HOW MASON & DIXON RAN THEIR LINE

By Robert Mentzer

The Mason & Dixon line meanders westward for 233 miles. It drifts to 900 feet south of the starting latitude below Gettysburg and gradually climbs to 260 feet north near Cumberland Maryland. It then drifts about 700 feet south of the line above Morgantown before finishing at 400 feet south. At first glance it seems that they didn't do a very good job of surveying. The truth is they did a superb piece of work with the level of scientific knowledge and the scientific instruments of their day. The story of how they ran their line is a tale worth telling.

It began with William Penn being granted land north of the 40th parallel in 1681. Penn desperately wanted a seaport town on the Delaware River. He settled Philadelphia on land that was known to be close if not below the 40th parallel and resisted any official attempts to determine the latitude. The Catholic Calverts of Maryland did not have the court connections to remove him. The dispute simmered for 70 years until a ruling was made very favorable to the Penns. The Pennsylvania-Maryland border was to begin 15 mile south of the original southern boundary of Philadelphia. This is almost 20 miles south of the 40th parallel. The American surveyors had trouble and the Penns and Calverts lost faith in them and asked the Royal Society to recommend someone. In November of 1763 Charles Mason and Jeremiah Dixon arrived in Philadelphia to run the line. They brought their own surveying instruments with them including a state-of–the-art 6-foot zenith sector for measuring latitude. It had been made especially for the survey by the great instrument maker John Bird. This was a vertically mounted telescope that was adjusted with a plumb bob to look at the zenith. The usual instrument for measuring latitude was the sextant. This was smaller and hand held since a fixed instrument was useless on the pitching deck of a ship. The small size of the sextant limited the accuracy to a few miles. Also a sextant looks at the horizon and that is impossible to do in the middle of a forest. The larger, fixed zenith sector could read to 0.1 arc second. This is equivalent to about 10 feet. Instruments seldom reach their theoretical limits. To put this in perspective, the finest star measurements made before the invention of the telescope were by Tycho Brahe around 1600 and were good to about 1 minute of arc. By 1730 the English Astronomer Royal James Bradley was making readings to .5 arc seconds. The Royal Observatory in the 1760's was reporting results to .1 arc second. So the finest instruments in the world at the time of the survey, instruments 4 times bigger that the zenith sector, mounted on stonewalls and surrounded by stone buildings were reading to 0.1 arc second. There is no way that the zenith sector, one-fourth as large, carried over hundreds of miles of road less and often mountainous wilderness, set up on widely varying terrain, and protected by a wood and canvas tent could match this accuracy.

Using The Stars To Find Latitude

The stars are so far away that our motion around the sun can be ignored. Only the spinning earth matters. This spin means stars rise in the east, peak along the north-south meridian and then sets in the west. If a star peaks at 44º today it will do the same every day. Mason & Dixon brought with them star tables prepared by the Royal Observatory. One of the stars they observed to determine the southern boundary of Philadelphia was

Delta Persei. It had a declination of 47º 0' 39.7". This means that if you stand at this latitude the star will cross the north-south meridian at the zenith. Mason & Dixon found that the star passed 7º 4' 11.7" north of the zenith. Only if they would have traveled 7º 4' 11.7" north would Delta Persei cross their zenith. They were 7º 4' 11.7" south of that latitude. Subtracting the 7º value form the declination gave them their latitude.

47º 0' 39.7" - 7º 4' 11.7" = 39º 56' 28.0"

MEASUREMENTS AT PMW

By May of 1764 Mason & Dixon had chained the necessary 15 miles south of Philadelphia and set up the zenith sector to determine the latitude of the westward line they would run. They referred to this location as post marked west (PMW). Over the next month they took readings of 5 selected stars as they crossed their north-south meridian near the zenith. Four of the stars crossed in a 2-hour period. The final star, Capella, crossed seven and one half-hours later. On May 6, 1764 about 3:30 in the morning all was ready. The zenith sector had been aligned on the north-south meridian and plumbed to vertical. Vega was the first to cross at 3:33 A.M. An hour later, at 4:39 Delta Cygnus crossed, 20 minutes before the sun rose in the east. At 5:17 Sadr crossed and finally, at 5:37 A.M., Deneb crossed. It was not until 2:01 P.M. that Capella, a faint dot against the glare of the daytime sky, passed through the field of view of their telescope. Bright stars can be seen in a telescope in the daytime if the scope is aimed at the correct spot. They would repeat their observations at this location over a dozen times in the next month.

