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LINES & POINTS

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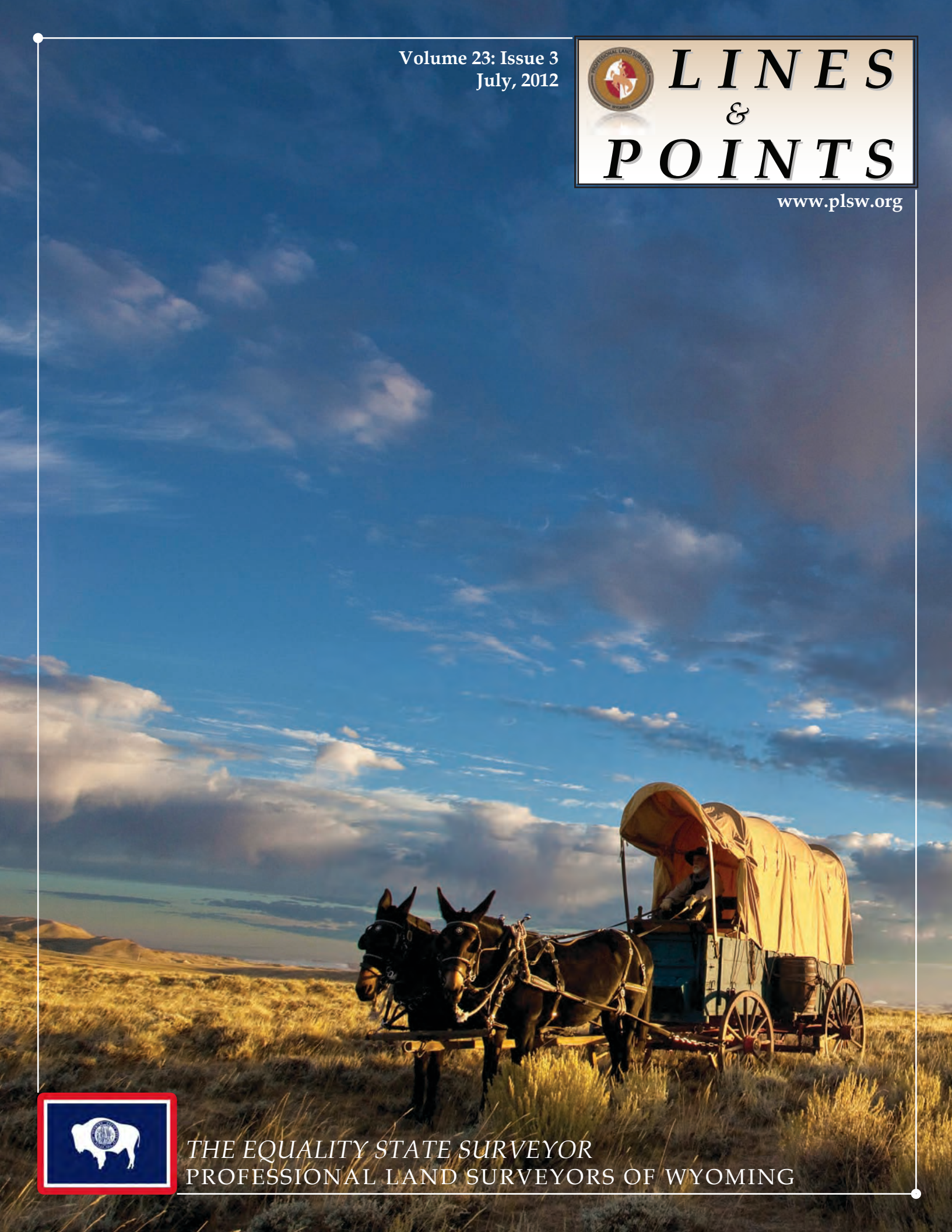
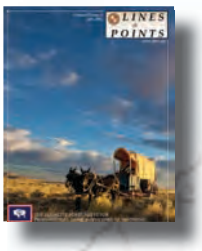


THE EQUALITY STATE SURVEYOR
PROFESSIONAL LAND SURVEYORS OF WYOMING



On The Cover

Oregon Trail at Prospect Ridge
(BLM photo by Bob Wick)

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PLSW (Professional Land Surveyors of Wyoming) is a statewide organization of Registered Land Surveyors licensed to practice in the Equality State of Wyoming. PLSW is dedicated to improving the technical, legal, and business aspects of surveying in the State of Wyoming. PLSW is affiliated with the National Society of Professional Surveyors (NSPS) and the Western Federation of Professional Land Surveyors (WestFed).

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PRESIDENT'S MESSAGE

Greetings all,

As summer hits high gear for us all the only notable issue that has come up since I last signed off is the NSPS merger. I attended the Spring NSPS Governors and Directors meetings in Charlotte, NC the first week of May and during the meeting we were informed that the merger is complete between NSPS and ACSM with only the details needing to be worked. Unfortunately, that will be as task in its self. I have expanded on this issue in the Governor's Report in this current issue

On another note, at the last BOD meeting the Directors were asked to go back to their chapters and work on getting articles for Lines and Points. The chapters have been put on a rotating schedule to provide an article for the publication on a quarterly basis. So if you have a story or experience you would like to share please put it together and get it to your Chapter Vice President or the Lines and Points staff. I would like to personally thank those who have provided the majority of the articles and content over the last couple of years.

