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SIMPLE METHODS and TABLES for DETERMINING TRUE MERIDIAN.

By

Howard J. Teas.

A

THESIS

Submitted to the faculty of the

UNIVERSITY of MISSOURI SCHOOL of MINES and METALLURGY

In partial fulfillment of the work required for the

Degree of

BACHELOR of SCIENCE in CIVIL ENGINEERING

Rolla, Mo.

1917.

Approved by Elmo G. Harris
Professor of Civil Engineering.

{Creditable for a one-man first study - Should be followed by more elaborate study. E.G.H.

29423

MSM
HISTORICAL
COLLECTION

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LIST of ILLUSTRATIONS.

INTRODUCTION:

The ordainary methods of determining the true meridian by observation on either Polaris or the sun are so tedious to calculate that most surveyors and students dread making them. Observation on Polaris at either elongation or clumination require less calculation and are much simpler, but this simplicity is offset by the fact that they must be taken at an exact instant. If a cloud crosses the sky at that time, the surveyor has to wait until the next night. Then again the observer must know the date, exact longitude and latitude and correct time for making the observation, and these are not always known in the field.

The method described herein was suggested ~~to me~~ by Professor Harris. Briefly, it consists of taking a complete sunset to sunrise set of observations of the total angle between Urser Minor Polaris and Urser Minor β and the corrosponding angle between Polaris and the known time meridian.

These angles were plotted to a large scale and connected up with a smooth curve. Then the table shown on page (21) was constructed from this chart.

Determining the meridian by the use of this table possesses several very distinct advantages over the common methods-

First, the table may be used independant of the date, time of night, or longitude of the observer.
Second, with the table, the meridian may be determined without any calculations whatever. This fact makes this method particulary adapted to railroad surveying and topography, mining, geology and exploration maping.

COMMON METHODS of DETERMINING MERIDIAN WITH a SURVEYORS TRANSIT.

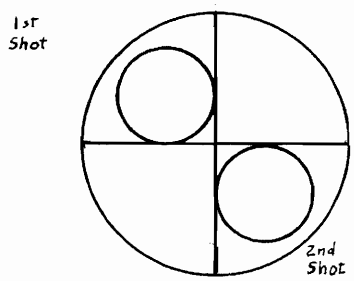
SOLAR OBSERVATION.

Procedure.

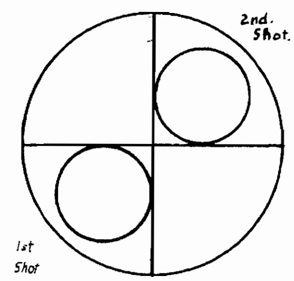
FIRST. Set the transit up over a point where shadows will not interfere, sometime between 9and 11 A.M. or 2 and 4 P.M. and sight on a reference point with the verner set at zero.

SECOND. Focus the image of the sun and the cross hairs on the back of the note book or on a white card as shown below.

Before noon



After noon



THIRD. Make two successive shots, once with the transit normal and once inverted, not over five minutes apart and record the exact time, horizontal and vertical angles of each. After each shift bring the bubble on the telescope to zero and read the vertical verner. Record the data as shown in the following example.

FOURTH. Average the results obtained as shown in the example.

FIFTH. With the longitude of the place and the local time of observation known, change the local time of the observation to Greenwhich time by adding algebraically to the former the difference in time between the place and Greenwhich. This procedure may best be explained by the following example.

SIXTH. Correct the average vertical angle by subtracting the correction for refraction from it. This correction is equal to 55" times the cot. of the vertical angle.

SEVENTH. Calculate the bearing of the time from the instrument to the point observed by the following formula.

$$\text{Cos.A} = -\frac{\text{Sin D.}}{\text{Cos.N} \times \text{Cos.L}} - \text{Tan.N Tan.L}$$

Where D = Declination of the sun.

N = Corrected altitude of the sun.

L = Latitude of the observer.

The sign of the first term in the second half of the equation will be minus if the declination is south, and the second term will be plus if the latitude is south. If the Cos.A is plus, the azimuth is between 0 and 90 as measured from the north; if minus, it is between 90 and 180.

EXAMPLE.

Observations made on the afternoon of March 9, 1917 by H. J. Teas. Transit set on pointX on the track sighting at transit point in north window of jym.

Field Notes.

Tel	Sun	Horizontal Verner		Vertical Verner		Date & Time.
		On mark	On sun	On sun	Bub. at 0	Mar. 9 1917
Norm		00° 00'	85° 35'	36° 35'	0° 01'	2: 34P:M.
Inv.		00° 00'	87° 25'	35° 24'	0° 01½'	2: 44P:M.
Av.		00° 00'	86° 30'	35° 59½	0° 01¼'	2: 39P:M.

Av. Vert. angle corrected for bubble 36° 00' 45"

KNOWN Latitude of Rolla 37° 57' 15" N.

Longitude of Rolla 92° W.

FROM the CURRENT SOLAR EPHEMERIS.

Apparent Declinational Greenwhich noon. 4° 6' 15"

Difference for one hour. 58.56"

Equation of time to be added to apparent time 10' 45.75"

Difference for one hour. 0.635"

CALCULATIONS.