Later, as they worked their way west, the spring constellations would be replaced by summer and then fall constellations. In July Vega crossed the meridian near 11 P.M., and Capella near 9:30 A.M. By October Vega crossed at 5:00 P.M. and Capella at 3:37 A.M.

Scatter in the Zenith Sector Data

At PMW, the PLANE EAST values for the star, Deneb, (Alpha Cygnus), ranged from 4º 42' 58.2" to 4º 43' 2.7", north of the zenith. (Table 1) This was a spread of 4.5" or 450 feet. The zenith sector may be able to read to .1 arc sec but in the real world the scatter is in the arc second range. To average out any imperfections in the optics of the telescope they rotated the instrument 180º and took a new set of measurements that they listed under the heading PLANE WEST. These readings showed a similar spread of a few hundred feet. When the east and west values are compared all stars that passed north of the zenith had greater west values and those that passed south of the zenith had greater east values. There were clearly imperfections in the optics. This variation of hundreds of feet could be minimized but not eliminated by averaging the small number of observations.

Running The Line

They spent the rest of 1764 running the north-south Maryland-Delaware boundary. By the middle of March 1765 they were ready to begin to run the line west when 3 feet of snow fell. It wasn't until April 5th that they began the line. The parallel is actually a curving line on a sphere. Surveyors run straight lines. They could have approximated the curve by running a series of short cords but Mason did not trust the measurement of large angles. At that time all angle scales were hand engraved. Angle scales over a small 10º range, such as the zenith sector, could be accurately done. Large scales always had errors. Ramsden would solve the problem with his great circle-dividing machine, but that was 12 years in the future. Mason determined to run a great circle route. Great circles do not curve right or left. They only follow the downward curvature of the earth. Figure 1 shows a great circle route from New York to London. Notice how straight the line is and how the parallels curve away from it and then back to it. Mason calculated that if he started out at an angle of 89º 55' 51" west of north he would be following a great circle that would recross the parallel in about 12 miles. The parallel would curve away from him to the south to a maximum of about 20 feet before curving back to the straight-line great circle after 12 miles. Figure 103a is from Mason's journal.
Since Mason didn't trust a scale with a large angle he devised an astronomical way of determining the angle. The time when a selected star crossed their meridian was noted. Mason had previously calculated how long it would take the star to exactly reach 89º 55' 51" west of north. Near this time the star was tracked with the transit. At the instant it reached the calculated angle the horizontal axis of the transit was locked and the telescope was rotated vertically down to the horizon. One half mile away a worker stood with a candle. He was directed to move the candle until it was in the cross hairs of the transit. The spot was marked and in the morning the line was laid out in that direction. They ran the line for about 12 miles, placing temporary wooden mileposts along the way. At 12.3 miles from PMW they stopped and set up the sector to check their latitude. The sector results showed they were 129 feet north of the starting latitude. They assumed that they had run a straight line and that the error was due to the original angle measurement. Figure 119 is from Mason's journal. The offsets were calculated. Table 2 shows some of the offsets. On their return the offsets would be measured from the temporary wooden posts south to where the milestones would be set. When Mason and Dixon returned to the temporary wooden post that was 12 miles from PMW they measured south 128 feet and placed the permanent stone. If they had been 128 feet north of the line the stone would now be on the line. The stone is actually 193 feet south of the starting latitude. By measuring north 128 feet from the 12-mile stone the location of the temporary post at 65 feet south of the starting latitude can be found. The zenith sector, 0.3 miles west of the 12-mile post, was in error by about 193 feet. By taking the offset values for a stone and measuring back north this value, the original temporary line can be recreated. The green line on graph 2 is the recreated original temporary line. They ran a reasonably straight line at almost the correct angle. Only the zenith sector measurement was seriously in error. They did not drop south 129 feet to continue the line. They had used

the transit to observe the stars to find the 89º 55’ 51” direction at the same time the sector measurements were being made. If they now dropped down it would cost them several more days to find the angle at the new location. They ran this line expecting to add 129 feet to any offsets. At 25.9 miles they stopped and set up the sector. When the sector told them they were 483 feet north they concluded they had run the solid orange line and prepared the necessary offsets. Applying reverse offset to the stones yields the green original temporary line they ran. They had just run a temporary line for 25 miles that stayed about 50 feet south of the line the entire way. Yet due to faulty zenith sector results they placed the stones up to 400 feet south of the true line.