Our next BOD meeting is 25th of August via teleconference and the Fall NSPS meetings will be the last week of September in Maryland. If you have any ideas, questions or concerns for the organizations please contact your Directors or Governor so we can discuss them at the next meeting.

Until then please have a safe summer season!!

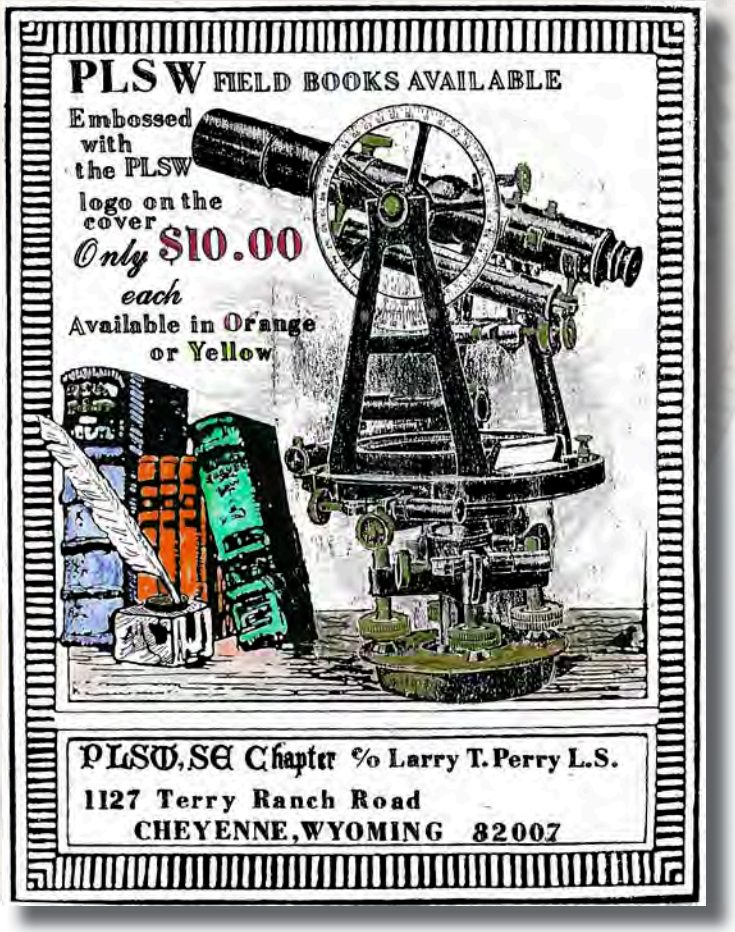
Respectfully,

Cotton D. Jones, PLSW President

ANNOUNCEMENTS

•The Wyoming Engineering Society is soliciting applications for the 2012 President's Project of the Year Award. The award increases the public's recognition of engineering and surveying projects in Wyoming. The guidelines for submission of a project may be found at www.eng.uwyo.edu/societies/wes. Please keep the guidelines in mind during this construction season as the projects progress and are completed so that all necessary documents and photos are compiled. Entries must be received in Laramie on or before Thursday, January 3, 2013. It is encouraged that the guidelines and application form be reviewed to determine a project worthwhile for statewide recognition

•The 2012 Fall Technical Session is scheduled for November 1-2 with speaker Herbert Stoughton, Geodetic Engineer. He will be speaking on "Writing Legal Descriptions for Parcels and Easements", "Overview of Map Projections Used by Surveyors" and "Early History of Public Domain". We are looking forward to another great session.



Governor's Report

We were successful in passing the NSPS 100% Membership dues structure change at the NSPS BOG meeting in Charlotte, NC the first week of May. The NSPS membership dues will now be $40 (down from $225) if an affiliate chooses to go "all in". This change should be affordable for our PLSW membership in order to incorporate NSPS membership as part of the PLSW membership to fulfill the 100% criteria requirement. I will be available for questions throughout this summer in order to sell/explain this program to our membership. If necessary, I will make a motion at our August BOD meeting requesting PLSW to increase 2013 dues to $110; it would then need to be put on the ballot for the 2013 Annual meeting. This program should be acceptable to our PLSW membership considering the value of membership in the national organization, which I will discuss and utilize a power point presentation during Fall Tech or any chapter meetings, etc. Furthermore, increasing the membership in NSPS will potentially add 18,000-plus surveyors and affiliates to the NSPS population, which will increase our lobbying ability in Washington, DC to protect our interests in areas such as LightSquared, etc. (strength in numbers). Also, any member who is a multi-state association member will only be invoiced with a dues increase for his/her state of residence.

We also merged ACSM (as opposed to dissolved) with NSPS in order to protect the ACSM name and mitigate any issues (legal and otherwise) concerning our programs and agreements for ABET, FIG, etc.

Finally, this program will help unify and strengthen every state surveying association throughout the United States and hopefully bring in other associations, such as AAGS and GLIS, in order to preserve, protect, and expand our beloved survey profession into the future and leave a legacy for those who follow in our footsteps. In 1776, a bunch of Virginia surveyors along with other colleagues got together one day and decided to unify and strengthen the loosely affiliated Colonial States and were very successful in their endeavors. We now call that successful program, The United States of America. I believe it's about time for a bunch of surveyors and colleagues to get together again, and get positive and make a stand for the surveying/geomatics profession. I certainly hope you all agree, because to quote Benjamin Franklin, "We must all hang together, or assuredly we shall all hang separately". As always, I welcome any ideas, comments, or suggestions.

