Proceedings of the Iowa Academy of Science

Volume 60 | Annual Issue Article 50

1953

Determination of Altitude with the Aneroid Barometer

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INTRODUCTION

As an integral part of its program of geologic and ground-water studies, the Iowa Geological Survey in cooperation with the United States Geological Survey has for many years systematically collected and analyzed drill cuttings and related information from water wells and other boreholes drilled throughout Iowa. The usefulness of these data is increased greatly by determining the exact location and land-surface altitude of the well sites. As most well samples are collected at approximately 5-foot intervals during the drilling operation and as depth measurements by many well drillers are not precise, land-surface altitudes having an accuracy of 5 feet are satisfactory for most purposes. The time and personnel available for this work prohibits the use of precise leveling instruments on the scale necessary for maximum coverage throughout the State. These instruments, of course, are essential where altitude work of a precise nature is needed in a small area.

A system of altitude determination using an accurate aneroid barometer, calibrated in feet, has been used by the Geological Survey with very satisfactory results for several years. The equipment consists of an altimeter, thermometer, watch, and notebook, and an automobile is used for rapid transportation between stations. Tabulation and correction of field data involve only slight modification of the general procedures recommended by the manufacturer of the instrument. These modifications tend to minimize personal errors and errors inherent in barometic altitude work, so that inexperienced operators are able to make satisfactory altitude determinations after a minimum of instruction. The temperature-correction tables furnished by the manufacturer were used.

Others throughout the State may have need for a rapid and economical method for approximate altitude determinations, and it is hoped that the methods presented here will be useful to them.

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[1]Published by permission of H. Garland Hershey, State Geologist and Director, Iowa Geological Survey, and W. E. Wrather, Director, U. S. Geological Survey.

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Acknowledgment is made to colleagues in the State and Federal Geological Surveys for their helpful criticism and suggestions.

Principles of Operation and Limitations

An understanding of the principles of operation of any instrument and its limitations is essential to obtain maximum results. It is well known that an inverse relationship exists between air pressure and altitude, and it is this relationship that is used in determining altitude by means of the aneroid barometer.

Changes in air pressure are recorded in aneroid barometers as movement of discs forming the sides of one or more evacuated boxes. This movement is very minute for small changes in pressure, and a multiplying linkage is necessary to magnify this movement into usable dimensions. One method of measuring this movement is comparable to use of a scale having a calibrated spring, the elongation of which is a measure of the weight applied. Another method which is used in more sensitive surveying altimeters is a "zero gaging" method similar to that used in the analytical balance in which weights are added to or removed from one side of the balance until the tendency pointer indicates a balance with the unknown weight on the opposing side. Every effort has been made in the manufacture of surveying altimeters to eliminate any lag in the multiplying linkage in the instrument, and apparently this has been accomplished to a remarkable degree.

As use of the aneroid barometer or altimeter for determination of altitude involves measurement of changes in air pressure, all factors which affect air pressure must be taken into consideration. Commonly, a high barometer reading is noted approximately 3 hours after sunrise and a low reading, approximately 6 hours later. A secondary high occurs during the night and a low occurs about sunrise. This fluctuation is known as the "diurnal range fluctuation" and causes an apparent variation in altitude readings of approximately 50 feet during a day. Weather changes caused by the passing of a major storm also result in barometric changes which could introduce large errors in altitude determinations. These barometric fluctuations generally proceed at a relatively slow rate and can be corrected for without much difficulty. Other barometric fluctuations that take place are very local and erratic and occur rapidly. These fluctuations are caused by such things as thunderstorms, local topography, and convection currents due to uneven heating of the earth's surface. These fluctuations are the most difficult to correct for, but the methods to be described minimize their effect.

The mechanism of surveying altimeters is not affected by temperature as long as the instrument temperature is uniform, but the effect of temperature on air pressure must be considered if optimum results are to be obtained. Most altimeters are calibrated to measure correct differences in altitude at 50°F, or a temperature of 510 Fahrenheit degrees above absolute zero. If air were a perfect gas, its density at any temperature would be inversely proportional to its absolute temperature. As air is not a perfect gas, the rate of change in density is approximately 0.2 percent per degree above or below 50°F. If the temperature of the air is above 50°F, its density is lessened, and to record a given difference in altitude a longer column of air must be traversed. On the other hand, if the air temperature is below 50°F, its density is greater, and to record a given difference in altitude a shorter column of air must be traversed.

Field Procedure

In order to utilize the maximum amount of time in the field for determining altitudes, as much of the preliminary work as possible is done in the office. Material is usually organized on a county basis or other convenient arrangement. Points where altitudes are desired are located as accurately as possible. An approximate location, with the landowner's name, is usually furnished with drill cuttings. With this information, it is often possible to make somewhat detailed locations from county landownership plats.

A great amount of time in the field usually can be saved if the availability of benchmarks is known. There are several types of benchmarks throughout the State which are of sufficient accuracy for use in altimeter work. Topographic maps are available for some areas of the State, and in these areas benchmark data used in the mapping are useful. A publication, "Altitudes in Iowa," is available in limited number from the Iowa Geological Survey. This publication lists altitudes at all railroad stations in the State as well as many U. S. Coast and Geodetic Survey and U. S. Geological Survey benchmarks. Other benchmarks that are usually available for any particular area are those of the State Highway Commission and some county engineers' benchmarks. In some counties in the State, Iowa Geodetic Survey benchmarks are available, but altitudes have not been reported for many of these. Along the Missouri and Mississippi Rivers, many U. S. Corps of Engineers benchmarks are available but often are not readily accessible. In the selection of benchmarks for use in altitude traverses, care should be exercised to see that the altitude datum of the benchmark is known.