Time at Rolla 2h 39'

Correction for Long. 6h 08'

Time corrected 8h 47'

Hourly change 58.56"

Change for $8^\circ 47' 58.56'' \times 8.783'' = 8' 34''$

Decl. at Rolla Decl. at Greenwhich x change for corrected time $4^\circ 36'15'' \times 8' 34'' = 4^\circ 44'49''$

Correction for Refraction= -Cot. Vert. angle x $55'' = -\text{Cot.}36^\circ 00' 45'' \times 55'' = -1'15.67''$

Vertical angle corrected $36\ 00'45'' = -0^\circ 1'15.67''$ $35^\circ 59' 29.33''$

$$\text{Cos. A.} = \frac{\text{Sin Decl.}}{\text{Cos Lat x Cos Alt.}} - \text{Tan Lat x Tan Alt.}$$

(1) (2)

$$= \frac{\text{Sin } 4^\circ 44'49''}{\text{Cos } 37^\circ 57'15'' \times \text{Cos } 35^\circ 59'29.33''} - \text{Tan } 37^\circ 57'15'' \times \text{Tan } 35^\circ 59'29.33''$$

(1)

Log Cos 37° 57'15"	9.896802 - 10
Log Cos 35° 59'29.33"	9.908019 - 10
	19.804821 - 10
Log Sin 4° 44'49"	19.917793 - 20
	9.804821 - 10
Log (1)	10.112972 - 10
(1)	-0.12971
Log Tan 35° 57'15"	9.860530 - 10
Log Tan 37° 59'29.33"	9.892676 - 10
Log (2)	19.753206 - 10
(2)	-0.56651
	-0.12971
	- 0.69622

Nat Cos A -0.69622

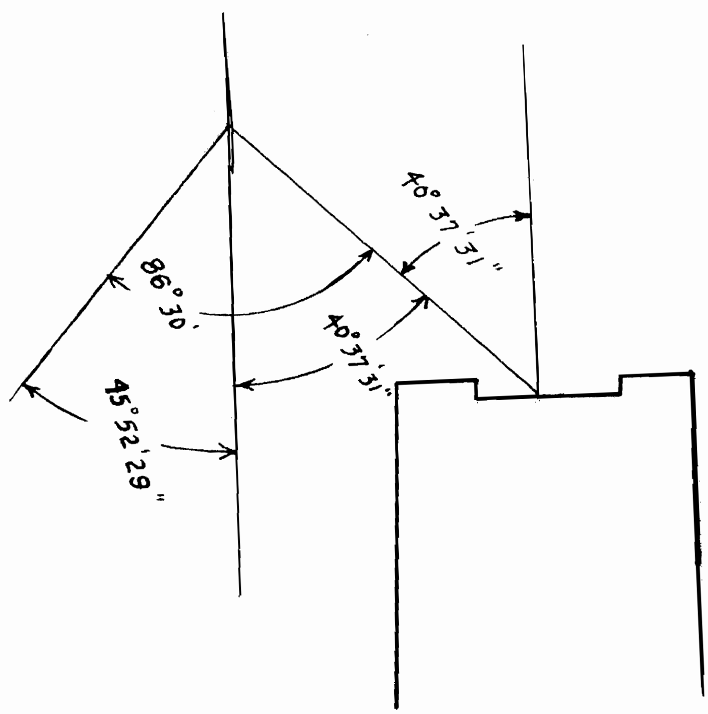
A 45° 52'29"

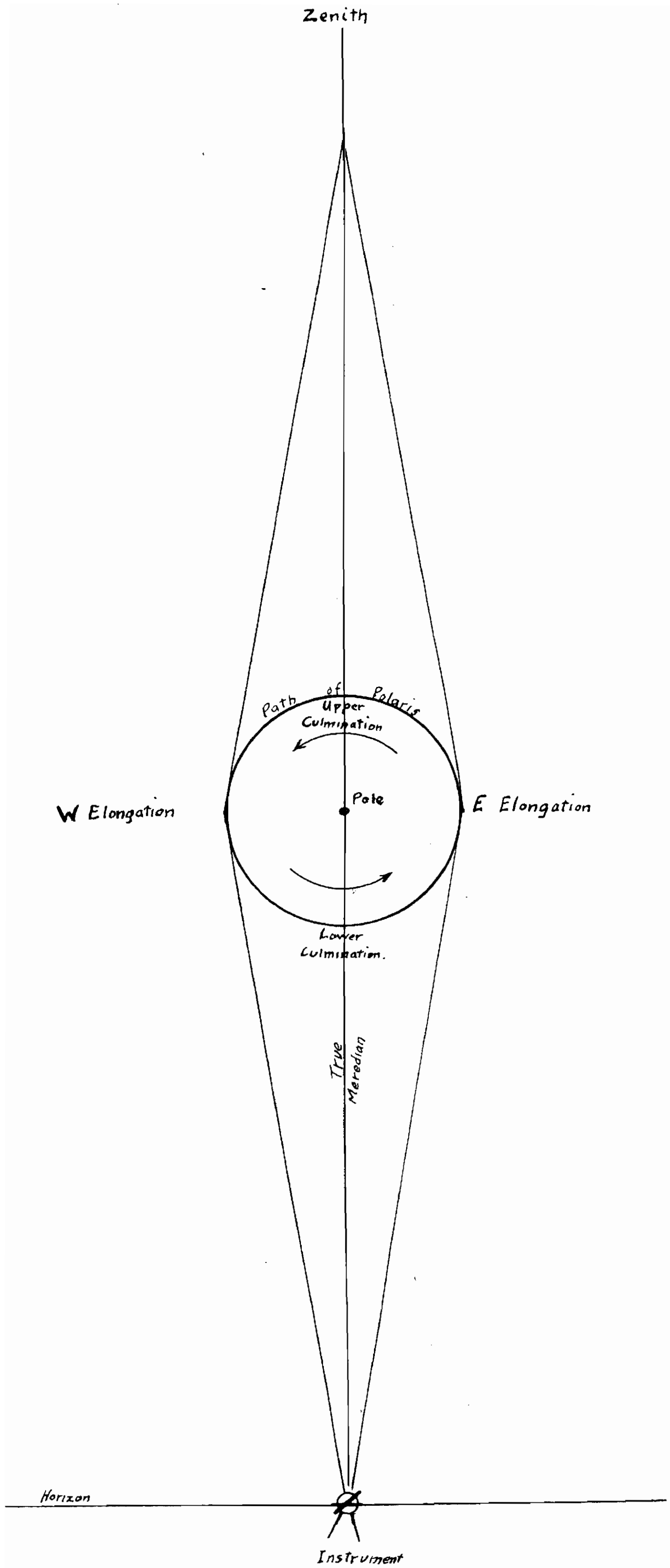
Av. Horiz. Angle =

86° 29' 60"

45° 52' 29"

40° 37' 31"




Zenith
Path of Polaris
Upper Culmination
Pole
W Elongation
E Elongation
Lower Culmination.
True Meredian
Horizon
Instrument

By OBSERVATION on POLARIS at CULMINATION.

