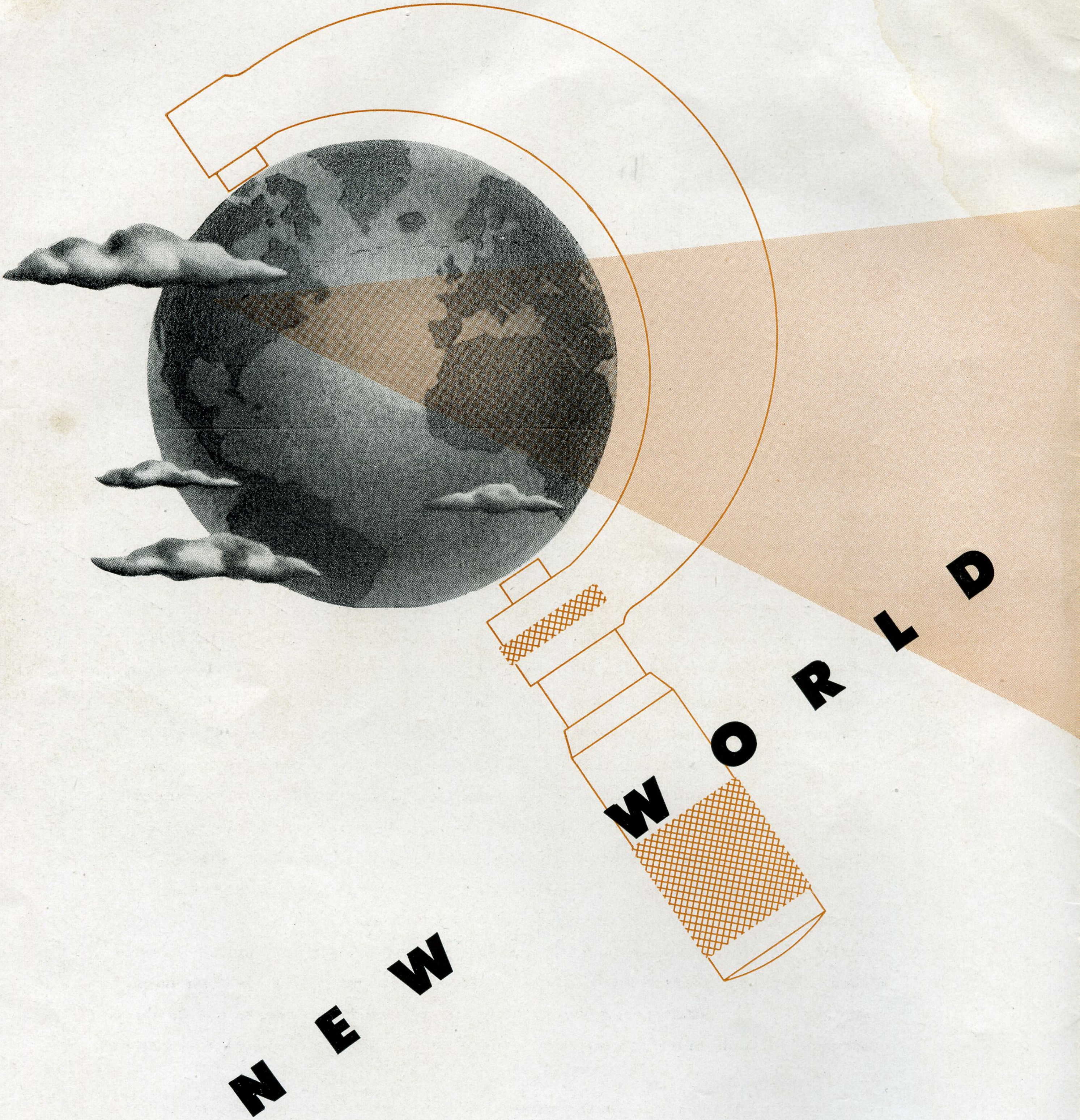
SURVEYING ALTIMETERS



AMERICAN PAULIN SYSTEM

MANUFACTURERS OF PRECISION INSTRUMENTS

LOS ANGELES, CALIFORNIA, U. S. A.


NEW WORLD

STANDARD

The American Paulin System presents their new "SA" series of surveying Altimeters embodying many important improvements and refinements. New world standards in sensitivity and accuracy have been attained.

Our exclusive system of instrumentation is the first new principle in Aneroid construction in over a hundred years. Ever since the time of Vidi, all aneroid altimeters and barometers have been constructed on the chain-and-lever principle, or minor adaptations, whereby the diaphragm fluctuations have been conveyed to readings on the dial through a combination of pivots, sectors, chains, bearings and levers, each of which represents a frictional part to detract from the sensitivity and accuracy of the instrument. All these parts are eliminated in American Paulin System construction, wherein pressure change is directly and without friction read in terms of feet altitude or inches pressure on the dial. Our instruments operate on the nul or zero-gauging principle and are temperature-compensated. They indicate altitude instantly without lag and it is never necessary to "tap" or vibrate the instrument to take readings. The altitude indicator is knife-edge and the balance indicator is needle point with mirror to eliminate parallax.

American Paulin System instruments are in use throughout the world. In this country they are specified by various departments of the Federal Government, States and Municipalities, as well as all leading surveyors, engineers, explorers, geologists, oil and mining companies, educational institutions, laboratories and many others.

These new instruments have been designed to give you a lifetime of accurate and reliable service in practical field use.

AMERICAN PAULIN SYSTEM

Manufacturers of Precision Instruments

1847 SOUTH FLOWER STREET

LOS ANGELES 15, CALIFORNIA • U.S.A.

Model SA-1

Code Word **SURVEYOR**

RANGE: Graduated in intervals of 2 feet, this instrument has a range of 4,360 feet (—760 feet to 0 to + 3,600 feet).

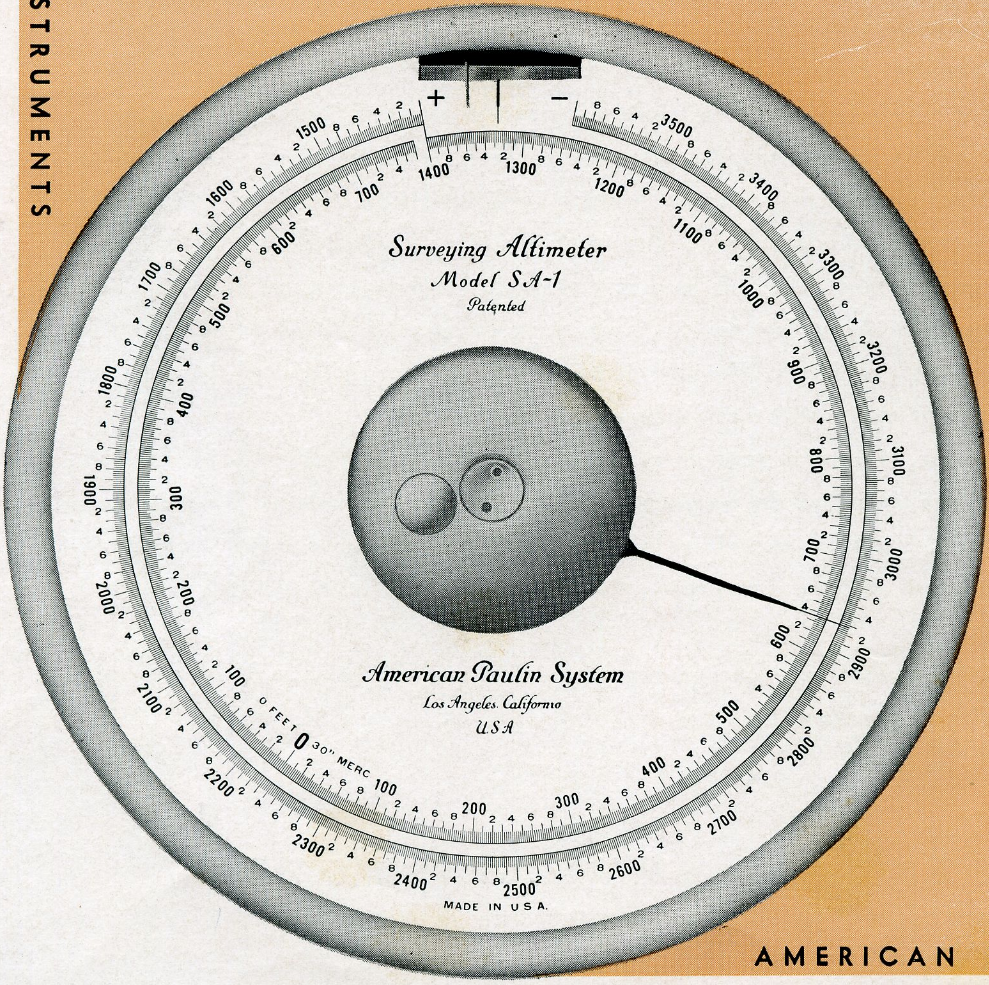
DIAL: Non-glare precision scale with etched text.

DIMENSIONS: Diameter 5″. Height 3″. Weight (with case) 43 oz.

CARRYING CASE: Instrument contained in handsome leather carrying case with hand and shoulder straps, designed for rugged field service.

EXTRAS FURNISHED: High-grade Magnifier and Pocket Thermometer.

PRICE IN U.S.A.: (including Case, Magnifier, Thermometer)........$200.00



Model SA-2

Code Word **ENGINEER**

RANGE: Graduated in intervals of 5-feet, this instrument has a range of 10,600 feet (—900 feet to 0 to + 9,700 feet).

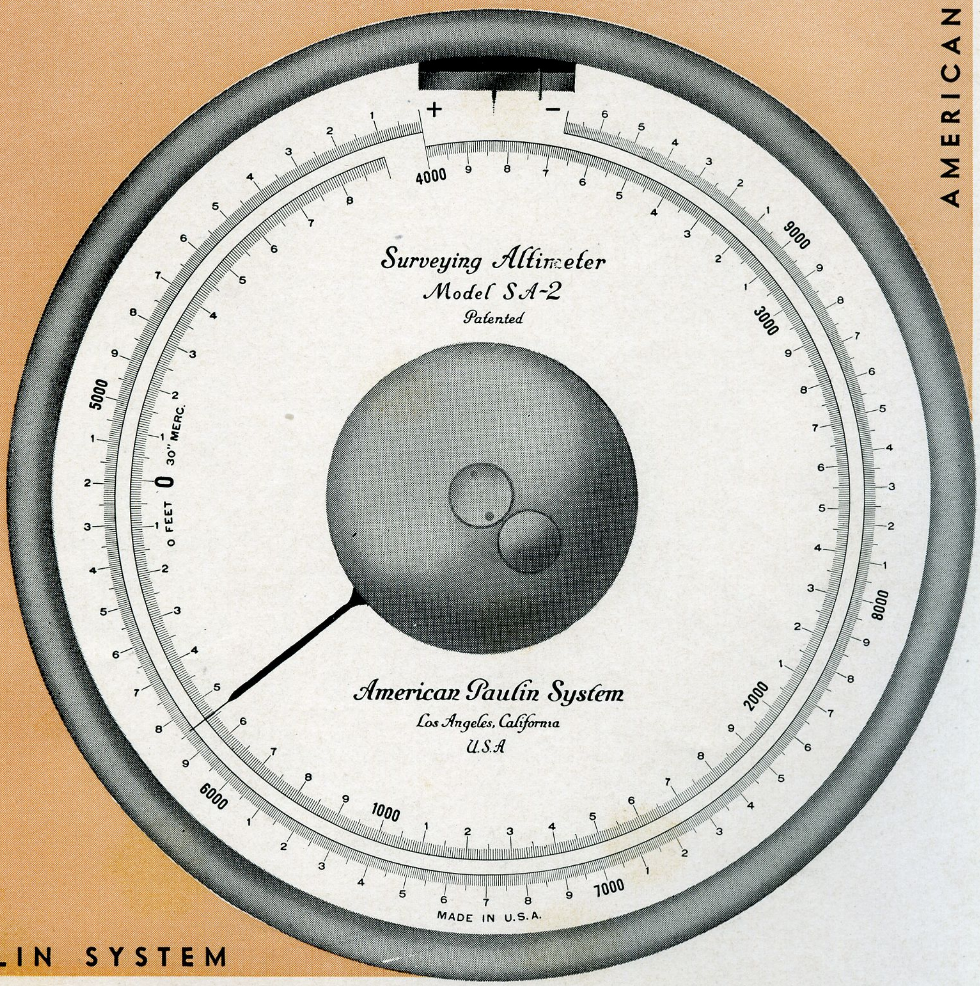
DIAL: Non-glare precision scale with etched text.