In the interest of the greatest possible accuracy, several steps are taken to minimize the effects of natural barometric and temperature fluctuations. Traverses are planned for completion in the shortest possible time between benchmark readings. It has been found that if the elapsed time between benchmark checks is limited to approximately half an hour, much of the uncertainty in applying barometric corrections can be eliminated. Two readings are made at all stations of unknown altitude during the traverse also to eliminate uncertainty in applying barometric corrections. The time and temperature are recorded carefully at each station.

JASPER COUNTY — SEPTEMBER 9, 1952

WEATHER - CLEAR, QUIET

Station	Time	Reading	Temp. °F.	Diff. in Elev.	Temp. Corr.	Total Corr.	Adjusted Reading	Bar. Corr.	Elevation
BM 1	8:45	845	59	-5	0	0	845	-3	842
BM 1	8:50	840	59	+102	+2	0	840	+2	842
Sta. 2	8:53	942	59	-7	0	+2	944	+5	949
Sta. 3	8:57	935	60	-107	-2	+2	937	+10	947
BM 1	9:03	828	60	+103	+2	0	828	+14	842
Sta. 2	9:06	931	60	-3	0	+2	933	+16	949
Sta. 3	9:10	928	61	+14	0	+2	930	+18	948
BM 4	9:15	942	61	-12	0	+2	944	+19	963
BM 5	9:21	930	61			+2	932	+13	945

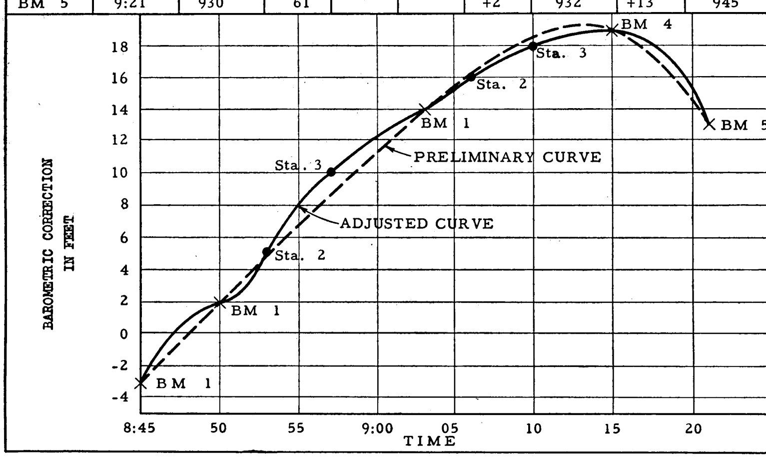

Figure 1. A form showing a convenient method of tabulating field data and computing temperature and barometric corrections.

Figure 1 represents a form found useful in tabulating a typical altitude traverse and indicates the method of computation. The traverse is started at a benchmark where two readings are taken approximately 5 minutes apart to establish the barometric trend. The time that the readings are taken, and the air temperature, are recorded at the benchmark and at all succeeding points of unknown

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
	+50°	0	0	0	0	0	0	0	0	0	0	0	0	0	0
+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
+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
+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
+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
+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
+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
+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
+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
+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
+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
+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
+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
+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
+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
+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
+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
+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
+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
+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
+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
+ 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
+ 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
+ 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
+ 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

Figure 2. Average air-temperature correction, in feet.

altitude. The traverse is then continued as rapidly as possible to the stations of unknown altitude, and a return is made to the same or another benchmark. The traverse is then repeated, ending again at a benchmark. The computations may be completed after each traverse, but when many altitudes are to be determined it is found more practical to complete the computations at night or on days when weather conditions are unfavorable for field work.

Temperature corrections are calculated for apparent differences in altitude between succeeding stations, so for convenience these differences are recorded on a line between successive readings. These differences are expressed algebraically—that is, plus when the instrument is carried to a higher altitude and minus when going down. The temperature corrections are then selected from figure 2, tabulation of temperature corrections covering the ranges of temperature and differences in altitude generally encountered within any given area of the State. As all temperature readings in the example were above 50°F, the corrections are expressed so as to add algebraically to these differences. The corrections, being cumulative, are totaled under the column headed Total Temperature Correction to give the correction applied to each reading. These corrections are then added to the original readings to give an altitude reading adjusted for temperature. Had any of the air-temperature readings been below 50°F, the temperature correction would have been expressed algebraically so as to subtract from the difference in altitude, and the computation of the adjusted reading made as described.

A graphical method is used to determine the barometric correction applied to the adjusted readings. As the altitudes of the benchmarks used are known, the barometric corrections, which are the differences between the adjusted readings and the true altitudes for these stations, are tabulated. These corrections are plotted against time on a rectangular coordinate graph paper of suitable scale. A line through these points gives a preliminary barometric-correction curve. The barometric corrections for the stations of unknown altitude are then plotted on the preliminary correction curve at the appropriate place on the time scale. These corrections are then applied to the temperature-adjusted readings. As two readings were made at each station of unknown altitude during the traverse, the preliminary curve can then be adjusted if a difference in the result is apparent. The final barometric-correction curve should then contain all the barometric corrections and in practice usually involves only slight modification of the preliminary curve.

Conclusion

In order to increase the usefulness of subsurface geologic and hydrologic data from wells drilled throughout the State, a rapid method of determining approximate land-surface altitudes was needed. A technique employing an altimeter, an adaption of the aneroid barometer, has been found satisfactory.

The accuracy of the altitudes obtained has, in most cases, fallen within 0.001 of the calibrated range of the instrument, as indicated by the manufacturer to be possible. The instruments in use in Iowa have a calibrated range of –760 to +3,600 feet, which should give an accuracy within 5 feet. Such results have been generally obtained by different operators working independently.

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