PROCEDURE.

FIRST. Complete the exact time of culmination by reference to the table given on page (20).

SECOND. Get the exact local time from the telegraph station.

THIRD. Set up the instrument over a station about 20 minutes before the calculated time of culmination for that date.

FOURTH. Start following Polaris with the tangent screws a minute or so before this time.

FIFTH. Clamp the instrument at the EXACT calculated time.

SIXTH. Check the observation by IMMEDIATELY lowering the telescope and sighting on either Cassiepeia Delta or Ursia Major Zeta. These two stars are in the same vertical plane with Polaris and the pole at culmination. (For the relative position of these stars, see page (12)).

SEVENTH. Depress the telescope and set a tack in a stake a hundred feet or more away.

Then the line from the plumb bob to this point is the true meridian.

By OBSERVATION on POLARIS at ELONGATION.

PROCEDURE.

FIRST. Find the bearing of Polaris at elongation. This may be found by interpulating the table on page (19) or by substituting in the following formula:

$$\text{Sin. Stars True Bearing} = \frac{\text{Sin. Polaris Dist. of Star}}{\text{Cos. Latitude of Observer}}$$

The mean polar distance of Polaris for the next four years is shown in the following table.

MEAN POLAR DIST. of POLARIS.

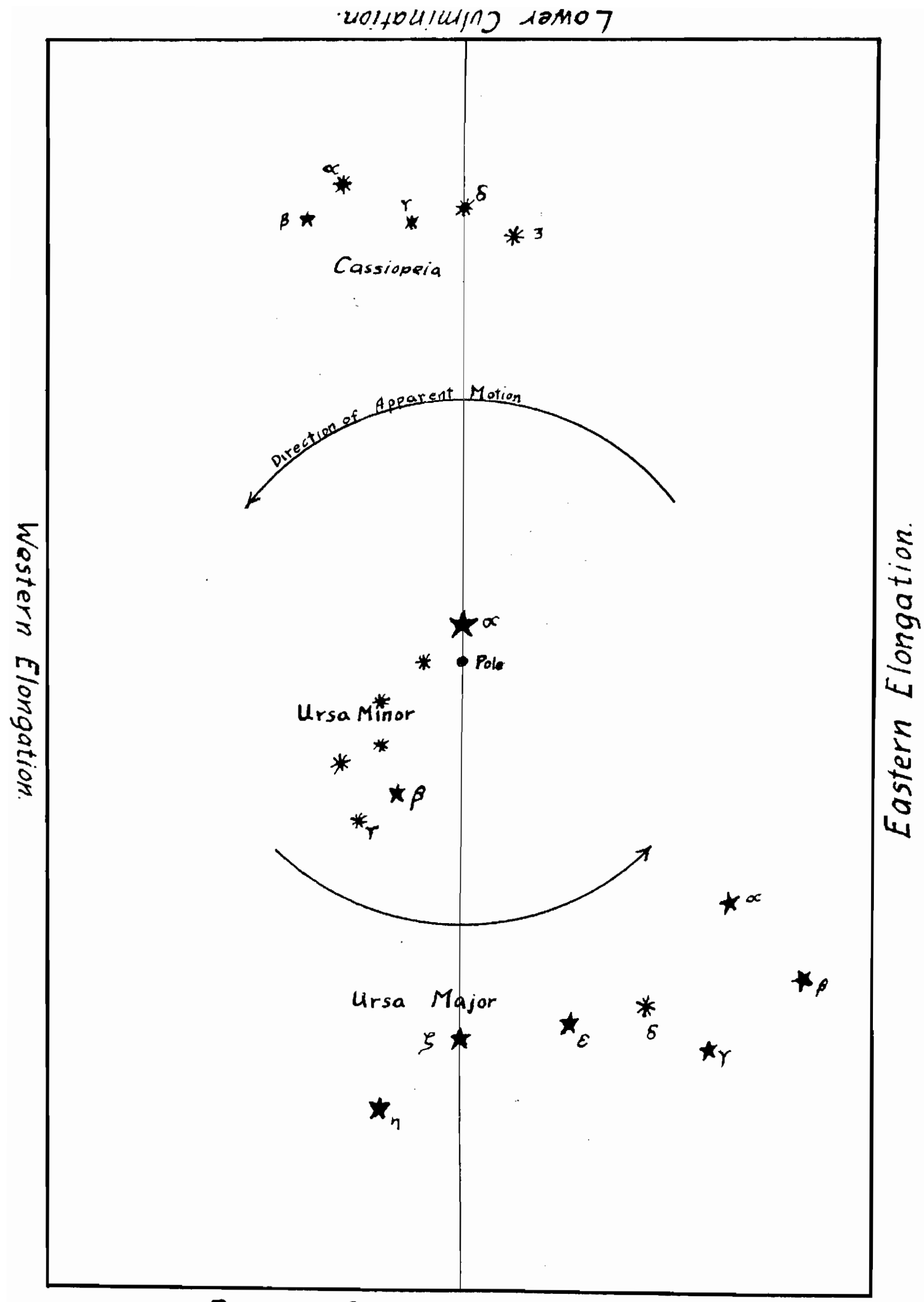
Year	Mean Polar Dist.		
1917	1°	08'	16.45"
1918	1°	07	57.94
1919	1°	07	39.45
1920	1°	07	20.98