DIMENSIONS: Diameter 5″. Height 3″. Weight (with case) 43 oz.

CARRYING CASE: Instrument contained in handsome leather carrying case with hand and shoulder straps, designed for rugged field service.

EXTRAS FURNISHED: High-Grade Magnifier and Pocket Thermometer.

PRICE IN U.S.A.: (including Case, Magnifier, Thermometer)........$200.00



AMERICAN PAULIN SYSTEM PRECISION INSTRUMENTS

Model SA-5

Code Word **GEOLOGIST**

RANGE: Graduated in intervals of 10-feet, this instrument has a range of 15,000 feet (—500 feet to 0 to + 14,500 feet).

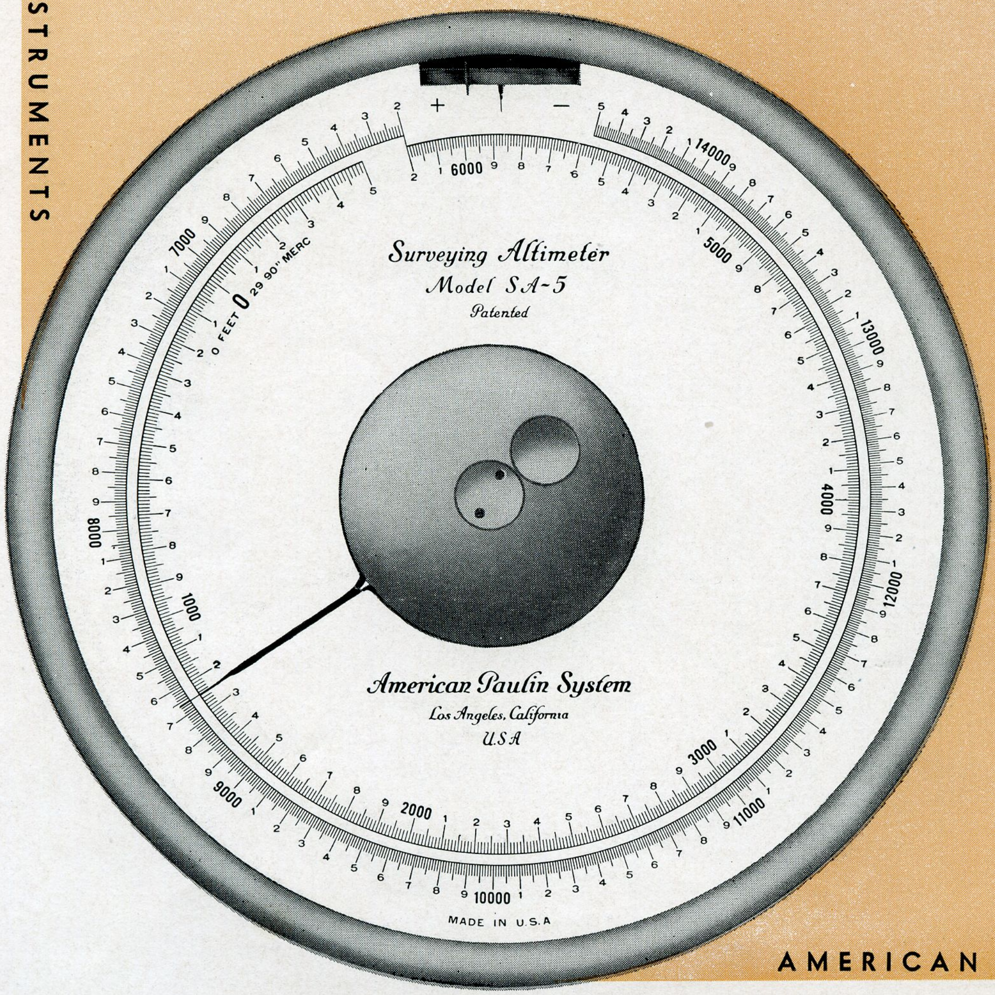
DIAL: Non-glare precision scale with etched text.

DIMENSIONS: Diameter 5″. Height 3″. Weight (with case) 43 oz.

CARRYING CASE: Instrument contained in handsome leather carrying case with hand and shoulder straps, designed for rugged field service.

EXTRAS FURNISHED: High-grade Magnifier and Pocket Thermometer.

PRICE IN U.S.A.: (including Case, Magnifier, Thermometer)........$200.00



AMERICAN PAULIN SYSTEM

Altitude Ranges In Meters

MODEL MSA-1. **Graduated in intervals of 1-meter, this instrument has a range of 1,325 meters (—250 meters to 0 to + 1075 meters).**

Code Word: **Global.**

MODEL MSA-2. **Graduated in intervals of 2-meters, this instrument has a range of 3,260 meters (—260 meters to 0 to + 3000 meters).**

Code Word: **Universal.**

MODEL MSA-6. **Graduated in intervals of 5-meters, this instrument has a (illustrated) range of 5,600 meters (—300 meters to 0 to + 5,300 meters).**

Code Word: **International**

GENERAL SPECIFICATIONS

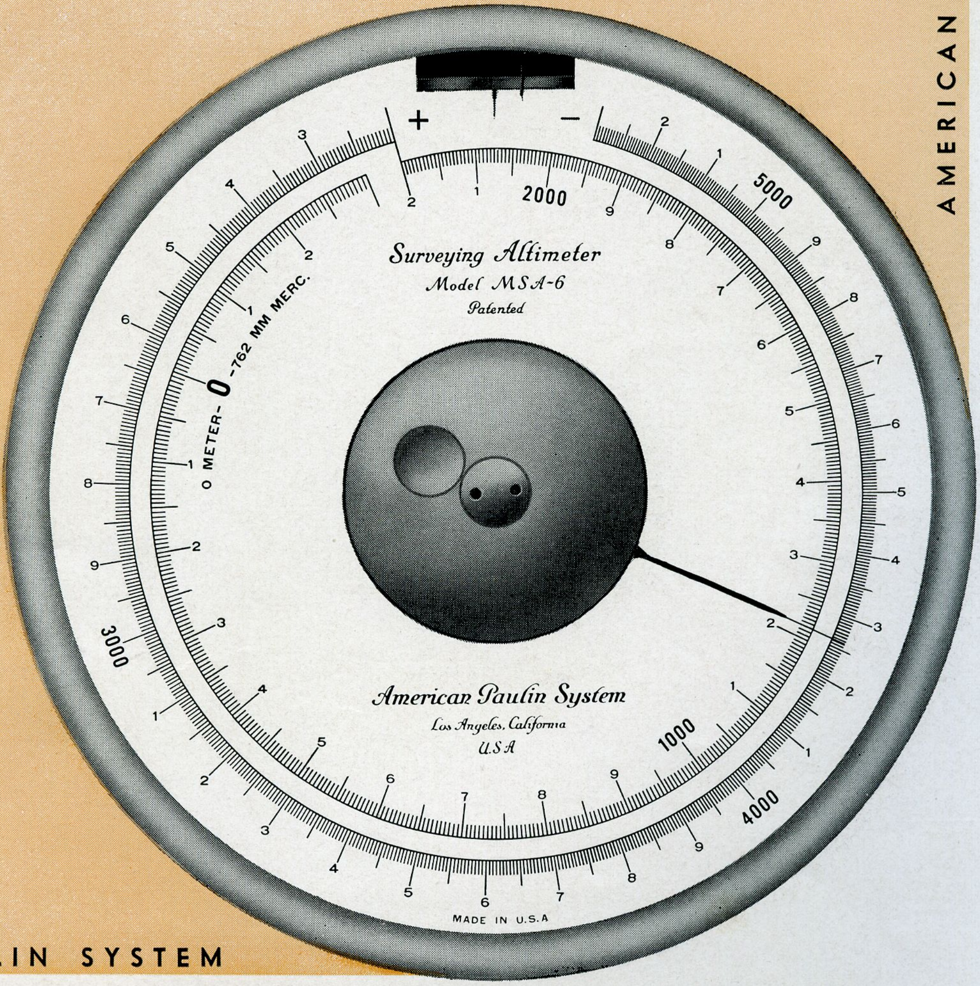
DIAL: Non-glare precision scale with etched text.

DIMENSIONS: Diameter, 5″. Height, 3″. Weight (with case) 43 oz.

CARRYING CASE: Instrument contained in handsome leather carrying case with hand and shoulder straps, designed for rugged field service.

EXTRAS FURNISHED: High-grade Magnifier and Pocket Thermometer.

PRICE IN U.S.A.: (Including Case, Magnifier, Thermometer) $200.00



MORE handsome than ever, this new precision surveying altimeter comes encased in a beautiful russet leather carrying case. Constructed to withstand the most rugged field conditions, and supply the utmost protection. Comes equipped with hand and shoulder straps.

Paulin System

ALTIMETRY MANUAL

A Useful treatise on the various uses of *Paulin System* ALTIMETERS

AMERICAN PAULIN SYSTEM
Precision Instruments
GENERAL OFFICES AND LABORATORIES
Los Angeles, California, U. S. A.

The *Paulin System* Altimeter As a Valuable Essential for The Modern Engineer

THE PAULIN ALTIMETER is not a substitute for any instrument in the modern engineer's field equipment. Nor can any other instrument be substituted for it. The Paulin Altimeter is a new and essential addition to the field equipment of every engineer.

The following statement of a prominent engineer points out pertinent facts on this subject:

"In excess of 90% of all field work done by engineers is in the nature of preliminary investigations as to the feasibility of the project under consideration. Not more than 10% of these investigations prove the undertaking to be feasible for one reason or another. It is, therefore, essential that the cost of preliminary investigation work be held down to a minimum and yet data as accurate as possible be obtained.

"One of the important features of field investigations is the determination of differences in elevation between a number of points. Such determinations are made by means of any of the following instruments:

"1. The precise level
"2. The transit
"3. The hand level
"4. The ordinary aneroid
"5. The 'PAULIN SYSTEM' ANEROID (Surveying and Altimeter)

"1. To use the level requires at least two men, a rod, an instrument, and tripod, and it usually requires a number of set ups of the instrument to get a difference in elevation of any two points greater than ten feet.

"2. To use the transit requires at least two men, a rod, and an instrument and tripod plus calculations to convert the verticle angle reading into feet of altitude.

"3. To use the hand level requires only one man but its accuracy is dependent on the observer's ability to hold the level so that the bubble remains motionless in the proper position while the observation is taken. The greatest difference in elevation which can be measured by one reading between any two points is the equivalent of the height from the ground to the observer's eye, which is about five feet.

"4. To use the ordinary aneroid requires only one man, but due to inherent mechanical faults in the instrument, erratic, inconsistent readings which take time to get, due to lag in the mechanism, can always be expected, and usually the instrument is so delicate that it often ceases to function for no apparent reason.

"5. To use the 'PAULIN SYSTEM' aneroid requires only one man, and due to its instant response to a change in elevation there is no delay in taking a reading. It is consistent in its performance, and therefore can be relied upon at all times to furnish accurate information."

The Use of the *Paulin System* Altimeter in Various Preliminary Surveys and Field Investigations

EQUIPMENT REQUIRED

1 "PAULIN SYSTEM" ALTIMETER
1 Steel Tape
1 Pocket Transit or Compass
1 Field Book

DAM SITES

1. Upon arriving at a proposed dam site such as illustrated on the next page a reading of the altimeter is taken at the initial point station No. 1. This point can of course be anywhere on the sides of the site along the axis of the proposed dam as well as at the bottom if the high point of the proposed dam has already been determined or will be determined in the office after the profile of the axis of dam has been drawn.

2. As soon as the reading is taken at station No. 1, the Pointer of the altimeter is set to read 10 feet higher than the previous reading and the observer proceeds up the side of the site until the Balance Indicator is again at zero. When this occurs the reading is recorded, because an elevation 10 feet higher than station No. 1 has been reached and established.

3. The above is based on the assumption that accurate 10 feet contours are desired. The observer can of course select any contour interval.

4. Station No. 2 has now been located. Before leaving station No. 1, the proper direction of the axis should be determined with the pocket transit and one end of the steel tape fastened by means of a rock, stake, steel pin or other means so that the slope distance between stations No. 1 and No. 2 can be measured upon arrival at station No. 2.