From the 25-mile location they had used the stars to find the 89º 55’ direction. They apparently thought this was too great a distance to offset so they laid off a triangle on the ground to shift the direction south enough that they would return to the true parallel after 11.37 miles. They then ran to 37.2 miles. The work was taking much longer then anyone had expected. It took at least a week to find the latitude with the zenith sector. Mason & Dixon didn’t set up the sector here. They laid off another ground triangle to change the line by 8’ 18” to run a new great circle segment. At 48.8 miles they stopped and set up the sector and found they were 56 feet south. Applying the reverse offsets yields the green temporary line they ran. They thought they ran the orange line shown out to 48.8 miles. The green line that they actually ran parallels the orange line, showing that they had the angles correct. Because they were actually 500 feet further south than the zenith sector results said, the offsets led to the stones being placed over 400 feet south of the line.

Graph 3 shows the line from 45 miles out to 135 miles. They used the stars to find the new direction at 48.8 miles and left from where they thought was 56 feet south. The green line out to 71.5 miles shows they again ran a straight line at the correct angle. The zenith sector value at 71.5 miles was 458 feet north, an error of 909 feet from their actual location at – 451 feet. Applying the offsets drove the stones to about 900 feet south of the line at 71.5 miles. At 71.5 miles they found the new direction from the stars and laid off an angle change on the ground to be back at the true parallel in 11.37 miles. From 71.5 miles to 94.8 miles the green line parallels the orange line showing that they again ran a straight line at the correct angle. At 94.8 miles the zenith sector said they were again 56 feet south, an error of 873 feet. They again found the direction from the stars and made no ground correction since they thought they were only 56 feet from the line. From mile 94.8 they ran to mile 117 and found their latitude. This time the zenith sector correctly told them they were 847 feet south. Since they had again run a straight line at the correct angle, the offsets brought the stones back to the correct latitude at 117 miles. You can actually read off the zenith sector errors from the stone positions. At 117..2 miles the sector correctly tells them they are at 847 feet south so they place the stone 847 feet north, right on the line, so no sector error.

At 117 miles they stopped for the year on October 7, 1765, west of Hagerstown Maryland. Before they left the new direction was found from the stars. On their return, April 1, 1766 they laid off a ground triangle to be back at the parallel after 11.4 miles. They then ran from 117 miles to 129 miles where they changed direction. The orange and green lines parallel, showing they again had the correct direction and ran a straight

line. The run from 129 miles to 140 miles was right along the line. The zenith sector at 140 miles gave a value of 20 feet south. Therefore the offsets were small and the stones were close to the line
They were now in country so mountainous that they could not get the milestones up the steep ridges. More and more they simply piled a stone cairn on the ridge tops. From here on I do not have good data. Graph 4 is mainly taken from USGS topographic maps and converted to NAD83. The results can easily vary by 50 feet. Any conclusions drawn are tentative but I want to show two changes that Mason & Dixon made in running the rest of the line. They next ran from mile 140 to mile 165, set up the sector and found they were 241 feet south of the line. The angle looks good and the line is probably straight with the variation due to poor data. The 1766 season ended at 165 miles and they returned in 1767 to continue the line. This time, they did not start where they had stopped but moved 240 feet north to where the stone was to be placed and where they thought the line was. This fact can be read from the offset tables. Table 3 shows the offset for the milestones on either side of a zenith sector reading. Out through 140 miles the values are close, 128 vs. 149, 374 vs. 380, 450 vs. 442, showing they did not move back to the line. At 165 the values are 231 vs. 10. For the first time they did not use astronomy to find the new angle when starting from a zenith sector station. Instead they laid off a ground triangle. They also ran for 35 miles before setting up the sector at 199.7 miles and finding they were 990 feet north. The green line that they actually ran shows a drift north that was probably caused by an incorrect angle measurement. The error in the zenith sector readings drove the line of stones down to – 500 feet. At 199.7 miles they again moved to where they had placed the stone, and where they thought the true parallel was, and ran from there. They again used a ground triangle, not the stars, for the angle. The green line shows they went off at the wrong angle. The zenith sector at 222.3 miles was off by 700 feet. The data isn't very good for the final 11 mile run but it appears that they had the correct angle this time.