EXAMPLE. For Rolla. (Lat. 37° 57' 15") in 1917.

$$\text{Sin True Bearing of Polaris} = \frac{\text{Sin } 1^\circ\ 08'\ 16.45''}{\text{Cos } 37^\circ\ 57'\ 15''}$$

$$= 1^\circ 26'\ 38''$$

SECOND. Find out the approximate time of eastern or western elongation. This may be done either by looking up from the table on page (20) the time of culmination and either adding or subtracting 5 hrs. 55' for eastern or western elongation or merely observing the stars on the night before. At either elongation, Polaris, Urser Major Zeta and Cassiopeia Delta are at the same altitude.



Position of Constellations when Polaris is at Upper Culmination.

THIRD. Set up the transit over a point where a clear view of the sky to the north may be obtained about thirty minutes before elongation. Sight on Polaris with the vertical cross-hair and follow along it with the cross motion until Polaris appears to move either down or up the cross-hair without changing its azimuth for five minutes or so.

FOURTH. Depress the telescope and set a tack in a stake about a hundred feet from the instrument.

FIFTH. Check the point by another sight on Polaris, with transit Telescope inverted. This is possible because Polaris apparently does not change its azimuth for about ten or fifteen minutes at elongation.

SIXTH. Sight on the point just set with the verner at zero and turn off the azimuth of Polaris obtained above to the east or west by the following rule.

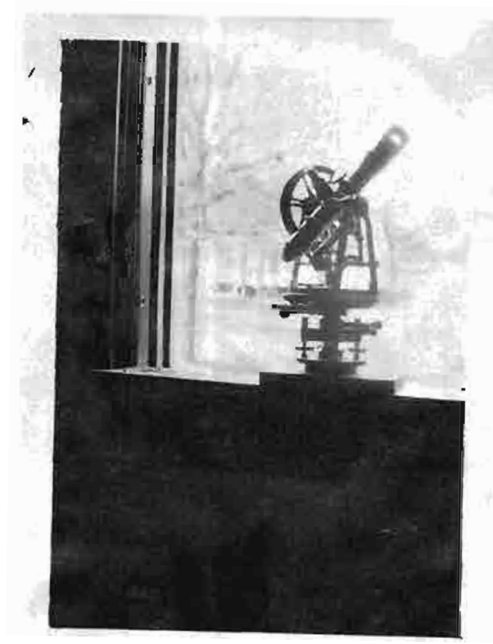
When Polaris is at west elongation, (the dipper in the east), turn the angle of the azimuth to the east to locate true north.

When Polaris is at east elongation,(the dipper in the west), turn the angle of the azimuth to the west to locate true north.

MISCELANEOUS METHODS.

There are several other methods of more or less accuracy which are sometimes used, but none of them are of any importance. Among these are observations on Polaris at any time, which are made and calculated like solar observations; observations of the sun, Polaris, or some other prominent star at equal altitudes near culmination; etc. These methods are seldome used and will not be described here.

The solar telescope method is not discussed as it requires additional apparatus.



PHOTOGRAPH SHOWING MOUNTING of the TRANSIT.

PROCEDURE FOLLOWED in OBSERVATION.

A transit base was first mounted in the north window of room 11 of Jackling Gymnasium. A transit was then set up on a point X near the running track and a solar observation made to determine the bearing of the line from X to the transit point. A stake was then set about 200 ft. up the road from the window and a tack set in it to give the true north. This point was then checked by two independent observations on Polaris at elongation as described above.

On the night of April 12, a set of observations were made covering a period of six hours beginning at dusk. The procedure was as follows: A light was first set up on the meridian point and the transit sighted on this point verniers at zero. The cross-hairs were illuminated with a light from a reading lamp. Polaris was then sighted and the vernier read and the reading recorded, showing wether it was east or west. Then Ursa Minor Beta was sighted, its bearing recorded and the difference in time between the two shots noted. This was repeated every five minutes. Sighting on Polaris and Ursa Minor Beta alternately and recording the time of each observation. On the night of April the 21, a complete set of observations were made from dusk to daylight. The procedure was the same as before, except that when Ursa Minor Beta was near its upper culmination observations were taken on it.

every two minutes, as it was changing its azimuth so rapidly that less frequent shots would not give enough points to plot a smooth curve.

This data was then plotted to a large scale on coordinate paper, with the vertical scale of 1/10 inch equal to one minute of time, and the horizontal scale of 1/10 inch equal to one minute of angle. This large horizontal scale was made possible by plotting sections of the curve two degrees in length at a time. A smooth curve was drawn thru the points. Next the bearing of Polaris for even degrees and minutes of total angle between Ursa Minor Beta and Polaris was taken from the chart with a scale and the values tabulated. See page (21).

In making the observations, a good deal of difficulty was experienced in locating and recognizing the stars quickly enuf so as not to allow any appreciable time to elapse between any pair of shots. Polaris is compartively easy to recognize because of its brilliancy and also because of a small star about a half a minute away which appears in the field of the transit at the same time that Polaris is sighted. It was much more difficult, however, to locate and recognize Beta because of the proximity of Gamma which forms the lower outer corner of the little dipper. Thru the transit, these stars are very difficult to distinguish one from the other, especially when Beta is near culmination. It is therefore advisable to make the observation as early in the evening as possible.

RECOMMENDATIONS for FURTHER STUDY.