5. Before leaving station No. 2 one end of the tape is fastened, the direction ascertained and another reading of the altimeter is taken and recorded. The Pointer is again set at an elevation 10 feet higher than station No. 2.

6. The same procedure as heretofore described covering stations No. 1 and No. 2 is now followed for all of the other stations until the ultimate height has been reached on both sides of the site.

TOPOGRAPHY

7. If topography is desired on both sides of the axis of the proposed dam, it can be taken by the following means:

8. Start at either of the top elevations, in this instance stations No. 11 and No. 21, set the Balance Indicator to zero, fasten one end of the tape as previously described and determine the directions with the pocket transit, then walk any desired distance in the determined direction to a point where the Balance Indicator remains at zero with the indicating hand still at the same point as when it was set at stations No. 11 or No. 21. Record the direction as obtained by the transit and measure the distance with the tape. The selection of a point which is more than 10 minutes, in point of time, distant from the previous point is not recommended. Another point beyond this one may now be selected and determined in the same manner as well as all subsequent points covering the area desired at the top elevation on both sides of the axis.

The same procedure is then followed on connection with the other levels at stations No. 10 and No. 20, No. 9 and No. 19, etc.

9. When plotting the notes follow the procedure shown in the illustration where the radius of each circle is equal to the slope distance.

RESERVOIR SITES

10. To determine and mark on the ground the flood line of any proposed reservoir it is only necessary to set the Balance Indicator of the instrument to zero at the elevation of the dam site which represents the high water line and then walk around the reservoir at such an elevation that the tendency pointer remains at zero. If it is desired to plot the flood line area to figure reservoir capacity the pocket transit and steel tape are to be used to obtain proper direction and get horizontal distances in the same manner as described in paragraph No. 8.

11. By using the above description as a basis, complete topography can be taken of the entire reservoir site.

PIPE LINES

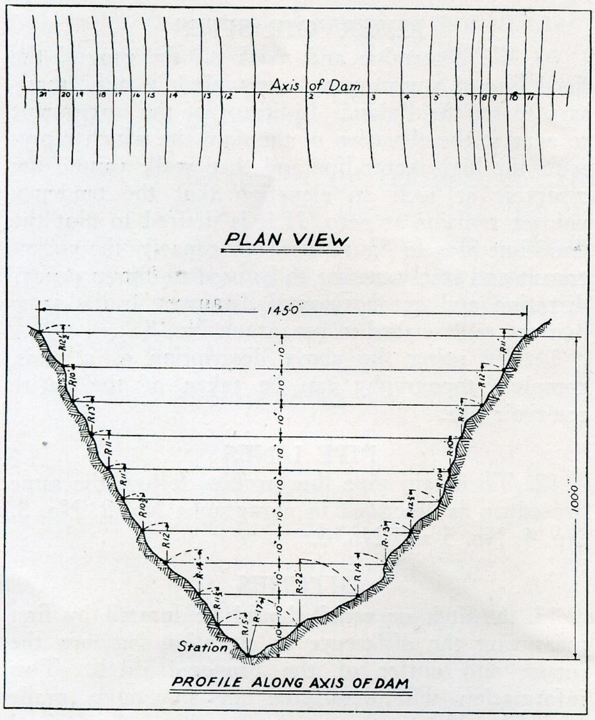
12. To obtain pipe line profiles follow the same procedure as described in paragraphs No. 2, No. 3, No. 4, No. 5 and No. 6.

DITCHES

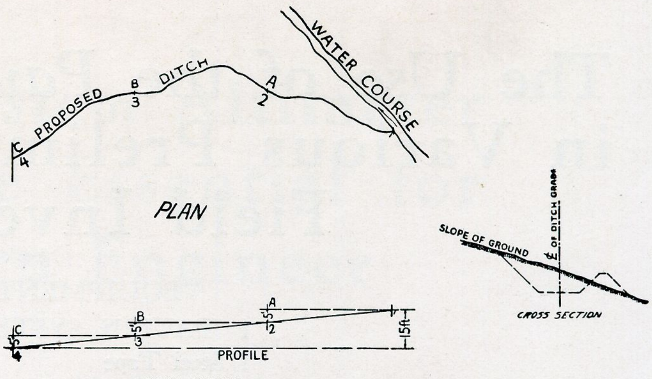
13. A ditch or canal should be located by first measuring the difference in elevation between the intake and outlet of the proposed ditch. This information will determine the maximum grade available. When the grade has been determined

start at the intake of the proposed ditch by setting the Balance Indicator to zero, then record the reading of the Pointer on the scale. Walk along at an elevation where the Balance Indicator remains at zero, setting stakes or making marks upon the ground to identify the ditch location. Approximately every 10 minutes stop and return to the last stake or mark to see if the Balance Indicator still remains at zero. If it does not remain at zero then reset it to zero regardless of whether the reading of the Pointer remains at the same figure or not, and continue the laying out of the line until a point has been reached where it is feasible to step down to a lower level representing at that point the grade of the ditch. Please note the illustration "Ditch Survey." Point No. 1 is the intake point, No. 4 the outlet. The difference in elevation between both of these points is 15 feet. The distance from point No. 1 to point No. 2 is determined and the grade per mile established. In this case the distance being 3 miles, the grade established is 5 feet to the mile. Hence at the end of every mile, points A, B and C, the operator of the altimeter steps down 5 feet which vertical distance is measured with the altimeter, and the same procedure is followed at the lower elevations as in connection with the first mile of the ditch. Having determined points 1, 2, 3 and 4, it becomes a simple matter to move all intermediate points down to the proper grade line.

14. If the ditch is to be located on the side of a hill (see illustration "Cross Section"), slope distances and topography can be taken in the same manner as heretofore described in paragraphs No. 2,



PROFILE ALONG AXIS OF DAM



DITCH SURVEY

No. 3, No. 4, No. 5, No. 6 and No. 7.

If any measurements are taken where the time occupied between any two readings is greater than 15 minutes, it is recommended that two altimeters of the same type be used in the manner described elsewhere in this manual.

HIGHWAYS AND RAILROADS

If greater accuracy is desired in the preliminary location of a highway or railroad than is possible by the use of the method illustrated in Example 3, the following suggested method may be used by employing two altimeters and two observers:

At the initial station No. 1 the two observers, A and B, adjust the altimeters to read alike. Observer A remains with his instrument at station No. 1 for one hour during which time the altimeter is read at least every ten minutes to record the barometric change in feet of altitude. Operator A should note in his field book the altimeter reading, the time when it was taken, and the air temperature at the time of each reading. During the hour that Operator A is taking stationary readings at station No. 1, Operator B is taking field readings along the projected course of the road. When the hour is up, Operator B establishes station No. 2 wherever he happens to be located at that time. He then remains at station No. 2 taking stationary readings for one hour in the same manner as described with reference to Operator A at station No. 1. During the time that Operator B remains stationary at station No. 2 Operator A goes to that station and takes field readings for one hour in the territory beyond station No. 2. Whenever field readings are taken the time of each reading and the air temperature at the time of each reading should be noted in the field book, in addition to the altimeter readings.

By alternating in this manner each operator will have for the other one the data necessary whereby to correct the field readings. Furthermore, this data will be very accurate as the readings of barometric change have been taken in the close vicinity of the field readings.

In general the details of procedure for the above suggested method should be carried out in accordance with Example 4 contained in this manual.

DETERMINATION *of* ALTITUDE with A *Paulin* System Altimeter

ROUGH DIFFERENCE IN ALTITUDE

IF it is desired to measure the difference in altitude between two points A and B, the instrument is first read at A and then at B. It should be remembered that the instrument ought to have the proper temperature, be exposed to direct sunshine as little as possible, and kept in a horizontal position on reading. *The difference between the two can be called "the rough difference in altitude between A and B."* For accuracy, allowances must be made for temperature and barometric changes.

ALLOWANCES FOR TEMPERATURE CHANGES

The pressure exerted by a column of air of a certain height is really dependent upon its temperature. In the same degree as the air grows warmer, it gets relatively lighter. The scale on a Paulin Altimeter is calculated for an air temperature of +50° F.

In order to obtain an accurate determination of the difference in height between A and B one must know the mean temperature of the stratum of air in question (by reading the temperature at A and B.) In the event of the latter exceeding +50° F. a correction is *added* to the rough difference in height, the magnitude of which correction may be said to amount to 2 feet for every 100 feet and for every 10 degrees by which the temperature exceeds +50° F. In the event of the temperature falling below +50° F., 2 feet is *deducted* in the same way for every 100 feet and every 10 degrees. In the following examples it is shown how with the aid of the Correction Tables (Pages 7-11) it is possible by a simple calculation to determine the magnitude of the correction.

ALLOWANCES FOR BAROMETRIC CHANGES

If all strata of air were perfectly at rest, the atmospheric pressure *at sea-level* would constantly be of "normal" magnitude, i.e., measured by a 30-inch column of mercury. Wind, unevenly distributed temperatures, and other causes, however, set the air strata in motion so that the atmospheric pressure is made to vary somewhat. This deviation is called "barometric change," for which allowances must be made for accurate readings.

EXAMPLE No. 1

Let us assume that it is desired to determine the difference in height between mountain top A and the lower lying mountain top B (2926 feet above sea-level). The altimeter reading on top of B is 2847 feet and the thermometer +61° F. On the top of A we read 4557 feet and +53° F. The "rough difference in height" is thus 4557 — 2847 = 1710 feet and the mean temperature of the air may be put at $+53° + \frac{61° - 53°}{2} = +57°$ F. At a temperature which is ten degrees above +50° F., thus at +60° F., the correction according to the table is +34 feet for 1700 feet. In order to further obtain the correction for 10 feet we take from the table the correction for 100 feet (= 2 feet) and divide it by 10; we obtain then for 10 feet 0.2 feet correction and consequently for 1710 feet = + 34 + 0.2 = +34.2 feet. But +57° is only 7° above +50° F. We must therefore multiply 34.2 by 7 and divide it by 10. The correction sought for is therefore + 24 feet and the difference in height between top A and B sought for is 1734 feet. Since B's elevation above sea-level is 2926 feet we find top A's elevation = 2926 + 1734 = 4660 feet above sea-level.

EXAMPLE No. 2

Let us assume that at station A we have read on the altimeter +279 feet and on the thermometer +39° F. We assume further that when we arrive at station B the center-knob must be turned in the *same direction as the hands of a watch* until the main pointer, in order to bring the balance indicator to zero, reaches the *other side of the zero point of the elevation scale. The figure read here in feet must be figured negative.* We assume that we have found —404 feet and on the thermometer +43° F. The rough difference in height is then 279 — (—404 = 279 + 404 = 683 feet, and the mean temperature of the air = +41° F.

From the table we find in a similar manner as before that the correction at *40° air temperature,* and 683 feet difference in elevation is approximately — 12 — 1.6 = —13.6 feet. In order to find the correction sought for (at +41° F.) this value should therefore be multiplied by 9 and divided by 10. We find consequently the correction = —12 feet, and the difference in elevation between A and B sought for = 683 — 12 = 671 feet.

EXAMPLE No. 3

In surveying a more or less limited area good values can be obtained even with *one altimeter,* if after passing all points of measurement one returns to the starting point in order to there check the change in barometric pressure. Corrections for such change are calculated in the manner specified below.

In table "A" on the next page we find in columns I and II the readings of altimeter and thermometer respectively which have successively been made at A, B, C, D, E and F, and thereupon again at A.