Best regards,

Cotton D. Jones, NSPS Governor - Wyoming

Eratosthenes of Cyrene's Contribution to Geodesy

Herbert W. Stoughton
Geodetic Engineer

Eratosthenes of Cyrene was the librarian of the great Museum (Library) in Alexandria (c. 245-180 B.C.). Although few of his writings survive, numerous references to them are found in the writings of others. The geodetic community acknowledges Eratosthenes for developing the method of arc measurement procedure to determine the size of the earth. This paper explores the interpretations of his efforts by nineteenth and early twentieth century authors of geodesy treatises. Although an original copy of Eratosthenes' work has not been found, a first century B.C. copy has been discovered, which is the earliest known edition of the text Measurement of the Earth.

Eratosthenes was born in Cyrene [Lybia], the major city of the Pentapolis (also called the capital of the Cyrenaica), about 275 B.C. An eleventh century document lists the date as the 126 Olympaid (276-273 B.C.). His father is thought to have been Aglaus or Amrosius. A tenth century enclylopedist stated that Eratosthenes was a pupil of the philosopher Ariston of Chios, the grammarian Lysanias of Cyrene (not the biblical Lysanias, tetrarch of Abilene), and the poet/critic Callimachus of Athens. Zimmerman (1975) says that Eratosthenes was a student of Zeno of Athens. Due to the scarcity of ancient records, the confusion about his early training and education is understandable.

It is known that Eratosthenes was residing in Athens when Euergetes I (also known a Ptolemy II, reign 241-221 B.C.) sent for him to tutor his son, Philopator (Ptolemy IV, reign 221-205 B.C.). It is thought that Eratosthenes also tutored Epiphanes (Ptolemy V, reign 205 - 180 B.C.). Eratosthenes served as Chief Librarian at Alexandria from c. 240 B.C. until his death. It appears that the Librarian of Alexandria also assumed the position of tutor to the Ptolemy's progeny. The Library of Alexandria is thought to have been the largest library in the ancient world.

Eratosthenes studied and wrote literary criticism, poetry, and works on the theater (comedy), literature, astronomy, geography, philosophy, and mathematics. Although most of his works do not survive, there are numerous references to his endeavors in the works of his contemporaries. Negative statements concerning Eratosthenes' works and writings are also found. Apparently inspired by jealousy and pettiness, such comments are not critical and learned arguments about the merits of Eratosthenes' endeavors.

Astronomers, geographers, mathematicians, and surveyors are introduced to Eratosthenes in historical outlines of the technical development of their subjects. Western classical scholars have traced and catalogued ancient Greek writings in an attempt to preserve the cultural heritage. However, George Biddell Airy's (1801-1892) classical Figure of the Earth (1830) made no mention of Eratosthenes' contributions. Alexander Ross Clarke, the eminent English geodesist, in his definitive work Geodesy (1880), likewise omits Eratosthenes and refers only to Airy. George L. Hosmer, whose Geodesy was the standard textbook in the United States until the 1960's, does not mention the historical efforts of Eratostheses.

The writings of others provide little insight into what Eratosthenes actually stated. The following are direct quotations by Jordan (1878), Helmert (1880), Merriman (1881), Gore (1886, 1889, and 1901), Dreyer (1905), and Crandall (1907).

Wilhelm Jordan, 1878

"The first historically certain measurement of the earth's size is that of Eratosthenes of Alexandria which took place about 230 B.C. Eratosthenes determined the circumference of the earth using a relationship that is still valid today, that the latitude difference between two points, which is the central angle between two parallels measured at the center of the earth, can be determined from the angles that the sun's rays make with the vertical at Alexandria and Syene at the time of the summer solstice. This angle and the approximate distance between the parallels of the two positions gave a determination of the value of the circumference of the earth of 250,000 stadia.

At the time of the summer solstice it was observed that in Syene (Aswan on the Nile River at the border between Egypt and Nubia (Africa)) the sun's rays fell vertically in a well shaft at noon. This is possible because Syene lies nearly on the Tropic of Cancer. At the same time, Eratosthenes geometrically determined that the angle which the sun's rays made with the vertical at noon in Alexandria was equal to 1/50 of 2π, which resulted in the determination of the above value of 250,000 stadia for the earth's circumference. If one takes 1 stadia = 185 meters, the resulting earth circumference is 46,250,000 meters (quadrant of 11,562,500 meters).

Friedrich Robert Helmert, 1880

"Historical Development of the Knowledge Regarding the Mathematical Surface of the Earth."

"Par. 1 Historical notes up to Newton's time. Even

in antiquity the curvature of the sea's surface could not remain unnoticed by the seafaring nations, where the first step toward the concept of spherical shape was made. About two and one half thousand years ago the Greeks had knowledge of this approximate shape of the surface of the earth. Aristotle compiled the experiences to prove it. Nevertheless it was not until about 220 B.C. the Alexandrian scientist Eratosthenes, as far is known, arrived at a scientifically founded value for the circumference (and with this for the radius of curvature) of the earth which was considered a sphere. He computed this from the estimated horizontal distance between Alexandria and Syene and the astronomically determined convergence of the plumb lines at the terminal points of this distance. Eratosthenes computed the circumference and radius of the circle by means of the circular arc and the central angle.