On account of the authors having to work alone and because of a long series of cloudy nights, the table is not complete, and has not been thoroughly checked. The author therefore suggests that a further study be made, and to facilitate efficient work offers the following recommendations as the result of his experience.

FIRST. That the subject be taken up by two or three investigators insted of one.

SECOND. That the meridian used be checked by every known method so that the investigators will be sure that it is as accurate as can be located with a transit.

THIRD. That two transits be used for the observations. They should be mounted in two adjacent windows, so that they will not interfere with each other. One observer should be stationed at each instrument and each follow with the transit one star continuously. In this way simeltaneous readings can be taken, which will permit the using of a much smaller vertical scale for ploting the results. It is of course needless to say that the instruments should be in the best of adjustment before use.

FOURTH. That the observations be made early in the year, so that as long as a set of readings as possibly may be made.

TABLES.

MISSOURI SCHOOL OF MINES

AZMUTH of POLARIS at ELONGATION.

Lat. N.	Year							
	1917		1918		1919		1920	
5°	1°	8.5m	1°	8.2m	1°	7.9m	1°	7.6m
10	1	9.3	1	9.0	1	8.7	1	8.4
12		9.7		9.4		9.1		8.8
16		11.0		10.7		10.4		10.1
18		11.8		11.5		11.1		10.8
20	1	12.6	1	12.9	1	11.9	1	11.6
22		13.8		13.4		13.1		12.7
24		14.8		14.5		14.1		13.8
26		16.0		15.7		15.3		14.9
28		17.4		17.0		16.7		16.3
30	1	18.9	1	18.5	1	18.2	1	17.9
32		20.5		20.1		19.8		19.4
34		22.4		22.1		21.7		21.3
36		24.5		24.1		23.8		23.4
38		26.8		26.4		26.0		25.6
40	1	29.2	1	28.8	1	28.4	1	28.0
42		32.0		31.6		31.1		30.7
44		35.0		34.6		34.1		33.6
46		38.4		37.9		37.5		37.1
48		42.2		41.8		41.3		40.8
50	1	46.3	1	45.9	1	45.4	1	44.9
52		51.0		50.5		50.0		49.5
54		56.3		55.8		55.2		54.7
56	2	02.2	2	1.7	2	1.1	2	00.5
58		9.0		8.4		7.8		7.2
60	2	16.6	2	16.0	2	15.3	2	14.7

FORM Ba
109-10-15-5000 H. P. & S Co.

MISSOURI SCHOOL OF MINES

LOCAL MEAN ASTRONOMICAL TIME of UPPER CULMINATION of POLARIS.

Date.	I9I7		I9I8		I9I9		I920		Diff. for 1 Day
	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Min.
Jan. I	6	45.6	6	47.0	6	48.4	6	49.9	3.95
Jan. I5	5	50.3	5	5I.7	5	53.I	5	54.6	3.95
Feb. I	4	43.2	4	44.6	4	46.0	4	47.5	3.95
Feb. I5	3	47.9	3	49.3	3	50.7	3	52.2	3.94
Mar. I	2	52.6	2	54.I	2	55.5	2	53.0	3.94
Mar. I5	I	57.4	I	58.9	I	00.3	I	57.7	3.93
Apr. I	0	50.6	0	52.I	0	53.5	0	50.9	3.93
Apr. I5	23	5I.6	23	53.I	23	54.6	23	52.0	3.92
May I	22	48.9	22	50.3	22	5I.8	22	49.3	3.92
May I5	2I	54.0	2I	55.4	2I	56.9	2I	54.4	3.92
June I	20	47.2	20	48.6	20	50.I	20	47.6	3.9I
June I5	I9	52.4	I9	53.8	I9	55.3	I9	52.8	3.9I
July I	I8	49.8	I8	5I.2	I8	52.7	I8	50.2	3.9I
July I5	I7	55.I	I7	56.5	I7	58.0	I7	55.5	3.92
Aug. I	I6	48.5	I6	49.9	I6	5I.4	I6	48.9	3.92
Aug. I5	I5	53.7	I5	55.I	I5	56.6	I5	54.I	3.92
Sept. I	I4	47.0	I4	48.5	I4	49.9	I4	47.4	3.92
Sept. I5	I3	52.I	I3	53.6	I3	55.0	I3	52.5	3.93
Oct. I	I2	49.3	I2	50.8	I2	52.2	I2	49.7	3.93
Oct. I5	II	54.3	II	55.8	II	57.2	II	54.7	3.93
Nov. I	I0	47.5	I0	49.0	I0	50.4	I0	47.9	3.94
Nov. I5	9	52.4	9	53.9	9	55.3	9	52.8	3.94
Dec. I	8	49.2	8	50.7	8	52.I	8	49.6	3.94
Dec. I5	7	54.0	7	55.5	7	56.9	7	54.4	3.94

FORM Ba
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TABLES SHOWING ANGLES BETWEEN URSA MINOR α and β and CORRESPONDING BEARINGS of POLARIS.

DIRECTION for USE of TABLE.

Set the instrument up on a clear night where there is an unobstructed view of the north sky. Locate and recognize Polaris and Ursa Minor Beta by the use of the chart on page (12), and note the approximate position, ie wether near upper culmination or elongation, etc. Sight on Beta with the vernier at zero, turn to Polaris and plant the instrument, noting the difference in time between the shots. Read the veriner and correct the angle read for the difference in time between the shots. Take from the proper table the bearing of Polaris corresponding to the angle read. Turn this angle off east or west as shown in the table. Set a stake and tack about a hundred feet from the instrument. The line from the tack to the instrument is then the true meridian.