Table "A"
to be used with Example No. 3

Station	I Altimeter reading in feet	II Air temperature ° F.	III Reading corrected for Barometric pressure	IV Difference in reading in feet	V Mean air temperature ° F.	VI Mean air temperature correction	VII Difference in altitude in feet
A	2789	+75°	2789	—151	+75.5°	+7.5	—158.5
B	2636	+76°	2638	— 49	+77.5°	+2.6	— 52.0
C	2585	+79°	2589	+171	+76.5°	+8.9	+180.0
D	2754	+74°	2760	+ 92	+73.0°	+4.1	+ 96.0
E	2843	+72°	2852	— 46	+72.5°	+2.0	— 48.0
F	2795	+73°	2806	— 17	+73.0°	+0.8	— 18.0
A	2776	+73°	2789				

Table "B"
to be used with Example No. 4

Station	I Altimeter 1 reading in feet	II Air temperature ° F.	Station	III Altimeter 2 reading in feet	IV Air temperature ° F.	V Difference in reading in feet	VI Mean air temperature ° F.	VII Mean air temperature correction	VIII Difference in elevation in feet
A	2787	+74°	A	2787	+74°	0	+74.0°	0	0
"	2788	+74°	B	2636	+75°	—152	+74.5°	+ 7.3	—159.0
"	2789	+75°	C	2590	+77°	—199	+76.0°	+10.2	—209.0
"	2789	+75°	D	2836	+74°	+ 47	+74.5°	+ 2.2	+ 49.0
"	2789	+76°	E	3104	+71°	+315	+73.5°	+14.5	+329.5
"	2788	+75°	F	3050	+68°	+262	+71.5°	+11.0	+273.0

On returning to A we find in the example referred to that the reading of the altimeter has changed from 2789 feet to 2776 feet (due to change in barometric pressure) and that the reading of the thermometer has changed from +75° to +73° F. We assume now that the measurement had been arranged in such a manner that the time between two ensuing readings is everywhere approximately alike, and that the change in barometric pressure during the short time that elapses between the first and last reading can be looked upon as having occurred uniformly and evenly.

If therefore the change in barometric pressure, as shown by the two readings, is 13 feet, it clearly amounts to at point F $\frac{5}{6} \times 13 = 10.8$ feet; at point E $\frac{4}{6} \times 13 = 8.7$ feet and so on.

In column III are entered the corrected altimeter readings with the errors due to changes in barometric pressure. The values 13; 10.8; 8.7; . . . etc., shall obviously be added to 2776; 2795; 2843; . . . etc., respectively.

In column IV are calculated the "differences in reading in feet" between A and B, B and C, etc. To these values are added the "average air temperature corrections" according to the "Correction Tables" (Pages 7-11).

EXAMPLE No. 4

The measurement is carried out by two observers, each one equipped with an instrument, one of which remains stationary at the starting point A. For the sake of simplicity it is assumed here that the two altimeters by adjustment of the pointer are made to read absolutely alike at A. If this should not be so the difference shall always be added as a constant correction (positive or negative) to every reading made with the stationary instrument.

Table "B" above shows how determination of the difference in elevation between station A and each one of the stations B, C, D, E and F takes place. The stationary instrument, "Altimeter 1," is read every ten minutes (if the greatest possible accuracy is desired, every five minutes) and at each reading the *altitude* and *time* noted. In this way the variations in atmospheric pressure may be said to be known for any minute whatsoever of the period during which the measurements are going on. Furthermore, the *temperature of the air* is noted down at certain suitable intervals, i.e., once every half hour.

The other observer proceeds from A to all the stations B, C, D, E and F where the elevation is desired to be ascertained. At all stations the *altimeter,* the *watch* and the *thermometer* are read. In column III are entered the readings on Altimeter 2 and in column I those readings which according to the records would have been obtained at A at precisely the same times. The difference between the respective values obtained at A, B, C, D, E and F, and corresponding at A are entered in column V. The sign (—) indicates that the spot has a lower elevation than A, the sign (+) that it has a higher elevation.

In columns II and IV are entered the simultaneously made readings of the air temperature, and in column VI the values for the "mean air temperature" calculated from the same. From the correction tables are calculated the corresponding corrections in the differences in reading. The differences in elevation B-A, C-A, D-A, etc., are entered in column VIII.

CORRECTION TABLES

for Change in Air Density Due to Change in Temperature

INSTRUCTIONS FOR USING THE TABLES

THE following pages present a series of tables to be used in computing results of Paulin System Altimeter readings.

If it is desired to measure the difference in height between two points A and B, the altimeter is first read at one place and then at the other.

The difference between the readings at A and B is *"Difference of Readings in Feet"* in the Correction Tables (Pages 8 to 11). This is corrected according to the instructions given at the top of the tables.

EXAMPLE 1

Read at A: on the altimeter ~~+3610~~ +3520 feet; on the therm. +66° F.

Read at B: on the altimeter +2895 feet; on the therm. 70° F.

"Difference of reading in feet" +625 feet; aver. air temp. +68° F.

On page 10 we find the correction approximately corresponding to the difference in reading found for an average air temperature of +68° F. to be +22.1 feet. The difference in height between A and B according to the calculation is consequently 647 feet.

EXAMPLE 2

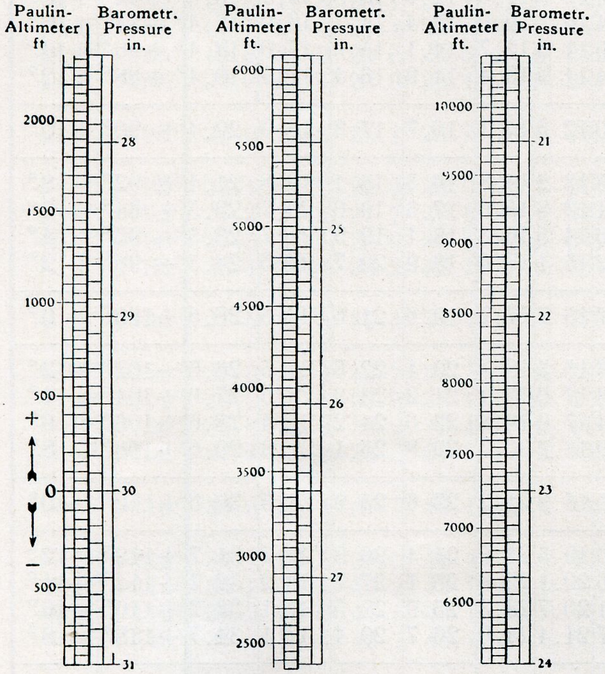
Read at A: on the altimeter +279 feet; on the therm. +40° F.

Read at B: on the altimeter —435 feet; on the therm. +42° F.

"Difference of reading in feet" +714 feet; aver. air temp. +41° F.

On page 10 we find the correction approximately corresponding to the difference in reading found for an average air temperature of +40° F. to be —14 feet. For an average air temperature of +42° F. we find —11.2 feet. As the proper correction we may therefore assume the average number, i.e., —12.6 feet. The difference in height between A and B according to the calculation is therefore 701.4 feet.

Scale showing the reading of a Paulin Altimeter in feet and corresponding barometrical pressure in inches.



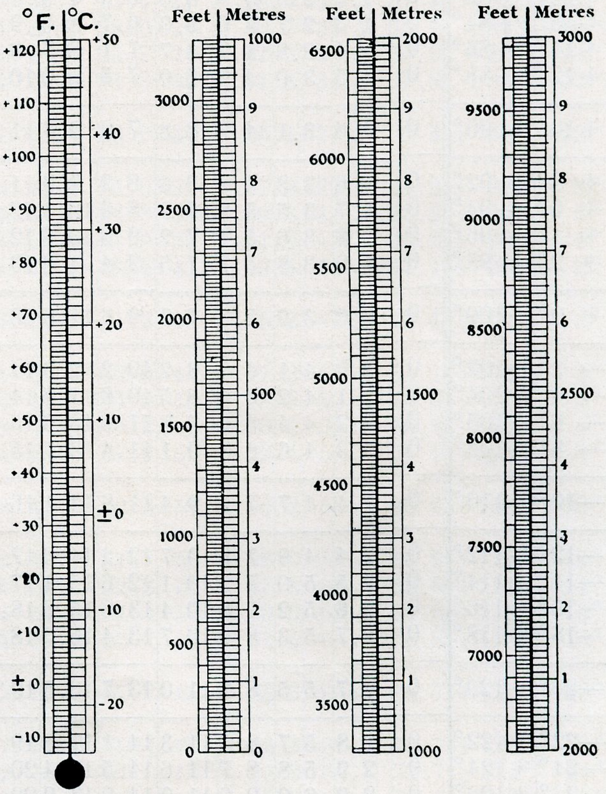
The zero point of the altitude-scale should correspond to a barometrical pressure of 30 inches of mercury. To check this the Paulin Altimeter is compared with a good mercury barometer.

The reading of the altimeter is found on the left side of the scale and on the right side, the corresponding inches of mercury.

When the instrument is to be compared with a mercury barometer the reading of the latter instrument must be corrected for temperature and latitude in order to obtain the barometrical pressure (mercury at 32° F. and gravity at 45° lat.).

By aid of this scale the altimeter can be used as a barometer.

Scale of Conversion from metres to feet and degrees Centigrade to degrees Fahrenheit.



Average Air Temperature Correction in Feet

For temperatures above 50° F. the values are to be added
For temperatures below 50° F. the values are to be subtracted

Average air temp. °F.		Difference of readings in feet 0	20	40	60	80	100	120	140	160	180	200	220	240	260	Average air temp. °F.	
	+50°	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+50°	
+48°	+52°	0	0.1	0.2	0.2	0.3	0.4	0.5	0.5	0.6	0.7	0.8	0.9	0.9	1.0	+52°	+48°
+46°	+54°	0	0.2	0.3	0.5	0.6	0.8	0.9	1.1	1.3	1.4	1.6	1.7	1.9	2.0	+54°	+46°
+44°	+56°	0	0.2	0.5	0.7	0.9	1.2	1.4	1.6	1.9	2.1	2.4	2.6	2.8	3.1	+56°	+44°
+42°	+58°	0	0.3	0.6	0.9	1.3	1.6	1.9	2.2	2.5	2.8	3.1	3.5	3.8	4.1	+58°	+42°
+40°	+60°	0	0.4	0.8	1.2	1.6	2.0	2.4	2.7	3.1	3.5	3.9	4.3	4.7	5.1	+60°	+40°
+38°	+62°	0	0.5	0.9	1.4	1.9	2.4	2.8	3.3	3.8	4.2	4.7	5.2	5.7	6.1	+62°	+38°
+36°	+64°	0	0.5	1.1	1.6	2.2	2.7	3.3	3.8	4.4	4.9	5.5	6.0	6.6	7.1	+64°	+36°
+34°	+66°	0	0.6	1.3	1.9	2.5	3.1	3.8	4.4	5.0	5.7	6.3	6.9	7.5	8.2	+66°	+34°
+32°	+68°	0	0.7	1.4	2.1	2.8	3.5	4.2	4.9	5.7	6.4	7.1	7.8	8.5	9.2	+68°	+32°
+30°	+70°	0	0.8	1.6	2.4	3.1	3.9	4.7	5.5	6.3	7.1	7.9	8.6	9.4	10.2	+70°	+30°
+28°	+72°	0	0.9	1.7	2.6	3.5	4.3	5.2	6.0	6.9	7.8	8.6	9.5	10.4	11.2	+72°	+28°
+26°	+74°	0	0.9	1.9	2.8	3.8	4.7	5.7	6.6	7.5	8.5	9.4	10.4	11.3	12.3	+74°	+26°
+24°	+76°	0	1.0	2.0	3.1	4.1	5.1	6.1	7.1	8.2	9.2	10.2	11.2	12.2	13.3	+76°	+24°
+22°	+78°	0	1.1	2.2	3.3	4.4	5.5	6.6	7.7	8.8	9.9	11.0	12.1	13.2	14.3	+78°	+22°
+20°	+80°	0	1.2	2.4	3.5	4.7	5.9	7.1	8.2	9.4	10.6	11.8	13.0	14.1	15.3	+80°	+20°
+18°	+82°	0	1.3	2.5	3.8	5.0	6.3	7.5	8.8	10.0	11.3	12.6	13.8	15.1	16.3	+82°	+18°
+16°	+84°	0	1.3	2.7	4.0	5.3	6.7	8.0	9.4	10.7	12.0	13.4	14.7	16.0	17.4	+84°	+16°
+14°	+86°	0	1.4	2.8	4.2	5.7	7.1	8.5	9.9	11.3	12.7	14.1	15.6	17.0	18.4	+86°	+14°
+12°	+88°	0	1.5	3.0	4.5	6.0	7.5	9.0	10.4	11.9	13.4	14.9	16.4	17.9	19.4	+88°	+12°
+10°	+ 90°	0	1.6	3.1	4.7	6.3	7.9	9.4	11.0	12.6	14.1	15.7	17.3	18.9	20.4	+ 90°	+10°
+ 8°	+ 92°	0	1.6	3.3	4.9	6.6	8.2	9.9	11.5	13.2	14.8	16.5	18.1	19.8	21.4	+ 92°	+ 8°
+ 6°	+ 94°	0	1.7	3.5	5.2	6.9	8.6	10.4	12.1	13.8	15.6	17.3	19.0	20.7	22.5	+ 94°	+ 6°
+ 4°	+ 96°	0	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.5	16.3	18.1	19.9	21.7	23.5	+ 96°	+ 4°
+ 2°	+ 98°	0	1.9	3.8	5.7	7.5	9.4	11.3	13.2	15.1	17.0	18.9	20.7	22.6	24.5	+ 98°	+ 2°
+ 0°	+100°	0	2.0	3.9	5.9	7.9	9.8	11.8	13.7	15.7	17.7	19.6	21.6	23.6	25.5	+100°	+ 0°
— 2°	+102°	0	2.0	4.1	6.1	8.2	10.2	12.3	14.3	16.3	18.4	20.4	22.5	24.5	26.6	+102°	— 2°
— 4°	+104°	0	2.1	4.2	6.4	8.5	10.6	12.7	14.8	17.0	19.1	21.2	23.3	25.5	27.6	+104°	— 4°
— 6°	+106°	0	2.2	4.4	6.6	8.8	11.0	13.2	15.4	17.6	19.8	22.0	24.2	26.4	28.6	+106°	— 6°
— 8°	+108°	0	2.3	4.6	6.8	9.1	11.4	13.7	15.9	18.2	20.5	22.8	25.1	27.3	29.6	+108°	— 8°
—10°	+110°	0	2.4	4.7	7.1	9.4	11.8	14.1	16.5	18.9	21.2	23.6	25.9	28.3	30.6	+110°	—10°
—12°	+112°	0	2.4	4.9	7.3	9.7	12.2	14.6	17.0	19.5	21.9	24.4	26.8	29.2	31.7	+112°	—12°
—14°	+114°	0	2.5	5.0	7.5	10.1	12.6	15.1	17.6	20.1	22.6	25.1	27.7	30.2	32.7	+114°	—14°
—16°	+116°	0	2.6	5.2	7.8	10.4	13.0	15.6	18.1	20.7	23.3	25.9	28.5	31.1	33.7	+116°	—16°
—18°	+118°	0	2.7	5.3	8.0	10.7	13.4	16.0	18.7	21.4	24.0	26.7	29.4	32.1	34.7	+118°	—18°
—20°	+120°	0	2.7	5.5	8.2	11.0	13.7	16.5	19.2	22.0	24.7	27.5	30.2	33.0	35.7	+120°	—20°
—22°	+122°	0	2.8	5.7	8.5	11.3	14.1	17.0	19.8	22.6	25.4	28.3	31.1	33.9	36.8	+122°	—22°
—24°	+124°	0	2.9	5.8	8.7	11.6	14.5	17.4	20.3	23.3	26.2	29.1	32.0	34.9	37.8	+124°	—24°
—26°	+126°	0	3.0	6.0	9.0	11.9	14.9	17.9	20.9	23.9	26.9	29.9	32.8	35.8	38.8	+126°	—26°