For eighteen centuries following no special progress was made, although the accuracy of the values arrived at by Eratosthenes had been surpassed. . . ."

Mansfield Merriman, 1881

"Eratosthenes (-230) seems, however, to have been the first to conceive the principles and make the observations necessary for a logical deduction of the size and shape of the sphere. He noticed that a Syene, in Southern Egypt, the sun at the summer solstice cast no shadow of a vertical object, it being directly in the zenith, while at Alexandria, in Northern Egypt, the rays of the sun at the same time of the year made an angle with the vertical of one-fiftieth of four right angles. From this he concluded that the circumference of the earth was fifty times the distance between these two places, and this being, according to the statements of travelers, 5,000 stadia, he claimed for the whole circumference 250,000 stadia. The exact length of the stadia is now unknown, so that we cannot judge of the accuracy of his result; it is probably much too large, since Ptolemy, a learned astronomical writer, who flourished four hundred years later, mentions 180,000 stadia as the length of the circumference; yet the name Eratosthenes will be honored in science as that of the originator of the method of deducing the size of the earth from a measured meridian arc."

J. Howard Gore, 1886, 1889, and 1900

"One of the first problems that suggested itself for solution in the intellectual infancy of mankind was 'What is the earth, its size and shape?' . . . . Of the authenticated announcements of hypotheses, Pythagoras was the first to declare that the earth was spherical. The honor is sometimes assigned to Thales (c. 635-546 B.C.) and Anaximander (c. 611-547). Archimedes gave an approximate value for the circumference 300,000 stadia. To Eratosthenes (B.C. 276) belongs the credit for making the initial step towards a determination of the circumference. He observed that at Syene , in Southern Egypt, an object on the day of the summer solstice cast no shadow, while at Alexandria the sun made an angle with the vertical equal to one fiftieth of a circumference. Considering that Alexandria was north of Syene, he reasoned that the entire circumference of the earth was 50 times the distance between those places, or 250,000 stadia; this he afterwards increased to 252,000 stadia. The neglect of the sun's diameter in the determination of the declination, and the false supposition that Alexandria and Syene were on the same meridian, introduced considerable inaccuracies in his results, the exact amount of which, we cannot estimate owing to our ignorance at to the length of the stadium."

J.E.L. Dreyer, 1905

"The next and most celebrated determination is that of Eratosthenes of Alexandria (276-194 B.C.), librarian of the great museum in that city. He was a native of Cyrene and studied at Alexandria and Athens, so that he had already acquired a name for learning, when he (about 235) was called to Alexandria, where he spent the rest of his life. He was a man of unusually varied attainments, but it is chiefly as a geographer that he is known to us, though only through the (often hostile) references to him in the works of Strabo and others. He seems in addition to his great work on geography to have written a special book on his determination of the size of the earth, which, however, is lost. He stated that at Syene a gnomon threw no shadow on the day of the summer solstice, while the meridian zenith-distance

(Continued on Page 15)

The entrada to the Edna Kennell Heritage Gallery at the National Historic Trails Interpretive Center invites visitors to enter and learn more about the General Land Office.

"Taking the Measure of the Land" includes three sub-themes that span 76 linear feet on three walls of the Edna Kennell Heritage Gallery, at the National Historic Trails Interpretive Center in Casper. BLM photos

The Bureau of Land Management's premier visitor center on the High Plains is the National Historic Trails Interpretive Center in Casper. Celebrating ten years of public service this August, the Trails Center provides a look over our nation's shoulder at America's great Westward Migrations and how pioneers changed the character of the nation in the mid-nineteenth century. Staffed by six permanent Bureau employees assisted by sixty active Volunteers and three STEP students, the Trails Center to date has welcomed more than a quarter-million visitors from all fifty states and seventy foreign nations to Wyoming, in the heart of the trans-Mississippi frontier.

The Trails Center sits high above the north bank of the North Platte River, offering a magnificent view of the river course and Casper Mountain to the south. As the result of a successful private-public partnership, the City of Casper deeded eleven acres of land to the Bureau of Land Management in the mid-1990s for location of the facility, while the newly-formed National Historic Trails Center Foundation became incorporated and began its role in 1993 as the nonprofit complement to the federal presence, pursuing funding for design, fabrication, and installation of exhibits to fill the proposed 23,000 square foot center.

William A. Richards earned a widely respected reputation as the fifth Surveyor General of Wyoming, fourth Governor of the State, and the 30th Commissioner of the General Land Office. Here he presides over a lottery drawing to open Indian lands to settlement early in the twentieth century.

Photo from the Frison Collection, Wyoming State Archives

It was a cadre of senior members of the Wyoming Chapter of the Oregon-California Trails Association (OCTA), inspired by provisions of the National Trails Act of 1968, which sought funding for a federal visitor center. Wyoming enjoys distinction as a landscape that channeled migration west of the Mississippi River along the routes of the Oregon, Mormon Pioneer, California, and Pony Express trails. The High Plains and "Stony Mountains" of Wyoming brought emigrants and Pony Express riders together in a single conduit along the North Platte and Sweetwater Rivers. Then, as today, water was the compelling reason for the chosen route of travel through present-day Wyoming, and for the settlement that eventually occurred here.