Total Angle from α to β		Corresponding Angle from α East to Meridian			
20°	58	1°	10′	30″	
	56		9	15	
	54		8	20	
	52		7	40	
	50		7	00	
	48	1	6	25	
	46		5	50	
	44		5	15	
	42		4	45	
20	40	1	4	20	Change of azimuth of Polaris per min. Time 30″
	38		4	00	
	36		3	30	
	34		3	00	
	32		2	30	
	30	1	2	00	
	28	1	1	45	
	26		1	15	
	24		1	00	
20	22		0	30	
	20	1	1	0	
	15	0	59	0	
	10	0	58	20	
	5	0	57	30	
20	0	0	56	45	
19	55	0	56	00	
	50		55	15	

Total Angle from α to β		Corresponding Angle from α East to Meridian			
19°	45′	0°	54′	20″	
	40		54	00	
	35		53	10	
	30		52	25	
	25		51	45	
	20		51	00	
	15		50	30	
	10		49	50	
	5		49	20	
19	0	0	47	30	
18	55	0	48	00	
	50		47	30	
	45		46	50	
	40		46	00	Change 3″ per Min.
	35		45	40	
	30		45	10	
	20		44	5	
	10		43	00	
18	0	0	42	00	
17	50	0	41	30	
	40	0	40	00	
	30		38	40	
	20		58	00	
	10		37	00	
17	0		35	50	
16	50		34	45	

Total Angle Between α+β °	'	Corresponding Angle from α E to Meridian °	'	"	
16°	40'	0°	33'	45	
	30		32	40	
	20		32	00	
	10		31	00	
16	0	0	30	00	
15	50	0	29	20	
	40		28	30	
	30		27	50	
	20		26	45	
	10		26	00	
15	0	0	25	00	Change .7' per min.
14	50	0	24	30	
	40		23	45	
	30		23	00	
	20		22	15	
	10		21	20	
14	0	0	20	50	
13	50		20	00	
	40		19	20	
	30		18	30	
	20		18	00	
	10		17		
13	00	0	16	15	
12	50	0	15	30	
	40		15		
	30		14	15	

Total Angle from α to β °	'	Corresponding Angle from α E to Meridian °	'	"	
12°	20'	0°	13'	45	
	10		12	50	
12	0	0	12	20	
11	50		11	40	
	40		11		
	30		10	30	
	20		10		
	10		9		
11	0	0	8	40	
10	50		8		
	40		7	15	
	30		6	50	
	20	0	6	15	Change .7 ' per min
	10		5	30	
10	0		5		
9	50		4	20	
	40		3	50	
	30		3		
	20		2	30	
	10		2		
9	0	0	1	20	
8	50		1		
	40		0	30	
8	30	0	0	0	

Total Angle from α to β		Corresponding Angle from α W to Meredian			
8°	20′	0°	0′	45″	
	10		1	20	
8	0		1	50	
7	50		2	45	
	40		3	15	
	30		3	45	
	20		4	40	
	10		5	15	
7	0	0	6	0	
6	50		6	25	
	40		7		
	30		7	40	
	20		8	15	
	10		8	45	
6	0		9	30	
5	50		10		
	40		10	30	Change .8 min. per min.
	30		11		
	20		11	30	
	10		12		
5	0		12	30	
4	50		13		
	40		13	30	
	30		14		
	20		14	30	
	10		15		

Total Angle from α to β		Corresponding Angle from α W to Meridian			
4°	0	0°	15′	45″	
4	20	0	14	30	
3	50		16	15	
	40		16	45	
	30		17	20	
	20		17	50	
	10		18	15	
3	0		19		
2	50		19	30	
	40		20		
	30		20	45	
	20		21	15	
	10		21	45	
2	0		22		
1	50		22	30	
	40		23		
	30		23	30	
	20		24		
	10		24	40	Change .[illegible]′ per min. of time
1	0		25		
0	50		25	30	
	40		26		
	30		26	30	
	20		27		
	10		27	30	
0	0	0	28		

BIOGRAPHY.

The following books were freely consulted in the preperation of this work;

Breed and Hosmer- Ptinciples and Practice of Surveying.

Hosmer - Text book of Practical Astronomy.

Coal Miners Hand Book.

INDEX.

DATA.

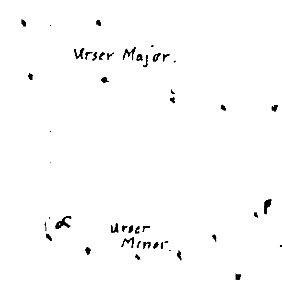
Time 2nd Shot	Time 1st Shot		Vernier Reading.				Total Angle.
			Sighting on Polaris		Sighting on β		
Min.	Hr.	Min.	E.	W.	E.	W.	
57	7	53		1° 12'	19° 48'		21° 00'
02	8	00		1 10'	19 48'		20 58'
06	8	05		1 9'	19 46'		20 55'
11.5	8	10		1 8'	19 45'		20 53'
16.7	8	15		1 7'	19 41'		20 48'
21.5	8	20		1 5'	19 39'		20 44'
26	8	25		1 4'	19 34'		20 38'
31	8	30		1 3'	19 31'		20 34'
36	8	35		1 2'	19 25'		20 27'
41	8	40		1 0'	19 20'		20 20'
46	8	45		0 59'	19 13'		20 12'
51	8	50		0 58'	19 08'		20 06'
56	8	55		0 57'	18 58'		19 55'
00½	9	00		0 51½'	18 35'		19 26½'
06	9	05		0 53'	18 42'		19 35'
10½	9	10		0 51½'	18 35'		19 26½'
16.5	9	15		0 50'	18 20'		19 10'
	9	18			18 7'		
21	9	20		0 49'	18 13'		19 02'
	9	23			18 06'		
26	9	25		0 47.5	18 01'		18 48.5'
	9	27			17 55'		
30.5	9	30		0 46'	17 50'		13 36'
	9	33			17 42'		
37	9	35			17 36'		
	9	37			17 30'		
	9	37			17 30'		
41	9	40		0 42'	17 23'		18 05'
	9	43			17 15'		
	9	45			17 9'		
	9	47			17 2'		
52	9	50.5		0 39'	16 52'		17 31'
57	9	56		0 37'	16 31'		17 08'
	10	03			16 11'		
	10	05			16 04'		
	10	08			15 55'		
11	10	10		0 32'	15 48'		15 20'

Checktins

SKETCHES.