Average Air Temperature Correction in Feet

For temperatures above 50° F. the values are to be added
For temperatures below 50° F. the values are to be subtracted

Average air temp. °F.		Difference of readings in feet														Average air temp. °F.	
		500	520	540	560	580	600	620	640	660	680	700	720	740	760		
	+50°	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+50°	
+48°	+52°	2.0	2.0	2.1	2.2	2.3	2.4	2.4	2.5	2.6	2.7	2.7	2.8	2.9	3.0	+52°	+48°
+46°	+54°	3.9	4.1	4.2	4.4	4.6	4.7	4.9	5.0	5.2	5.3	5.5	5.7	5.8	6.0	+54°	+46°
+44°	+56°	5.9	6.1	6.4	6.6	6.8	7.1	7.3	7.5	7.8	8.0	8.2	8.5	8.7	9.0	+56°	+44°
+42°	+58°	7.9	8.2	8.5	8.8	9.1	9.4	9.7	10.1	10.4	10.7	11.0	11.3	11.6	11.9	+58°	+42°
+40°	+60°	9.8	10.2	10.6	11.0	11.4	11.8	12.2	12.6	13.0	13.4	13.7	14.1	14.5	14.9	+60°	+40°
+38°	+62°	11.8	12.3	12.7	13.2	13.7	14.1	14.6	15.1	15.5	16.0	16.5	17.0	17.4	17.9	+62°	+38°
+36°	+64°	13.7	14.3	14.8	15.4	15.9	16.5	17.0	17.6	18.1	18.7	19.2	19.8	20.3	20.9	+64°	+36°
+34°	+66°	15.7	16.3	17.0	17.6	18.2	18.9	19.5	20.1	20.7	21.4	22.0	22.6	23.3	23.9	+66°	+34°
+32°	+68°	17.7	18.4	19.1	19.8	20.5	21.2	21.9	22.6	23.3	24.0	24.7	25.5	26.2	26.9	+68°	+32°
+30°	+70°	19.6	20.4	21.2	22.0	22.8	23.6	24.4	25.1	25.9	26.7	27.5	28.3	29.1	29.9	+70°	+30°
+28°	+72°	21.6	22.5	23.3	24.2	25.1	25.9	26.8	27.7	28.5	29.4	30.2	31.1	32.0	32.8	+72°	+28°
+26°	+74°	23.6	24.5	25.5	26.4	27.3	28.3	29.2	30.2	31.1	32.1	33.0	33.9	34.9	35.8	+74°	+26°
+24°	+76°	25.5	26.6	27.6	28.6	29.6	30.6	31.7	32.7	33.7	34.7	35.7	36.8	37.8	38.8	+76°	+24°
+22°	+78°	27.5	28.6	29.7	30.8	31.9	33.0	34.1	35.2	36.3	37.4	38.5	39.6	40.7	41.8	+78°	+22°
+20°	+80°	29.5	30.6	31.8	33.0	34.2	35.4	36.5	37.7	38.9	40.1	41.2	42.4	43.6	44.8	+80°	+20°
+18°	+82°	31.4	32.7	33.9	35.2	36.5	37.7	39.0	40.2	41.5	42.7	44.0	45.3	46.5	47.8	+82°	+18°
+16°	+84°	33.4	34.7	36.1	37.4	38.7	40.1	41.4	42.7	44.1	45.4	46.7	48.1	49.4	50.8	+84°	+16°
+14°	+86°	35.3	36.8	38.2	39.6	41.0	42.4	43.8	45.2	46.7	48.1	49.5	50.9	52.3	53.7	+86°	+14°
+12°	+88°	37.3	38.8	40.3	41.8	43.3	44.8	46.3	47.8	49.3	50.7	52.2	53.7	55.2	56.7	+88°	+12°
+10°	+ 90°	39.3	40.9	42.4	44.0	45.6	47.1	48.7	50.3	51.8	53.4	55.0	56.6	58.1	59.7	+ 90°	+10°
+ 8°	+ 92°	41.2	42.9	44.5	46.2	47.8	49.5	51.1	52.8	54.4	56.1	57.7	59.4	61.0	62.7	+ 92°	+ 8°
+ 6°	+ 94°	43.2	44.9	46.7	48.4	50.1	51.9	53.6	55.3	57.0	58.8	60.5	62.2	64.0	65.7	+ 94°	+ 6°
+ 4°	+ 96°	45.2	47.0	48.8	50.6	52.4	54.2	56.0	57.8	59.6	61.4	63.2	65.1	66.9	68.7	+ 96°	+ 4°
+ 2°	+ 98°	47.1	49.0	50.9	52.8	54.7	56.6	58.4	60.3	62.2	64.1	66.0	67.9	69.8	71.6	+ 98°	+ 2°
+ 0°	+100°	49.1	51.1	53.0	55.0	57.0	58.9	60.9	62.8	64.8	66.8	68.7	70.7	72.7	74.6	+100°	+ 0°
— 2°	+102°	51.1	53.1	55.1	57.2	59.2	61.3	63.3	65.4	67.4	69.4	71.5	73.5	75.6	77.6	+102°	— 2°
— 4°	+104°	53.0	55.2	57.3	59.4	61.5	63.6	65.8	67.9	70.0	72.1	74.2	76.4	78.5	80.6	+104°	— 4°
— 6°	+106°	55.0	57.2	59.4	61.6	63.8	66.0	68.2	70.4	72.6	74.8	77.0	79.2	81.4	83.6	+106°	— 6°
— 8°	+108°	57.0	59.2	61.5	63.8	66.1	68.3	70.6	72.9	75.2	77.5	79.7	82.0	84.3	86.6	+108°	— 8°
—10°	+110°	58.9	61.3	63.6	66.0	68.3	70.7	73.1	75.4	77.8	80.1	82.5	84.8	87.2	89.6	+110°	—10°
—12°	+112°	60.9	63.3	65.8	68.2	70.6	73.1	75.5	77.9	80.4	82.8	85.2	87.7	90.1	92.5	+112°	—12°
—14°	+114°	62.8	65.4	67.9	70.4	72.9	75.4	77.9	80.4	83.0	85.5	88.0	90.5	93.0	95.5	+114°	—14°
—16°	+116°	64.8	67.4	70.0	72.6	75.2	77.8	80.4	83.0	85.6	88.1	90.7	93.3	95.9	98.5	+116°	—16°
—18°	+118°	66.8	69.5	72.1	74.8	77.5	80.1	82.8	85.5	88.1	90.8	93.5	96.2	98.8	101.5	+118°	—18°
—20°	+120°	68.7	71.5	74.2	77.0	79.7	82.5	85.2	88.0	90.7	93.5	96.2	99.0	101.7	104.5	+120°	—20°
—22°	+122°	70.7	73.6	76.4	79.2	82.0	84.9	87.7	90.5	93.3	96.2	99.0	101.8	104.7	107.5	+122°	—22°
—24°	+124°	72.7	75.6	78.5	81.4	84.3	87.2	90.1	93.0	95.9	98.8	101.7	104.7	107.6	110.5	+124°	—24°
—26°	+126°	74.6	77.6	80.6	83.6	86.6	89.6	92.6	95.5	98.5	101.5	104.5	107.5	110.5	113.5	+126°	—26°

Average Air Temperature Correction in Feet

For temperatures above 50° F. the values are to be added
For temperatures below 50° F. the values are to be subtracted