More than 360 miles of these National Historic Trails traverse lands administered by the Bureau of Land Management in Wyoming. That fact, combined with the location of Casper as the last safe fording location along the North Platte River for westbound emigrants, made Casper the site of choice for OCTA members that championed the Trails Center's construction. Unanimously supported by Wyoming's Congressional delegation, the Trails Center's enabling legislation passed muster and was signed as P.L.105-290 by then-President Clinton in October, 1998.

A 100-seat theater is the venue for the Trails Center's 18-minute feature film presentation, while seven exhibit galleries offer a closer look at examples of the emigrant and Native American experience during the historic period. Throughout the year - and especially during June, July, and August - a variety of free interpretive presentations and temporary exhibits hosted by the Trails Center are attended by thousands of visitors eager to learn more about the migrations, our common heritage from that period of our nation's history, and what our public lands have to offer in the present day.

Settlement of the public domain was a dynamic process that involved the full spectrum of American society's demographics and ethics throughout the nineteenth and first half of the twentieth centuries. Sanctioned by the national government through political and military support, and the structured processes of the General Land Office, the consequences of emigrant migrations were not without order. From Ohio Statehood in 1803 to the Oregon Compromise with Great Britain in 1846, for example, twelve designated Territories became twelve States through the process defined by Congress in the Ordinance of

1787, and the administration of public land surveys and title transfer to private ownership by land entry in all its historic forms, as recorded by the General Land Office.

Chronically underfunded and understaffed, the General Land Office worked tirelessly to provide a measured, orderly procedure by which individual citizens could acquire a portion of the public domain and thereby extend a societal benefit that would help realize America's true potential. If a man was given the opportunity to own and improve land, to establish and nurture institutions that complement permanent settlement, and to pass that ownership and responsibility on to his heirs, as Thomas Jefferson posited, that man would fight to defend the same opportunity for his children, and the homeland that empowered him. Jefferson was correct in his reasoning; his influence in government is part of the fabric of our nation.

In this commemorative year the Trails Center emphasizes the role of the General Land Office in making our grand westward migration effective at building a continental nation, through display of a temporary exhibit titled "Taking the Measure of the Land". The work of eleven Surveyors-General in Wyoming Territory and State is one aspect of the exhibit, which will be on display through Labor Day. In addition to the 200th Anniversary of establishment of the General Land Office and the 150th Anniversary of the Homestead Act of 1862, there are to be remembered the War of 1812, the 150th anniversary of establishment of the United States Department of Agriculture, and the Morrill Act and Pacific Railway Act of 1862. To learn what these landmark events have in common, the Bureau of Land Management cordially invites members of the Professional Land Surveyors of Wyoming to stop in during your next visit to Casper and draw your own thoughtful conclusions.

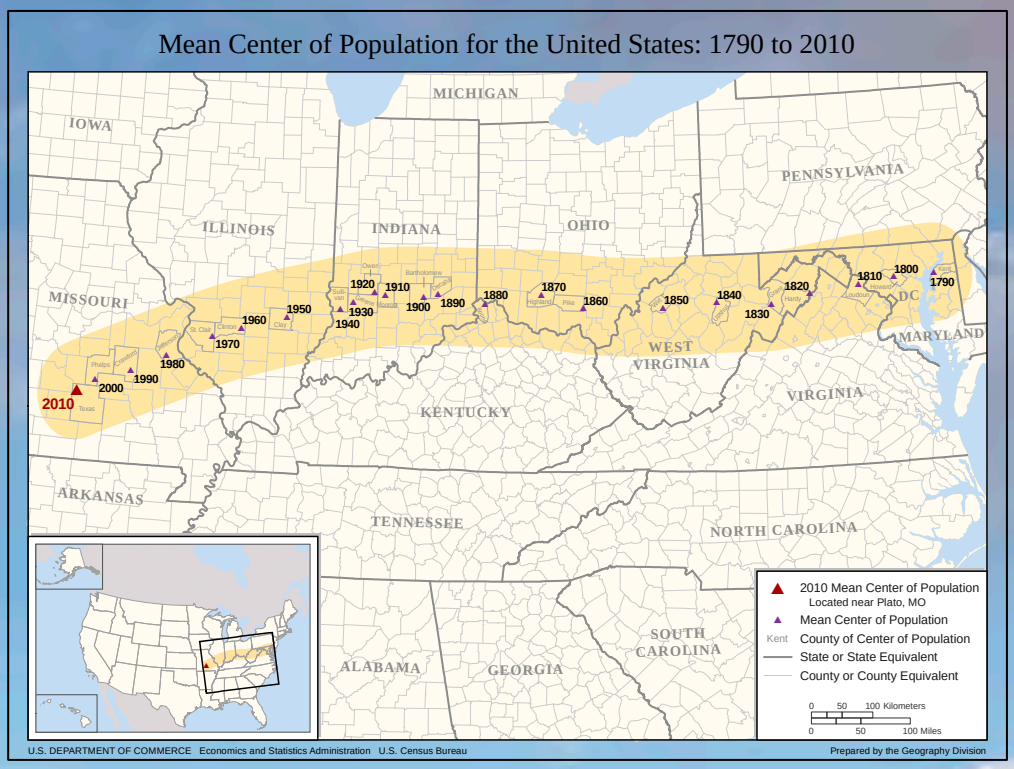
Your legacy is validation of the work of more than 127 Deputy Surveyors that performed surveys of Wyoming Territory and State from 1870 to 1910, in the conduct of some 344 contracts with the General Land Office, through its Commissioner in Washington, D.C. and the Surveyor General's Office in Cheyenne. The Trails Center is honored to interpret 142 years of continuity in the surveying discipline that affirms land ownership in Wyoming today, thanks to the work of your members.