April 21,1917.

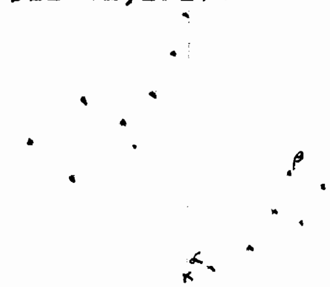
Checked sight on point.



At 9 P.M.

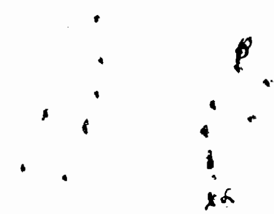
Time 2nd Shot	Time 1st. Shot		Vernier Reading				Total Angle
			Sighting on Polaris		Sighting on β		
Min	Hr.	Min.	Angle to E.	Angle To W.	Angle to E	Angle to W	
16	10	15		0°30' →	15° 25'		15° 55'
	10	18			15 18'		
	10	20			15 10'		
	10	23			14 58'		
26	10	25		0°26' ←	14 50'		51 16'
31	10	30		0 25' →	14 26'		14 51'
	10	33			14 17'		
	10	35			14 08'		
	10	38			13 53'		
41	10	40		0 21' ←	13 46'		14 07'
46	10	45		0 20' →	13 19'		13 39'
	10	48			13 10'		
	10	50			13 02'		
	10	53			12 46'		
56	10	55		0 16' ←	12 38'		12 54'
1.5	11	00		0 14' →	12 06'		12 20'
	11	03			11 58'		
	11	05			11 48'		
	11	08			11 31'		
11	11	10		0 11' ←	11 22'		11 33'
16	11	15		0 09' →	10 51'		11 00'
	11	18			10 39'		
	11	20			10 28'		
	11	23			10 11'		
26	11	25		0 06' ←	10 01'		10 07'
31	11	30		0 03' →	9 25'		9 28'
	11	33			9 13'		
	11	35			9 03'		
	11	38			8 46'		
41	11	40		0 00' ←	8 34'		8 34'
50	11	45	0 02	→	7 36'		7 34'
	11	53			7 14'		
		55			7 05'		
		58			6 45'		
	11	59	0 09'	←	6 39'		
1½	12	00			6 35'		6 25'
6½	12	03	0 09'	→	5 52'		5 42½'

SKETCHES.
Aptil 21,1917.



At 10 P.M.

Checked on point



At Midnight.

Time.			Vernier Reading.				Total Angle.
1st Shot	2nd Shot		Sighting on Polaris.		Sighting on β		
Min.	Hr.	Min.	E.	W.	E.	W.	
	12	08			5° 41'		
	12	10			5 30'		
	12	12			5 17'		
	12	15			4 57'		
	12	18			4 39'		
21½	12	20	0° 16''		4 26'		4° 10'
24	12	23	0 16.5		3 57'		3 41.5'
	12	26			3 46'		
	12	28			3 31'		
32	12	31	0 20'		3 13'		2 53'
35	12	34	0 20½'		2 45'		2 24.5'
	12	36½			2 35'		
	12	38			2 25'		
	12	40			2 10'		
	12	42			1 57'		
	12	44			1 44'		
	12	46			1 31'		
50	12	48	0 26'		1 18'		0 52'
	12	51			0 58'		
	12	50			0 27'		
	12	58			0 11'		
1	1	00	0 30'		0 0'	0 2'	0 32'
10	1	05	0 31'			1 8'	1 39'
	1	12				1 24'	
	1	14				1 37'	
	1	16				1 50'	
	1	18				2 2'	
21½	1	20	0 37'			2 20'	2 57'
26	1	26	0 38'			2 57'	3 35'
	1	38				3 11'	
	1	30	0 42'			3 25'	
36.5	1	35	0 42'			3 58'	4 40'
41.5	1	40	0 43'			4 40'	5 23'
46	1	45	0 45'			5 02'	5 47'
51	1	50	0 46'			5 40'	6 26'
56	1	55	0 48'			6 07'	6 55'
01	2	00	0 49'			6 42'	7 31'
06	2	05	0 51'			7 09'	8 00'
11	2	10	0 52'			7 43'	8 35'
16	2	15	0 54'			8 09'	9 03'

SKETCHES.

April 22,1917.

Checked on point

April 22, 1917.

Time.			Vernier Readings.				Total Angle.
2nd Shot	1st. Shot		Sighting on Polaris		Sighting on β		
Min.	Hr.	Min.	E.	W.	E.	W.	
22.5	2	20	0° 55'	←		8° 51'	9° 46'
26.	2	25	0 57'	→		9 06'	10 03'
36.5	2	30	0 58'	←		10 14'	11 12'
41	2	40	1 01'	→		10 32'	11 33'
46	2	45	1 02'	←		11 02'	12 04'
52	2	51	1 04'	→		11 30'	12 34'
57	2	55	1 05'	←		12 00'	13 05'
01	3	00	1 06'	→		12 16'	13 22'
07	3	05	1 07'	←		12 22'	13 29'
11	3	10	1 08'	→		12 40'	13 48'
16	3	15	1 09'	←		13 32'	14 42'
21	3	20	1 10'	→		13 48'	14 58'
26	3	25	1 11'	←		14 16'	15 27'
31	3	30	1 13'	→		14 34'	15 57'
36	3	35	1 14'	←		15 19'	16 33'
[illegible]	3	40	1 15'	→		15 41'	16 56'
52	3	50	1 16'	←		16 01'	17 17'
56	3	55	1 17'	→		16 08'	17 25'
01	4	00	1 18'	←		16 37'	17 45'
07	4	05	1 19'	→		16 41'	18 00'
12	4	10	1 19.5'	←		17 01'	18 20.5
16	4	15	1 20'	→		17 11'	18 31'
21	4	20	1 21'	←		17 29'	18 50'
26	4	25	1 21'	→		17 40'	19 01'
31	4	30	1 22'	←		17 53'	19 15'
36	4	35	1 23'	→		18 04'	
	4	45	1 24'	→			
	4	50	1 25'	← →			
	4	55	1 25'	←			