Average air temp. °F.		Difference of readings in feet												Average air temp. °F.	
		780	800	820	840	860	880	900	920	940	960	980	1000		
	+50°	0	0	0	0	0	0	0	0	0	0	0	0	+50°	
+48°	+52°	3.1	3.1	3.2	3.3	3.4	3.5	3.5	3.6	3.7	3.8	3.8	3.9	+52°	+48°
+46°	+54°	6.1	6.3	6.4	6.6	6.8	6.9	7.1	7.2	7.4	7.5	7.7	7.9	+54°	+46°
+44°	+56°	9.2	9.4	9.7	9.9	10.1	10.4	10.6	10.8	11.1	11.3	11.5	11.8	+56°	+44°
+42°	+58°	12.3	12.6	12.9	13.2	13.5	13.8	14.1	14.5	14.8	15.1	15.4	15.7	+58°	+42°
+40°	+60°	15.3	15.7	16.1	16.5	16.9	17.3	17.7	18.1	18.5	18.8	19.2	19.6	+60°	+40°
+38°	+62°	18.4	18.8	19.3	19.8	20.3	20.7	21.2	21.7	22.1	22.6	23.1	23.6	+62°	+38°
+36°	+64°	21.4	22.0	22.5	23.1	23.6	24.2	24.7	25.3	25.8	26.4	26.9	27.5	+64°	+36°
+34°	+66°	24.5	25.1	25.8	26.4	27.0	27.6	28.3	28.9	29.5	30.2	30.8	31.4	+66°	+34°
+32°	+68°	27.6	28.3	29.0	29.7	30.4	31.1	31.8	32.5	33.2	33.9	34.6	35.4	+68°	+32°
+30°	+70°	30.6	31.4	32.2	33.0	33.8	34.6	35.4	36.1	36.9	37.7	38.5	39.3	+70°	+30°
+28°	+72°	33.7	34.6	35.4	36.3	37.2	38.0	38.9	39.8	40.6	41.5	42.3	43.2	+72°	+28°
+26°	+74°	36.8	37.7	38.7	39.6	40.5	41.5	42.4	43.4	44.3	45.3	46.2	47.1	+74°	+26°
+24°	+76°	39.8	40.9	41.9	42.9	43.9	44.9	46.0	47.0	48.0	49.0	50.0	51.1	+76°	+24°
+22°	+78°	42.9	44.0	45.1	46.2	47.3	48.4	49.5	50.6	51.7	52.8	53.9	55.0	+78°	+22°
+20°	+80°	46.0	47.1	48.3	49.5	50.7	51.8	53.0	54.2	55.4	56.6	57.7	58.9	+80°	+20°
+18°	+82°	49.0	50.3	51.5	52.8	54.1	55.3	56.6	57.8	59.1	60.3	61.6	62.8	+82°	+18°
+16°	+84°	52.1	53.4	54.8	56.1	57.4	58.8	60.1	61.4	62.8	64.1	65.4	66.8	+84°	+16°
+14°	+86°	55.1	56.6	58.0	59.4	60.8	62.2	63.6	65.0	66.5	67.9	69.3	70.7	+86°	+14°
+12°	+88°	58.2	59.7	61.2	62.7	64.2	65.7	67.2	68.7	70.2	71.6	73.1	74.6	+88°	+12°
+10°	+ 90°	61.3	62.8	64.4	66.0	67.6	69.1	70.7	72.3	73.8	75.4	77.0	78.6	+ 90°	+10°
+ 8°	+ 92°	64.3	66.0	67.6	69.3	70.9	72.6	74.2	75.9	77.5	79.2	80.8	82.5	+ 92°	+ 8°
+ 6°	+ 94°	67.4	69.1	70.9	72.6	74.3	76.0	77.8	79.5	81.2	83.0	84.7	86.4	+ 94°	+ 6°
+ 4°	+ 96°	70.5	72.3	74.1	75.9	77.7	79.5	81.3	83.1	84.9	86.7	88.5	90.3	+ 96°	+ 4°
+ 2°	+ 98°	73.5	75.4	77.3	79.2	81.1	83.0	84.8	86.7	88.6	90.5	92.4	94.3	+ 98°	+ 2°
+ 0°	+100°	76.6	78.6	80.5	82.5	84.5	86.4	88.4	90.3	92.3	94.3	96.2	98.2	+100°	+ 0°
— 2°	+102°	79.7	81.7	83.7	85.8	87.8	89.9	91.9	94.0	96.0	98.0	100.1	102.1	+102°	— 2°
— 4°	+104°	82.7	84.8	87.0	89.1	91.2	93.3	95.5	97.6	99.7	101.8	103.9	106.1	+104°	— 4°
— 6°	+106°	85.8	88.0	90.2	92.4	94.6	96.8	99.0	101.2	103.4	105.6	107.8	110.0	+106°	— 6°
— 8°	+108°	88.8	91.1	93.4	95.7	98.0	100.2	102.5	104.8	107.1	109.4	111.6	113.9	+108°	— 8°
—10°	+110°	91.9	94.3	96.6	99.0	101.3	103.7	106.1	108.4	110.8	113.1	115.5	117.8	+110°	—10°
—12°	+112°	95.0	97.4	99.9	102.3	104.7	107.2	109.6	112.0	114.5	116.9	119.3	121.8	+112°	—12°
—14°	+114°	98.0	100.6	103.1	105.6	108.1	110.6	113.1	115.6	118.2	120.7	123.2	125.7	+114°	—14°
—16°	+116°	101.1	103.7	106.3	108.9	111.5	114.1	116.7	119.3	121.9	124.4	127.0	129.6	+116°	—16°
—18°	+118°	104.2	106.8	109.5	112.2	114.9	117.5	120.2	122.9	125.5	128.2	130.9	133.6	+118°	—18°
—20°	+120°	107.2	110.0	112.7	115.5	118.2	121.0	123.7	126.5	129.2	132.0	134.7	137.5	+120°	—20°
—22°	+122°	110.3	113.1	116.0	118.8	121.6	124.4	127.3	130.1	132.9	135.8	138.6	141.4	+122°	—22°
—24°	+124°	113.4	116.3	119.2	122.1	125.0	127.9	130.8	133.7	136.6	139.5	142.4	145.3	+124°	—24°
—26°	+126°	116.4	119.4	122.4	125.4	128.4	131.4	134.4	137.3	140.3	143.3	146.3	149.3	+126°	—26°

PRELIMINARY SURVEY PROCEDURE

By RAYMOND A. HILL, C. E.

American Paulin System

MAKERS OF PRECISION INSTRUMENTS

General Offices and Laboratories

LOS ANGELES, CALIFORNIA, U. S. A.

Dealers in Principal Cities Throughout the World

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by RAYMOND A. HILL, C. E.

THE following pages are compiled and published by the Educational Division of the American Paulin System, in the interests of greater efficiency and economy of time and labor in the making of preliminary surveys under all conditions. The observer and author of this work, Raymond A. Hill, M. Am. Soc. C. E., of the widely known firm of Quinton, Code and Hill, Consulting Engineers, explains in detail the practical use of the Paulin System Altimeter in connection with all branches of preliminary field surveying. Geologists, Scientists, Topographers, Surveyors and Educators will find these pages of rare interest and technical value.

AMERICAN PAULIN SYSTEM

EFFECTIVE USE OF THE PAULIN ALTIMETER

by *RAYMOND A. HILL, C. E.

*Quinton, Code & Hill, Consulting Engineers, Los Angeles, Calif.

TWO fundamental factors are obviously essential to satisfactory use of any instrument; first, an understanding of the principles of operation; second, appreciation of its limitations. The Paulin Altimeter is no exception, and full advantage of its use depends upon an understanding of the general theory and practice of barometric leveling and of the mechanical peculiarities of this instrument, from which realization of its limitations naturally follows.

Barometric leveling is primarily a determination of altitude by differences in air pressure, it being a matter of common knowledge that there is less pressure at high altitudes than at low altitudes. Originally this determination was made with mercurial barometers, but on account of the difficulty of transporting these instruments, the method was little used until the invention of the aneroid barometer.

The aneroid barometer of the type which has been in general use for a great number of years consists primarily of one or more evacuated metal boxes usually formed from two corrugated disks which tend to collapse due to external air pressure. The deflection of these disks is necessarily greater when the air pressure is high and less when the air pressure is low; that is, at low elevations there is a greater tendency to squeeze the faces of the box together than at points of higher elevation.

In the ordinary aneroid this movement of the disks is multiplied tremendously through linkage and other devices, and causes the pointer to move around the dial as the pressure changes. If perfect calibration of the deflection of these boxes and of the multiplying mechanism were possible, the pointer would indicate the exact air pressure at any time. However, it is almost impracticable to make the deflection of the box exactly proportional to the air pressure, and it is still more difficult to prevent further error creeping in due to friction and play in the numerous mechanical parts which multiply the compression so that it can be read on the dial. Such instruments are sensitive to small changes in elevation, but their accuracy is necessarily quite limited.

The Paulin Altimeter is a special form of aneroid barometer which differs, however, from the ordinary type in that it is a "zero-gauging" instrument. The ordinary aneroid may be likened to a spring balance where the reading of weight depends upon proportional elongation of the spring. The Paulin Altimeter, on the other hand, is comparable to the type of scale used in laboratories or for other accurate weighing where known weights are placed on one pan and the object to be weighed is placed on the other, the true weight then being determined by adding to or subtracting from the known weights until the tendency pointer is at zero on the scale. In other words, the Paulin Altimeter is so arranged that the force required to bring the disks of the evacuated boxes back to their normal position is exactly recorded when the tendency pointer is brought to its zero position. The mechanical arrangement of the Paulin Altimeter is such that friction is almost entirely eliminated, so that the usual lag of the ordinary aneroid is not present. Consequently, while it is an aneroid barometer and is therefore subject to all the variables of barometric leveling, much more accurate results can be obtained with these altimeters than with the older types of instruments.

Since barometric leveling is dependent on the measurement of air pressure, conditions which tend to affect the density of air, other than change in elevation, necessarily introduce factors which must be taken into account. The change in barometric pressure for differences in elevation is not great, amounting to only about 1/1000th of an inch of mercury for each one foot of elevation. Consequently, a very slight barometric change will produce the same effect as a considerable difference in elevation.

A change in weather conditions, such as the approach of a storm, has the most marked effect; sudden changes in temperature or other influences tending to form local low pressure areas, which may be evidenced by whirlwinds, will give rise to erratic readings. Aside from these changes, however, there is a normal variation in barometric pressure during each day which amounts to approximately 1/10th of an inch of mercury—equivalent to 100 feet difference in elevation; this is known of as the "diurnal range." The diurnal range can be taken care of with little difficulty, and unless the approach of a storm is very sudden, major changes are not a frequent source of error. However, sudden and erratic variations in pressure will generally prevent accurate barometric leveling.

Temperature in itself has no effect upon the accuracy of the Paulin Altimeter, as expansion and contraction have been compensated by the selection of proper materials of construction. It is not to be implied, however, that the Paulin Altimeter or any instrument of precision can be taken suddenly through a change in temperature without affecting the accuracy of the reading; time must be allowed for the entire instrument to become uniformly heated or cooled. If sufficient time be not allowed for this equalization of temperature, certain parts of the instrument will be at a higher temperature than others, and distortion will be inevitable as the instrument is adjusted for uniform temperature.

The expression "compensated for temperature" is quite generally misconstrued and the erroneous conclusion that temperature does not affect readings of differences of elevation is quite common.

Temperature Corrections for Differences of Elevation

Aneroid barometers are generally calibrated for a temperature of 50° or 60° F., usually the former. Paulin Altimeters are calibrated for the former temperature, that is, the dials are graduated to record true differences in elevation when the temperature of the air is at 50° F. If a Paulin Altimeter be moved from one point to another 1000 feet higher, the instrument will record this difference of 1000 feet in elevation only when the air is at that temperature, in other words, it measures the length of a column of air of that density. If the temperature be above 50° F. the density of the air is lessened and consequently a longer column of air must be traversed in order to record the same difference in pressure. On the other hand, if the air temperature be less than 50° F., the density of the air is greater and a smaller length of column of air will show the same difference in pressure. Consequently, at temperatures above 50° F. the apparent difference in elevation is too small, and conversely too great when the temperature is below 50° F. When material changes in elevation are being encountered, adjustment of readings is thus important. Under some conditions it is sufficient to estimate the temperature; in most cases, however, the use of a thermometer is advisable.

These differences are practically proportional to the temperature and amount to approximately 2/10ths of one per cent for each degree of temperature above or below 50° F. If air were a true gas its density at any temperature would be inversely proportional to the absolute temperature. Since absolute zero is 460° below zero Fahrenheit, Paulin Altimeters are calibrated for an absolute temperature of 510°. A one degree change therefore should cause a pressure variation of 1/511th or 0.1961%. Actually, the rate of change, due to the fact that air is not a true gas, is 0.2039% for each degree above or below 50° F.

Generally it is simpler to use the sum of the temperatures at each two successive readings and apply a plus or minus correction of 1/10th of one per cent of the difference in elevation for each degree that this sum is above or below 100° F. For example, if the temperature at point 1 were 60° and at point 2 were 70° the mean temperature would be 65° or 15° above the temperature for which the instrument is calibrated. Using 2/10ths of one per cent for each degree, the correction would therefore be +3%; if the difference in elevation as read were 200 feet, the true difference of elevation, assuming no barometric change, would be 200 plus 3% of 200 or a total of 206 feet. In ordinary practice the sum of the two temperatures, that is, 60° plus 70°, or 130°, would be calculated, and the positive difference of 30° above 100° would be multiplied by 1/10th of one per cent, arriving at the same 3% of the apparent difference in elevation to be added in order to obtain the true difference in elevation.

For purposes of illustration, there is given below a set of readings—in feet or meters—which might have been taken at a time when the temperature was above 50° F., assuming for simplicity that no barometric change took place.

Adjustment for High Temperature

TABLE 1

No.	Reading	Diff. in Readings	Temp. °F.	T_1+T_2	Corrections Percent	Corrections Actual	Total	Adjusted Reading
1	1000		60				0	1000
		+1000		130	+3.0	+30		
2	2000		70				+30	2030
		+ 500		145	+4.6	+23		
3	2500		75				+53	2553
		—1000		155	+5.6	—56		
4	1500		80				— 3	1497
		— 500		155	+5.6	—28		
5	1000		75				—31	969

In the foregoing table it will be noted that the difference between readings is expressed algebraically, that is, plus when the instrument is being carried to a higher elevation and minus when going down. Since the mean temperature is uniformly above 50°, or the sum of each pair of successive readings is above 100°, the actual differences in elevation are greater than indicated on the dial. The actual correction is the algebraic product of the difference and the percentage correction—necessarily positive when the difference is positive and negative when the difference is negative, as under these conditions the percentage correction is always positive. These actual corrections could be applied to the differences, but it is simpler to take the algebraic sum of these and then to add or subtract this accumulated correction from the instrument reading, thereby adjusting the reading for temperature and differences in elevation. These values are shown in the last column of this table.