With continuous encouragement and artifact and document loans by John Lee and Joel Ebner, and assistance from many other good folks in organizations as diverse as the Smithsonian Institution, National Park Service, South Dakota State Historic Preservation Office, the Library of Congress, Wyoming State Archives, the American Heritage Center at the University of Wyoming, and the Western History Center at Casper College, the United States General Land Office is being commemorated for its vital role in American history at the National Historic Trails Interpretive Center. Visit the Trails Center seven days per week from 8:00 a.m. to 5:00 p.m., at 1501 North Poplar in Casper, Wyoming, just southwest of the Casper Events Center.

Our telephone number is 307-261-7780; our web site can be found at: http://www.blm.gov/wy/st/en/NHTIC.html

Westward expansion of our nation was enabled through the structured process of surveying and title transfer of public domain lands, complemented by a host of land disposal and settlement legislation. Today the National Historic Trails Interpretive Center in Casper keeps this heritage alive through exhibits and special public programs year-around.

BLM photo by Bob Wick



This Census Bureau graphic shows the pace of westward population movement throughout the nineteenth century, which then slowed during the Great Depression, and accelerated following World War II.

Map courtesy of U.S. Department of Commerce, Census Bureau

A Great Find

A BLM Cadastral Survey crew working on a boundary survey project in the Bakken Oil Play was surveying along the Little Missouri River in North Dakota when they staked out a search area for an original corner and found it fell near a cut bank along the river. One of the crew members jumped down along the bank to make sure they were not missing anything and discovered the original marked stone intact, lodged in the cut bank. One more high water event and there is a good chance the position of this stone would have been lost forever.

YOU'VE USED THEM, BUT CAN YOU PLACE ALL TWENTY-THREE?

A while back I was entering one of the Wyoming County Courthouses (Photo "J" on the next page, if memory serves me) after many previous days entries for research, and it came to me that the handle I was pulling is probably a common sight to many surveyors in that county. At that point the idea for this little "Match Game" started taking shape.

One of the benefits of working for WYDOT's Photogrammetry and Surveys Department is that I get to travel all over this great state. Although I have not done research in every county courthouse, I have now visited each of them.

The attempt was made to photograph the historic handles when possible and hopefully, after over a years worth of travel for different WYDOT projects in nearly every county, renovations have not changed the handles on any of the initial courthouse handle pictures.

Here is the challenge to all my colleagues (who may have been kicked out of any of these wonderful historical document havens do to the staff wanting to go home for the night): you will probably recognize the handles of your home county's building of public records, but have you ever been to and can you remember the doors on the other twenty-two? Just to make it more interesting, I'm also asking for each county's seat and it's numeric license plate designation.

A drawing will be held at the 2012 Fall Technical Session from all the correct answers so bring a photocopy of your work.

Good Luck!

Michael Flaim, PELS

Photo	County	Seat City/Town	Number
A			
B			
C			
D			
E			
F			
G			
H			
I			
J			
K			
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V			
W			


A


B


C


D


E


F


G


PULL
H


I


J


K


L

Thank you to the Laramie County Sheriff Deputy that chased me down and around the block after snapping the picture of the courthouse door. He kindly listened to my strange explanation and didn't escort me back through the doors!

(Continued from Page 6)

of the sun at Alexandria was 1/50 of the circumference of the heavens, which arc therefore represented the difference of latitude; while the linear distance of these two places, which he assumed to be on the same meridian, was 5,000 stadia. Consequently the circumference of the earth was 250,000 stadia, for which value either Eratosthenes himself or some successor of his afterwards substituted 252,000 stadia, evidently in order to get a round number , 700 stadia, for the length of a degree. This value was adopted by Strabo and Pliny.

The question now arises: what was the length of the stadium adopted by Eratosthenes? The answer to this is given in the statements of Pliny, that Eratosthenes put a schoenus equal to 40 stadia. Now an Egyptian σχοινοζ was 12,000 royal cubits of 0.525 meter, therefore the stade was 300 such cubits or 157.5 m = 516.73 feet, and 252,000 times this is 24,662 miles, which corresponds to a diameter of 7,850 miles, only 50 miles less than the true value of the polar diameter of the earth. To a great extent this close agreement is no doubt due to the chapter of accidents, though on the other hand it must be remembered that we only possess the merest outline of the proceeding of Eratosthenes, but are quite ignorant whether he took any precautions to guard against error, particularly in observing the zenith-distance of the sun at Alexandria. Kleomedes (Cleomedes) adds, the observations of the shadow of a gnomon at the winter solstice at Syene and Alexandria gave the same result, 1/50, but he gives no details. The latitude of Syene is 24°50′, that of the Museum of Alexandria about 31°11.7′ (Ptolemy assumed 23°58′), the difference is 7°6.7′, which happens to be close to 7°12′ of Eratosthenes. But the Tropic of Cancer did not pass through Syene in the days of Eratosthenes, as the obliquity of the ecliptic about the year 224 was 23°43′20″, while Eratosthenes found 23°51′20″. Before this time it had been assumed = 24°, so that he was nearer the truth.