Time 2nd shot		Time 1st shot		Vernier Readings				Total Angle
				Sighting on Polaris		Sighting on β		
Min.		Hr	Min	E	W	E	W	
7	38	7	37		1° 21.5'	18° 14.5		19° 39'
	32		32		1 23.5'	18 22'		19 45'
	35		33.5		1 24	18 26.5'		19 50.5'
	41.5	7	40		1 24'	18 38.5'		20 02.5'
	48.5		46		1 24.5'	18 49'		20 13.5'
	54.5		52		1 24	18 56'		20 20'
8	0.5		59		1 22.5'	19 5.5'		20 28'
	9	8	8.5		1 21'	19 15.5'		20 36.5'
	17.5	8	19		1 20.5'	19 26.5'		20 46.5'
	23	8	21.5		1 20'	19 28.5'		20 48.5'
	32	8	31		1 19'	19 36'		20 55'
	36.5		35		1 18'	19 39'		20 57'
	41.5		40		1 17.5'	19 43'		21 00.5'
	46		45		1 16'	19 45'		21 01'
	51.5		50		1 15'	17 47'		21 02'
8	56.5	8	55		1 14'	19 48.5'		21 02.5'
9	01	9	00		1 13.5'	19 49'		21 02.5'
9	06	9	05		1 12'	19 50'		21 02'
9	11	9	10		1 11'	19 49'		21 00'
	16		15		1 10'	19 48'		20 58'
	21		20		1 07.5'	19 47'		20 56.5'
	26		25		1 08'	19 45'		
	31.5	8	30		1 9'	19 17.5		20 55.5'
	38	8	36.5		1 8'	19 45'		20 53'
	41.3	8	40		1 8'	19 42'		20 50'
	46	8	45		1 6'	19 41'		
	52.5	8	40		1 4.5'	19 35'		
	56	8	55		1 2.5'	19 32'		
	1	9	0		1 2'	19 28'		
	6	9	5		1 0'	19 23'		
	11.5	9	10		0 59'	19 15'		
	16	9	15		0 58'	19 11'		
	21	9	20		0 57'	19 21'		
	26.4	9	25		0 55'	18 56'		
	31	9	30		0 54'	18 46'		
	35.5	9	35		0 52'	18 39'		
	41	9	40		0 51'	18 27'		
	46	9	45		0 49.5'	18 18'		

Apbil 2,1917.
April 13, 1917

This data not used.

Time			Vernier Readings			
2nd Shot	1st Shot		Sighting on Polaris		Sighting on β	
Min	Hr.	Min.	E	W	E	W
51	9	50		0° 49'	18° 05'	
56	9	55		0 46'	17 56'	
1	10	0		0 45'	17 40'	
6	10	5		0 43'	17 30'	
11	10	10		0 41'	17 13'	
16	10	15		0 40'	17 1'	
21	10	20		0 38'	16 43'	
26	10	25		0 36'	16 30'	
31	10	30		0 34.5	16 10'	
37	10	35		0 32.5	15 56'	
42	10	40		0 31'	15 30'	
46.5	10	45		0 29'	15 19'	
52	10	50		0 28'	14 50'	
56	11	55		0 25.5	14 39'	
1	11	0		0 24'	14 13'	
9	11	6		0 21'	13 52'	
11.5	11	10		0 20'	13 26'	
16	11	15		0 18'	13 9'	
21	11	20		0 17'	12 40'	
26	11	25		0 15'	12 22'	
31	11	30		0 13'	11 51'	
36	11	35		0 11'	11 31'	
41	11	40		0 10'	10 59'	
46	11	45		0 75'	10 39'	
51	11	50		0 6'	10 7'	
56	11	55		0 3.5	9 44'	
01	12	0		0 2'	9 15'	
06	12	5	0 0'	0 0'	8 49'	
11.5	12	10	0 1'		8 10'	
16.5	12	15	0 4'		7 48'	
21	12	20	0 5.5'		7 15'	
26	12	25	0 7.5'		6 49'	
31.5	12	30	0 9'		6 06'	
	12	35	Lunch	First	Course.	
41	12	40	0 13'		5 8'	
41	12	40	0 13'		5 8'	

Data not used in final curve.

SKETCH.

April 13, 1917.

April 14, 1917.

Time			Vernier Readings			
2nd Shot	1st Shot		Sighting on Polaris		Sighting on β	
Min.	Hr.	Min.	E	W	E	W
51.5	12	50	0° 17'		5° 8'	
56	12	55	0 19'		3 32'	
1	1	0	0 20'		2 51'	
6	1	5	0 23'		2 24'	
12	1	10	0 24'		1 35'	
16.5	1	15	0 26'		1 18'	
21	1	20	0 27'		0 37'	
26	1	25	0 30'		0 10'	
32	1	30	0 31'			0 38'
36	1	35	0 32'			0 56'

Data not used in final curve.

April 14, 1917.

CURVES.