The true cause of the meander-gravity variations

When Mason & Dixon returned to England they told the Astronomer Royal that they felt they had run the line with a spread of no more than 40 to 50 feet. The spreads for the individual stars are a few hundred feet, yet the zenith sector was off by as much as 900 feet. This hints at an underlying problem. At the time Mason & Dixon were working scientists like Henry Cavendish were arguing that proximity to large masses such as mountains could pull the plumb bob off the vertical. With no experimental proof or correction tables Mason & Dixon could only assume that there was no measurable effect. In 1774 the Astronomer Royal was able to detect a difference between two observing sites, one north and one south of a mountain. After correcting for the difference in latitude of the sites an 11 arc second difference remained that was attributed to gravity deflection. Today the United States has been mapped for deflections in gravitational attraction. The National Geodetic Survey has a website where a computer program gives the gravity deflections for a given latitude and longitude.

The deflections for each of the 12 sites where the zenith sector was used were obtained and corrections made to the values. The blue line on Graph 5 shows the zenith sector errors. These are the errors not the readings. At 12.5 miles the reading was 129 ft north but since the actual location was 66 feet south, the error was 195 feet. The red line is the zenith sector errors corrected for the gravity deflections at each location. With the corrections the errors are all within 200 feet. The data beyond 130 miles is not very good and there are some extrapolations to zenith sector locations between stone locations so the red line should be viewed with a little caution. Yet every zenith sector result was improved, except the one at 117 miles that was correct to start with. Suddenly their estimate of only being 40 or 50 feet off the true line looks almost prophetic. Had they had just one modern device, a scientific calculator with the deflection program in it, they would have come very close to achieving their estimate.

How Did The Mason And Dixon Line Get its Name?

The only state boundary named after the surveyors is the Mason & Dixon line. No one thinks about naming boundary lines after the surveyors any more than naming buildings after the construction firms. So how did it get its name? There is very little written on the topic. The Encyclopedia Britannica states that the name came from the debates over the Missouri Compromise in 1820. Another author writes that the famous Virginia Congressman and orator, John Randolph, popularized the term in these debates.

The term actually shows up much earlier. In 1776, only 8 years after the survey, Thomas Jefferson wrote in a letter "….but I wish they would compromise by an extension of Mason And Dixon's line."
In 1779 George Bryan writes to Joseph Reed "….perhaps we would be as well off with Mason and Dixon's line continued."
In 1781 Joseph Reed writes to Jefferson "From the termination of Mason and Dixon's line to the Ohio…"
In 1781 John Dickinson writes "…in the latitude of Mason and Dixon's line…"

All these statements refer to the line as a geographic thing, not a political and show that the term was in common usage by the educated soon after the line was completed.
The biographers of John Randolph state that his Missouri Compromise speeches have been lost. The speeches that he made in 1824 in opposition to a tariff bill that would be very damaging to the South have survived. In one speech he says, "…and then we who belong to that unfortunate portion of the confederacy which is south of Mason and Dixon's line…". In another he states, "…this bill is an attempt to reduce the country south of Mason and Dixon's line…". So 37 years before the Civil War a prominent politician on center stage in Washington is using the term is its modern form.

A logical but tentative conclusion is that Randolph heard the term and, being a great orator, used it as a figure of speech to define the difference between slave and free states.

THEIR LEGACY

Mason and Dixon took a less than perfect zenith sector and transported this delicate scientific instrument over 200 miles of road less and often mountainous wilderness with no discernable loss in accuracy of the instrument. They worked in mosquito ridden summer heat and the snows of spring and fall. They ran the line up mountains so steep that they could not transport the heavy milestones up them and had to pile rocks to mark the line. In spite of the threat of Indian attack in the western mountains they maintained discipline in the group. A twist of fate has made their names famous in American history, yet the excellence of their work shows that they truly deserved to be known as the men who ran THE MASON- DIXON LINE.