Between point 1 and 2 there was an apparent difference of 1000, which, on account of the mean temperature being 65° F. was actually 1030 feet—or meters. The third point was apparently 500 feet higher, but actually 523 feet higher, so that the elevation of the third point is 2030 plus 523 or 2553 feet. The fourth point was apparently 1000 feet lower than the third, but on account of the lessened air density the actual difference was 1056 feet, so that the adjusted reading for point 4 is 2553 minus 1056, or 1497 feet. The same value is obtained by accumulating the +30, +23 and —56 corrections, giving a net correction of —3 to be deducted from the instrument reading of 1500 feet.

A similar process is followed out when the temperature is below 50°, the principal difference being that the percentage correction is minus instead of plus. The following are readings which might have been taken under such a condition.

combinations; first, when the mean temperature is above 50° F. and there has been an apparent gain in elevation, and, second, when the mean temperature is below 50° F. and there has been an apparent drop in elevation. The first is the product of two positives and the second is the product of two negatives. In all other cases the correction of the difference is obviously negative. The accumulated or total correction to be applied to the instrument readings is either positive or negative, depending upon the sum of the individual corrections for all preceding differences. If the air temperature were uniform throughout an entire day the total correction would be equal to zero at the close of a circuit, but this condition does not hold in practice, and the sum of all the corrections to the differences will rarely equal zero, usually by as much as 10 or 15 feet.

It must be realized that the adjusted readings obtained by this process do not in themselves give the true elevation or the true differences in elevation between successive points. They are merely the readings which would have been obtained had the temperature been exactly 50° F. at all times. In order to obtain true differences of elevation or actual elevations the correction for barometric changes must be determined.

Correction for Barometric Changes

Three classes of barometric changes have been mentioned; namely, the effect of major storms, the effect of local disturbances, and the normal diurnal range. The effect of the first and the last can be ascertained, and sometimes the influence of local erratic pressure changes can be minimized. However, it is usually impracticable to do barometric leveling when thunder storms are occurring or when numerous whirlwinds are forming, and if accurate results are required no attempt should be made to obtain elevations under these conditions.

Major changes, however, can be corrected for in the same manner and by the same calculations which adjust for diurnal changes; in fact, no attempt need be made to separate these two.

Adjustment for Low Temperature

TABLE 2

No.	Reading	Diff. in Readings	Temp. °F.	T_1+T_2	Corrections Percent	Corrections Actual	Total	Adjusted Reading
6	800		30				0	800
		+400		66	—3.5	—14		
7	1200		36				—14	1186
		+800		74	—2.6	—21		
8	2000		38				—35	1965
		—600		80	—2.0	+12		
9	1400		42				—23	1377
		—800		90	—1.0	+ 8		
10	600		48				—15	585

In the above table it will be noted that in passing from point 6 to point 7 there was an apparent difference of +400 feet in altitude, but the mean temperature was only 33°, or a correction of —3.5%. This correction multiplied by the difference gives an actual correction of —14 feet, or a true difference of 386 which when added to the 800 gives an adjusted reading of 1186 feet for point 7. The same process is followed in all other calculations, the principal point being to take proper care of the algebraic sign in each case.

The correction of the apparent difference in elevation between two successive readings is positive for two

Analysis of long time records of hourly readings of barometers by the United States Weather Bureau, shows clearly that under average conditions, there is a high barometer at about three hours after sunrise and a low about six hours later, also that there is a secondary high during the night and a secondary low about sunrise. According to these records the range in pressure in latitude 30° is approximately 1/10th of an inch of mercury, and is greater than that amount in the tropics and less in higher latitudes. Consequently, readings of any barometer will show a variation during any day of about 50 feet plus or minus, even though there be no storm condition or change in temperature.

The normal condition of a high barometer about three hours after sunrise results in the reading of an apparent elevation lower than the true elevation. About six hours later, however, a reading at the same point would show an apparent gain of about 100 feet in elevation due to the lessening in the barometric pressure of approximately 1/10th of an inch of mercury. In general, therefore, it is to be expected that if the aneroid be set to read true elevations in the morning, it will read about 100 feet high in the afternoon, or if set to read correctly in the afternoon it will read 100 feet low in the morning.

Naturally the most accurate results are secured by barometric leveling at those times of day when the change in pressure is slow. Little variation takes place from two to four hours after sunrise, and between eight and ten hours, but during the middle of the day the rate of change becomes quite marked, amounting usually to as much as 30 feet per hour, or one foot every two minutes, and for short periods a rate of change of one foot per minute is not uncommon. Consequently, the exact time at which a reading is taken is of importance.

This diurnal variation is characteristic but not uniform, and furthermore it is influenced by major changes in barometric pressure over large areas. As a result, it is necessary to determine the proper correction to be applied to each aneroid reading.

Determination of the amount of diurnal variation and of other major barometric changes can be made in two ways. The simplest procedure is to have one instrument read at frequent intervals at the same point throughout the day. If the location of this stationary instrument be reasonably close to the area over which barometric leveling is being carried out, the variations in barometric pressure as indicated by that instrument can be used to correct the readings obtained with any other instrument. This procedure, however, is frequently not practicable, and in many cases is not entirely satisfactory. Unless a number of different observers are taking aneroid readings within a comparatively small area, the advantage to be gained by using a stationary instrument does not compensate for the fact that one instrument is rendered unavailable for other work and that an observer is required to be constantly at one point.

In most cases, especially for reconnaissance where barometric leveling is most advantageous, a single instrument is used or the area covered is so large that the observations would not be sufficiently controlled by a stationary instrument. If an extra instrument and an observer be available, the diurnal variation should of course be ascertained as an aid in establishing corrections. If not, the following procedure has been given very severe tests and it has been found that quite accurate results are possible when only a single Paulin Altimeter is used, or when several are used independently.

Procedure for Single Instrument

In order that the principles involved and the method of calculation may be better understood, reference is made to the accompanying set of notes, and to the corrected curve for barometric change corresponding to that set of readings.

On account of irregularities in the variations in barometric pressure which occur every day, it is necessary to determine enough points to control each curve of daily variation. This control, if a stationary instrument be available, can very largely be taken from the record of that instrument. However, in the case of a single instrument, observations must be made at points of known elevation several different times during the day.

The frequency with which readings are taken at these control points naturally depends upon the degree of accuracy required. If elevations to the nearest 20 feet are all that is needed, control points at the beginning, at the middle and at the end of the day will usually be sufficient, if the general form of the diurnal curve has previously been established. For most work, however, a reading early in the morning, another at the time of highest barometric pressure, another about mid-day, another at the time of lowest barometric pressure and one at the close of the day are almost necessary.

This checking back to points of known elevation is frequently the cause of lost time. In order to obviate this to some degree, especially in areas where points of known elevation are rare, a method of calculation from double readings on points of unknown elevation gives fairly accurate results. This, of course, involves checking back upon some point read earlier in the day, preferably after an interval of several hours. It might seem that a good deal of time would still be wasted; however, it has been found that by proper planning of the work, routes can generally be followed which will avoid duplication of travel but at the same time will permit readings to be taken at points of intersection along these routes. If the route of an observer using this method were plotted on a map, it would be seen that he was making a series of intersecting loops, touching at points of known elevation.

In the sample set of notes, for example, the observer started at a U.S.G.S. bench mark and proceeded to a railroad crossing where he took a reading. In the afternoon he arranged his travel in such a way that he again came to this same crossing where he took a second reading. The fourth and fifth points were single observations; the sixth reading was taken at a point of known elevation; the seventh reading was at a transmission tower where he expected to return later the same day or possibly some subsequent day—actually, the second reading at this tower was late in the afternoon. The next reading was at a double point, and the other observation at this point was taken an hour or more later. At 11:02 a reading was taken at a point of known elevation. At 12:16 the observer evidently stopped for lunch and before leaving at 1:00 he took another reading at the same point, which was in accord with the general principle that as many readings as possible should be taken at the same point. Soon after a reading was taken at another known point; then at an unknown point read earlier in the day; then at another point which later was checked; then at a single point; then at a known point; then at a series of single points; and finally the last three readings were checked back on either double points or on points of known elevation. The last reading in this case came at the point of starting, although the circuit could well have been closed at any other point of known elevation.

It should be noted that two readings at the initial point were taken at an interval of six minutes. Generally the first reading is taken soon after the instrument is brought out of a building and before it has had time to adjust itself to the outdoor temperature. On that account it is always advisable to wait about five minutes and then to take a second reading at the starting point before commencing the circuit for the day. It will also be seen that the time was recorded to the minute in all cases.

Three types of readings have been referred to in the above; namely, readings at control points, at double points, and single readings. A fourth class of readings, known as "check points," are obtained which are in effect double points, but duplicate the observation of a previous day and not an observation on the same day. The method of handling the check points is similar to the method used with double points, but involves the diurnal curves for two or more days instead of the curve for one day only.

The use of check points is of advantage when barometric levels are being extended rapidly into areas where few elevations are known. A series of aneroid readings are taken at successive points along a general route which does not intersect itself. On some subsequent day the same observer, or another observer traverses the same route, or intersects that route at intervals, and obtains readings at the points previously observed.

Calculation of Adjusted Readings

In the accompanying tabulation of the notes for one day the adjusted readings have been computed by the method described under the heading "Temperature Corrections for Differences of Elevation." The adjusted readings are therefore the readings which would have been obtained had the temperature of the air been precisely that for which altimeters are calibrated.

Determination of Diurnal Correction

At 7:02 the reading on the U.S.G.S. bench mark was 398 while the correct elevation was 462, requiring a correction of +64 feet. Six minutes later the reading was 402 which would require a +60 correction. The four foot difference between these was probably due to the instrument not having become adjusted to the outdoor temperature at the time the first reading was taken. Both of these corrections, however, were plotted on coordinate paper as shown on the chart, with the time as abscissa. The next observation on a point of known elevation was at 9:10 and the computed correction was +86; similar points were obtained for readings at 11:02 with a correction of +79, at 1:25 with a correction of +20, at 3:44 with a correction of —16, and at 5:21 with a correction of +10. These points are shown on the diagram by open circles, and the dashed line drawn through these points represents the first assumption as to the curve of diurnal variation plotted so as to read directly in terms of the necessary correction to the adjusted readings at each hour or minute of the day.

If no other data had been available, this curve would have been used, and the result might easily have been from 5 to 10 feet in error. Actually, however, two readings were taken at the railroad crossing—indicated by the letter "a" in the column of actual elevations. The adjusted reading at 7:32 was 561 feet, while at 1:51 the adjusted reading was 615 feet. As the afternoon reading was 54 feet higher than the morning reading, the necessary correction to arrive at the same elevation was 54 feet less. The trial variation curve at the time of the morning reading showed +66 feet and at the time of the afternoon reading +10 feet, or a difference of 56 feet, which was reasonably close.

Another pair of readings, "b," were 873 feet adjusted at 9:47, and 958 at 4:55, or a difference of 85 feet. At the time of the first reading the trial variation curve showed a probable correction of +87 feet, and in the afternoon of —2 feet, or a total difference of 89 feet. In order to adjust this discrepancy of four feet between the actual difference in the readings and the difference from the curve, the curve would either have to be lowered in the morning or raised in the afternoon, or both.

The third double point, that is "c," had more influence in establishing the form of the variation curve.

PAULIN ALTIMETER RECORD

INSTRUMENT NO. 585 DATE January 11 1929

LOCATION
Along foothills back of
Alhambra and on line of conduit.

REMARKS

Foggy in morning
Wind started shortly after noon.
Clovdy in the afternoon.