The stade used by Eratosthenes was a shorter one than the Olympic one of 185 m. (440 cubits of 0.462.) or the Ptolemaic or Royal Egyptian stade of 210 m. (400 cubits of 0.525 m.). It was an itinerary measure used to express distances, which had been measured by pacing them, and it has always been known to have been smaller than the Olympic stade, According to Martianus Capella, Eratosthenes found the distance between Syene Meroe "per mensores regios Ptolemaei," i.e., by the professional papers or βηματισται (itinerum mensores), and it was therefore natural that he should use the literary measure employed by them.

Charles L. Crandall, 1907
"Historic Outline"

The first authenticated hypothesis of the spherical form of the earth by Pythagoras, who is purported to have been born about 582 B.C.

The first determination of the circumference by Eratosthenes, 230 B.C. He originated the method of deducing the size of the earth from a measured meridional arc, for he found that while the sun's rays were vertical at noon during the summer solstice at Syene in southern Egypt, they made an angle 2π/50 with the vertical at Alexandria in northern Egypt, and reasoned from this that the earth's circumference must be 50 times the distance between the points. The distance according to the statements of travelers, was 5,000 stadia, giving the circumference by assuming both points to be on the same meridian (Syene is about 3° East of Alexandria. Jordan (Vermessungskunde, Stuttgart, 1890, vol. 3, p. 2) estimates this value to be about 16% in excess by taking 1 stadium = 185 m, the exact value of the stadium being unknown.

Commentary

The reader will note that several writers addressed the issue of the relationship between the stade and the meter. It is not this writer's intention to evaluate the length interrelationships, but to read and note the modern (nineteenth and twentieth century) authors' versions (interpretations) of Eratosthenes' procedure to Eratosthenes' actual writings on the subject.

There is one reference stating that the writings were lost (Dreyer, 1905). This is partially true. For, although the original manuscript may no longer exist, Eratosthenes' text has survived. It was the practice of writers of mathematical and scientific works to incorporate almost verbatim the work of earlier writers in their own writings. Cleomedes (Kleomedes), a mid-first century B.C. Greek astronomer, incorporated Eratosthenes/ Measurement of the Earth into his writings. Cleomedes' writings are said to be based on the writings of Posidonius (c. 135-51 B.C.), which no longer exist. Following is the English translation of Eratosthenes' Measurement of the Earth as it appears in Cleomedes' treatise.

Eratosthenes of Cyrene
Measurement of the Earth

Such then is Posidonius's method of investigating the size of the earth, but Eratosthenes' method depends on a geometrical argument, and gives the impression of being more obscure. What he says will, however, become clear if the following assumptions are made. Let us suppose, in this case also, first that Syene and Alexandria line under the same meridian circle,

secondly, that the distance between the two cities is 5,000 stades; and thirdly, that the rays sent down from different parts of the sun upon different parts of the earth are parallel; for the geometers proceed on this assumption. Fourthly, let us assume that, as is proved by the geometers, straight lines falling on parallel straight lines made the alternate angles equal, and fifthly, that the arcs subtended by equal angles are similar, have the same proportion and the same ratio to their proper circles - this also being proved by the geometers. For whenever arcs of circles are subtended by equal angles, if any one of these is (say) one-tenth of its proper circle, all the remaining arcs will be tenth parts of their proper circles.

Anyone who has mastered these facts will have no difficulty in understanding the method of Eratosthenes, which is as follows. Syene and Alexandria, he asserts, are under the same meridian. Since meridian circles are great circles in the universe, the circles on the earth which lie under them are necessarily great circles also. Therefore, of what ever size this method shows the circle on the earth through Syene and Alexandria to be, this will be the same size of the great circle on the earth. He then asserts, as is indeed the case, that Syene lies under the summer tropic. Therefore, whenever the sun, being in the Crab at the summer solstice, is exactly in the middle of the heavens, the pointers of the sundials necessarily throw no shadows, the sun being in the exact vertical line above them; and this is said to be true over a space 300 stades in diameter. But in Alexandria at the same hour the pointers of the sundials throw shadows, because this city lies farther to the north than Syene. As the two cities lie under the same meridian great circle, if we draw an arc from the extremity of the shadow of the pointer to the base of the pointer of the sundial in Alexandria, the arc will be a segment of a great circle in the bowl of the sundial, since the bowl lies under the great circle. If then we conceive straight lines produced in order from each of the pointers through the earth, they will meet in the center of the earth. Now since the sundial at Syene is vertically under the sun, if we conceive a straight lin drawn from the sun to the top of the pointer of the sundial, the line stretching from the sun to the center of the earth will be one straight line. If now we conceive another straight line drawn upwards from the extremity of the shadow of the pointer of the sundial in Alexandria, through the top of the pointer to the sun, this straight line and the aforesaid straight line will be parallel, being straight lines drawn through from different parts of the sun different parts of the earth. Now on these parallel straight lines there falls the straight line drawn from the center of the earth to the pointer at Alexandria, so that it makes alternate angles equal; one of these is formed at the center of the earth by the intersection of the straight lines drawn from the sundials to the center of the earth; the other is the intersection of the top of the pointer in Alexandria and the straight line drawn from the extremity of its shadow to the sun through the point where it meets the pointer. Now this latter angle subtends the arc carried round from the extremity of the shadow of the pointer to its base, while the angle at the center of the earth subtends the arc stretching from Syene to Alexandria. But the arcs are similar since they are subtended by equal angles. What ever ratio, therefore, the arc in the bowl of the sundial has to its proper circle, the arc reaching from Syene to Alexandria has the same ratio. But the arc in the bowl is found to be the fiftieth part of its proper circle. Therefore the distance from Syene to Alexandria must necessarily be a fiftieth part of the great circle of the earth. And this distance is 5,000 stades. Therefore the whole great circle is 250,000 stades. Such is the method of Eratosthenes.