TABLE 1

ZENITH SECTOR VALUES AT PMW

PLANE EAST

	A. LYRAE	D. CYGNUS	G. CYGNUS	A. CYGNUS	CAPELLA
	1º 9’ 10.5”	4º 50’ 6.3”	0º 12’ 59.5”	4º 43 0.8”	6º 0’ 29.8”
	10.0	8.0	13 0.0	42 58.2	28.3
	10.5	9.0	12 58.0	43 2.7	29.0
	9.0	11.3	57.0	0.0	30.0
	10.0	9.6	56.0	1.0	29.3
	7.7			1.5	
	5.5			0.5	
	3.8			2.3	
	3.7				
SPREAD (feet)	**680**	**500**	**200**	**450**	**170**

PLANE WEST

	A. LYRAE	D. CYGNUS	G. CYGNUS	A. CYGNUS	CAPELLA
	1º 8’ 59.0	4º 50’ 14.8”	0º 12’ 52.6”	4º 43’ 4.3”	6º 0’ 32.7”
	59.5	15.0	51.0	4.2	32.3
	58.0	15.0	51.0	4.0	31.7
	59.8	15.3	51.0	7.5	32.2
	58.2	16.8	50.3	5.4	
	57.3	16.3	49.8	6.5	
	57.3	18.0	50.0	7.8	
	58.4		49.0	8.0	
			48.0	8.3	
SPREAD	**250**	**320**	**460**	**430**	**100**
WEST AV. VERSUS EAST AV.	**E400**	**W410**	**E490**	**W190**	**W550**

The stars with greater WEST averages passed north of M &D’s zenith, the stars with greater EAST averages passed south of the zenith.

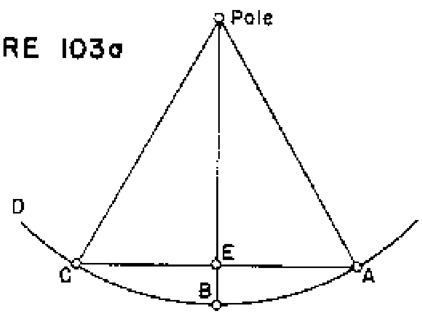
TABLE 2

ZENITH SECTOR OFFSETS AT 12.3 MILES

MILE	ARC OFFSET	DRIFT OFFSET	TOTAL OFFSET
12.3	0	129	129
12.0	2	126	128
10.0	14	105	119
8.0	20	84	104
6.0	21.6	63	84.6
4.0	17.6	42	59.6
2.0	9.8	21	30.8

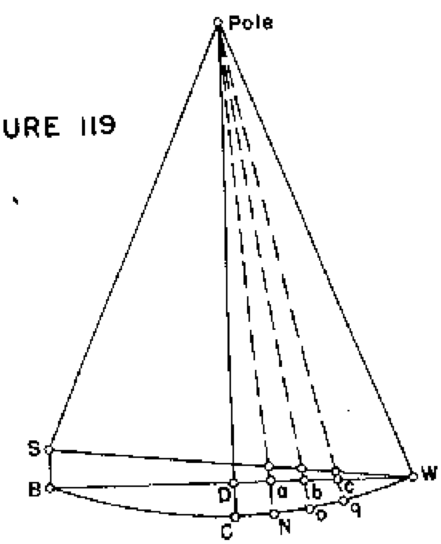
FIGURE 1

FIGURE 103a



AEC = GREAT CIRCLE ABC = PARALLEL EB = ABOUT 20 FEET
ABOUT 12 MILES

FIGURE 119



WS= ASSUMED LINE WB= GREAT CIRCLE WCB= PARALLEL

SB= 129 FEET

TABLE 3

OFFSETS ON EITHER SIDE OF ZENITH SECTOR STOPS

ZENITH SECTOR			
12.31 MI	130 FT. N	12. MI 128 FT-S	13 MI 149 FT-S
25.94 MI	383 FT N	25 MI 374 FT-S	26 MI 380 FT-S
48.8 MI	56 FT S	48 MI 50 FT-N	49 MI 50 FT-N
71.54 MI	460 FT N	71 MI 450 FT-S	72 MI 442 FT-S
94.79 MI	56 FT S	94 MI 52 FT-N	95 MI 61 FT-N
117.16 MI	847 FT S	117 MI 841-N	118MI 783 FT-N
140.2 MI	20 FT S	140 MI 18 FT-N	141 MI 22 FT-N
165.68 MI	241 FT S	165 MI 231 FT-N	**166 MI 10 FT-N**
199.8 MI	990 FT N	199 MI 971 FT-S	**200 MI 2 FT-N**
222.3 MI	357 FT S	222 MI 349 FT-N	**223 MI 10 FT-N**
233.17 MI	223 FT S	233 MI 214 FT-N	