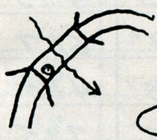
"a"

622
620
621

"b" 965
963
964

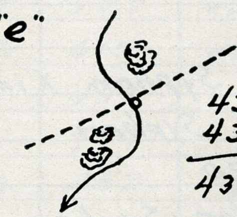
"c" 1753
1753
✓

"d"



882
881
(870)
881

"e"



430
432
431

P. Bauman
COMPUTER

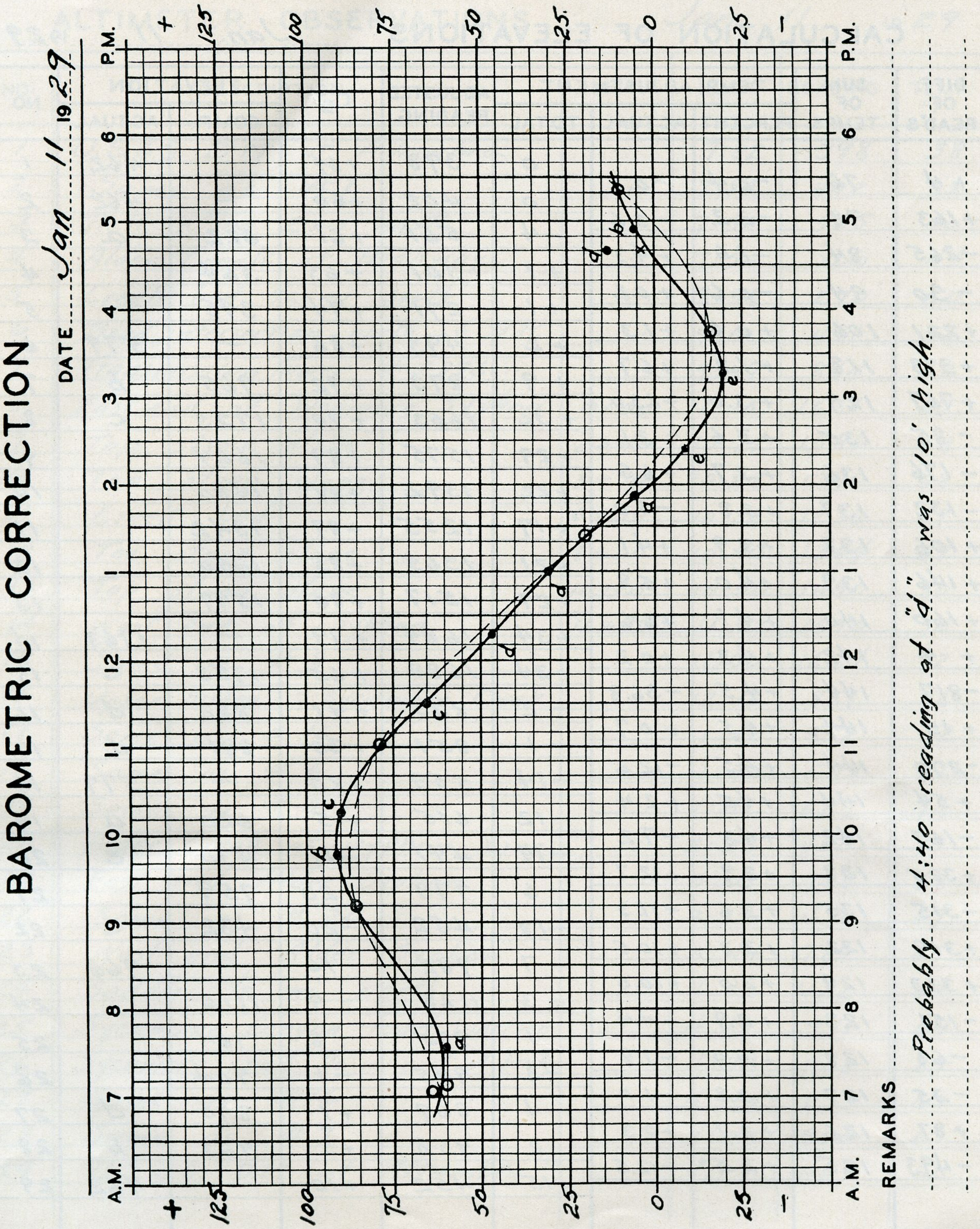
J. Jewett
OBSERVER

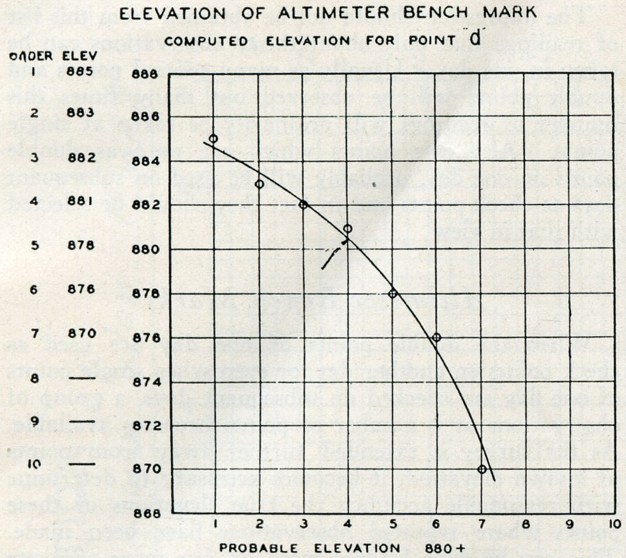
ALTIMETER OBSERVATIONS Jan 11 1929

NO.	DESCRIPTION	DIST.	HOUR	READING	TEMP. °F
1	U.S.G.S. B.M. at Alhambra		7:02	398	38
2	Same as #1		7:08	402	38
3	R.R. X'ing 2 mi east		7:32	565	40
4	Alder Creek at Highway		7:50	300	44
5	Creek bed 1/2 mi south		8:30	270	50
6	Road intersection north of R.R.		9:10	491	56
7	Transmission tower #2876		9:47	864	62
8	East end of Sycamore Syphon	0+00	10:15	1631	67
9	Top steep slope	2+40	10:22	1546	68
10	Toe steep slope	3+70	10:28	1370	68
11	Creek bed	6+50	10:32	1238	69
12	Toe steep slope	8+60	10:43	1344	69
13	Top steep slope.	10+20	10:56	1490	70
14	West end of Syphon	16+75	11:02	1650	70
15	Same as #8		11:30	1654	72
16	Upper bridge - Sycamore Creek		12:16	837	72
17	Same as #16		1:00	852	72
18	Same as #6		1:25	573	72
19	Same as #3		1:51	627	72
20	Alder Creek at Syphon X'ing		2:25	460	70
21	East end Alder Syphon		3:05	785	68
22	Same as #20		3:18	470	67
23	West end Alder Syphon		3:44	789	65
24	Saddle 1/2 mi north		4:12	1122	64
25	Sycamore Canyon road junction		4:18	971	64
26	Sycamore road 1/2 mi east of bridge		4:32	908	64
27	Same as #16		4:40	873	63
28	Same as #7		4:55	960	63
29	U.S.G.S. B.M. at Alhambra		5:21	467	62

CALCULATION OF ELEVATIONS Jan. 11 1929

DIFF. OF READ'S	SUM OF TEMPS.	TEMP. ADJUSTMENT			ADJUSTED READING	C_B	ELEVATION		NO.
		PERCENT	ACTUAL	TOTAL			COMP.	ACTUAL	
				0	398	+64	—	462	1
+4	76	−2.4	−0.1	0	402	+60	—	462	2
+163	78	−2.2	−3.6	−4	561	+61	622	a	3
−265	84	−1.6	+4.3	+1	301	+63	364		4
−30	94	−0.6	+0.2	+1	271	+74	345		5
+221	106	+0.6	+1.3	+2	493	+86	—	579	6
+373	118	+1.8	+6.7	+9	873	+92	965	b	7
+767	129	+3.0	+23.0	+32	1663	+90	1753	c	8
−85	135	+3.6	−3.1	+29	1575	+89	1664		9
−176	136	+3.7	−6.5	+22	1392	+88	1480		10
−132	137	+3.8	−5.0	+17	1255	+87	1342		11
+106	138	+3.9	+4.1	+21	1365	+85	1450		12
+146	139	+4.0	+5.9	+27	1517	+80	1597		13
+160	140	+4.1	+6.6	+34	1684	+79	—	1763	14
+4	142	+4.3	+0.2	+34	1688	+65	1753	c	15
−817	144	+4.5	−36.8	−2	835	+47	882	d	16
+15	144	+4.5	+0.7	−1	851	+30	881	d	17
−279	144	+4.5	−12.6	−14	559	+20	—	579	18
+54	144	+4.5	+2.4	−12	615	+5	620	a	19
−167	142	+4.3	−7.2	−19	441	−11	430	e	20
+325	138	+3.9	+12.7	−6	779	−20	759		21
−315	135	+3.6	−11.3	−18	452	−20	432	e	22
+319	132	+3.3	+10.5	−7	782	−16	—	766	23
+333	129	+3.0	+10.0	+3	1125	−9	1116		24
−151	128	+2.9	−4.4	−1	970	−6	964		25
−63	128	+2.9	−1.8	−3	905	−1	904		26
−35	127	+2.8	−1.0	−4	869	+1	870	d	27
+87	126	+2.7	+2.3	−2	958	+5	963	b	28
−493	125	+2.5+	−12.5	−15	452	+10	—	462	29


BAROMETRIC CORRECTION
DATE Jan 11 1929
A.M.
7 8 9 10 11 12 1 2 3 4 5 6
P.M.
+ 125 100 75 50 25 0 25 −
REMARKS Probably 4:40 reading at "d" was 10' high.



were secured, there would be a total of seven elevations for point "d," ranging from a maximum of 885 to a minimum of 870. These would be arranged and plotted as shown. A curve drawn through these points indicates that the probable true elevation is between 880 and 881.

A variation of 10 feet between the elevations obtained on different days is to be expected unless a large number of intermediate points and control points are taken. Usually, however, it will be found that most of the values group themselves within a range of about five feet and that only a scattering few lie outside of these limits. Furthermore, on the day corresponding to these scattering values other observations on single points are probably in error to about the same extent and in the same direction, consequently the differences of elevation between successive readings are usually subject to less variation than the absolute readings as determined on different days. However, if such a variation from the probable elevation is of sufficient consequence, the diurnal curve for that day should be re-drawn to conform to the true corrections, and adjustments should then be made of the previously calculated elevations of the single points observed on that day.

Summary

Until the invention of the Paulin Altimeter full advantage could not be taken of the speed and economy of barometric leveling in reconnaissance, topographic and other surveys not requiring a high degree of accuracy. The mercurial barometer, while accurate, is not portable; the ordinary aneroid, while portable, has inherent faults which restrict its application. The Paulin Altimeter on the other hand combines the advantage of accuracy without sacrifice of portability.

While the lag and mechanical variabilities of the older types of aneroids have ingeniously been eliminated, certain physical factors common to all classes of barometric leveling must be taken into account before accurate results can be obtained.

These instruments are calibrated to record differences in elevation when the air temperature is exactly 50° F. Consequently, adjustment of readings is necessary for any other temperature although the instruments themselves are compensated for temperature. The density of air is almost inversely proportional to the absolute temperature, so that at temperatures above 50° F. the air is lighter and a greater vertical distance must be traversed to record the same difference in elevation; the converse is obviously true when the temperature is below the standard of the instrument. For all practical purposes the correction to be applied to the difference in elevation between successive points is equal to plus or minus 0.1% for each degree Fahrenheit that the sum of the temperatures at these points exceeds or is less than 100° F.

Barometer readings after adjustment for air temperature must be further corrected for barometric changes induced by local disturbances, by movement of storm centers, and by the normal diurnal variation which alone is usually sufficient to affect the readings by as much as 100 feet. When these influences are very erratic, close barometric leveling becomes impracticable, but on the great majority of days it is entirely feasible to measure the effect of these extraneous factors. In other words, the corrections to the adjusted readings, which are necessitated by barometric changes, can readily be determined by following out the method which has here been presented.

Whenever accurate results are a requisite, the Paulin Altimeter—or any form of barometer—must be supplemented by a thermometer and a watch, both of which must be read with the same care as the instrument itself. In some types of reconnaissance, however, both temperature and time may be estimated and the necessary adjustments and corrections then approximated.

Where care has been used to avoid the introduction of abnormalities, it has been found that absolute elevations within 1/1000th of the range of the instrument can be expected in the great majority of cases, and that differences in elevation between successive points can be obtained with the same degree of accuracy even though there be greater errors in the absolute elevations.

When used intelligently for the purpose for which it was designed, a Paulin Altimeter will give entirely satisfactory results, but when the attempt is made to displace precision surveys the user has himself to blame for failure. Their accuracy is sufficient, however, to warrant the substitution of barometric leveling in a multiplicity of instances and its extension to new uses.

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