Figure 1 will help to elucidate Clomedes. S is Syene and A is Alexandria. The center of the earth is O. The sun's ray at the two places are represented by the broken (dashed) straight lines. If α be the angle made by the sun's rays with the pointer of the sundial at Alexandria (OA produced), the angle SOA is also equal to α, or one-fiftieth of four right angles. The arc SA is known to be 5,000 stades and it follows that the whole circumference of the earth must be 250,000 stades.

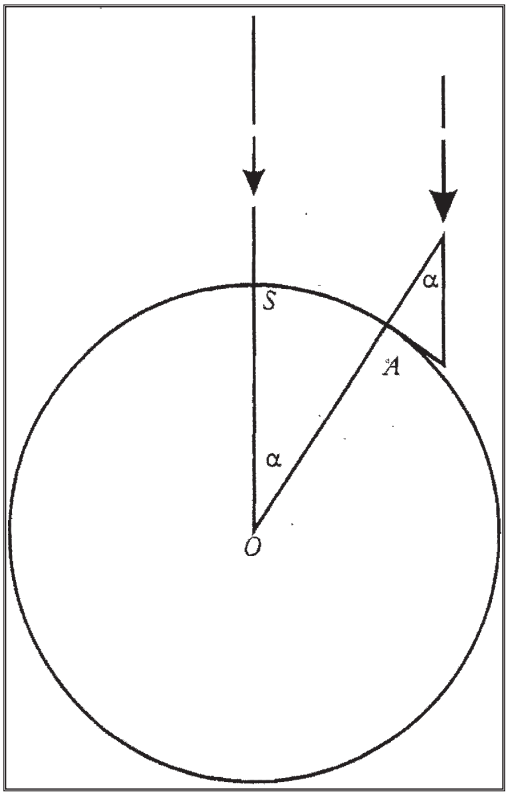

Figure 1. Eratosthenes' Method.

Postscript

Eratosthenes, and his successors, used the meridian arc length and the difference in zenith distances to celestial objects located in the same meridian to calculate a circumference for a spherical earth. When Isaac Newton published his treatise Principia where he proposed that the earth was not a sphere, but an ellipsoid generated by rotating the ellipse about is minor axis, which coincided with the earth's polar axis (axis of rotation), Eratosthenes approach was perfectly applicable. By measuring meridional arc lengths at different latitudes of the earth, and measuring the zenith distances to celestial objects (stars), thus determining the differences in latitude at the end points of each meridional arc the "flattening of the sphere" to an ellipse could be computed. The problem was to measure appreciably long meridional arc lengths in order to minimize the errors of terrestrial observations in the arc length determinations. The arc lengths had to be several tens to a few hundred kilometers. At the time, early eighteenth century, the art and science of measuring linear distances to a high degree of accuracy and precision was extremely limited. However, Willebrod van Roijen Snell (Snellius) (1580-1626) and Tycho Brahe (1546-1601) independently developed triangulation. Triangulation is the application of the trigonometric principle of measuring the angles of a triangle (spherical) and knowing the length of a side, and then computing the remaining lengths of the triangle. The simplest configuration of a triangulation network is to form a "chain" of triangles with a common side between adjacent triangles, measuring a minimum of two of the angles in each triangle, and employing the principle of the law-of-sines to compute the lengths from one end of the chain (called an arc) to the opposing end. The azimuth of lines in the northerly and southerly triangles were observed, and a length of one of the sides (called baselines) of the northerly and southerly triangles was accurately measured. By adding the second baseline and azimuth determination at the terminal end of the triangulation network provided an estimate of error or degradation in the quality of the survey observations which provided an estimate of the error of uncertainty of the meridional arc length. Until the advent of the space age when satellite tracking replaced triangulation, major geodetic networks employed triangulation. Only after World War II did electronic distancers, which produced highly accurate geodetic lengths, become available were additional lengths measured in triangulation networks to decrease degradation of the lengths from one end of the network to the other end of the network.

Although Eratosthenes (and his contemporaries) thought that the earth was a sphere, his application of astronomy, geometry, and trigonometry would have a long period of application for surveying, mapping, geophysical, and engineering programs which is still applicable today.

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