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BIOGRAPHICAL MEMOIR

OF

JOHN FILLMORE HAYFORD

1868-1925

BY

WILLIAM H. BURGER

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John F. Hayford

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FOREWORD

In February 1928 President T. H. Morgan of the National Academy of Sciences invited the writer to prepare a memoir of John F. Hayford, a member of the Academy, who died in March 1925. This invitation was accepted, and since that time, as occasion permitted, material was gathered a little at a time. Owing to the writer's ill health and the pressure of his duties as Professor of Civil Engineering in the College of Engineering at Northwestern University, there were periods when very little time could be spent on the work, but at last it is near completion in so far as the writer considers possible without an undue expenditure of time and energy. He believes that it is fairly complete as to events and dates, and it is hoped that the results indicate in a measure the extreme admiration which the writer had for the man whom he had known through a period of twenty-six years, in camp life on field surveys, in connection with various scientific societies and organizations, in the atmosphere of a great educational institution, and in his home. It is further hoped by the writer that this memoir is a fitting, final tribute to the man whom he had known as Chief, Councillor, Colleague, and above all, as Friend.

WILLIAM H. BURGER.

Evanston, Illinois, March 15, 1931.
School of Engineering, Northwestern University.

PREPARATION OF MEMOIR

In the preparation of this memoir the writer has made use of the large collection of letters, documents, diaries, reprints of publications, pamphlets, and other material which were placed in storage at the College of Engineering at Northwestern University by Director Hayford and which were kindly turned over to

the writer by his successor; also permission was granted to examine the fifteen years' accumulation of correspondence in the Director's file; also his son, Maxwell, transmitted such material along this line as was found at his home at the time of his death, and who has also reviewed the manuscript of this memoir. He is also indebted to the relatives, friends, and colleagues who so kindly furnished assistance in response to requests, and especially for the information furnished by Major William Bowie, Mr. Hayford's successor in the U. S. Coast and Geodetic Survey, and finally, to Mr. C. H. Swick of the same bureau for his review of the manuscript.

Added to the above is the fact that the writer had enjoyed an almost uninterrupted acquaintance with the Director for twenty-six years, first as a member of his force in field and office work in Washington and later as a member of his faculty at Northwestern University. During these twenty-six years the writer's fields of work were closely related to some of the fields in which the Director worked, and, therefore, on many occasions the writer was invited to participate in examination or discussion of the investigations carried on by the Director, and many times was able to assist in computations and in other forms of service.

While the duty of collecting the material and trying to form a presentable memoir from it has been a rather heavy burden on account of the continued ill-health of the writer combined with his college and other work, it has been throughout a most pleasant duty to work on this a final tribute to him whom the writer esteemed so highly.

The writer first formed the acquaintance of Mr. Hayford on July 21, 1899, when he reported as Aid in the United States Coast and Geodetic Survey for duty in the Geodetic Division under Mr. Hayford's charge and was assigned to a party doing precise leveling in Nebraska. On his return from this field party in October of the same year, the writer was assigned to duty in the Computing Division and remained in Washington during the winter working on precise levels under Mr. Hayford's direction. As the writer had been selected to take charge of a field party in the following spring, a party to use the newly de-

signed Coast and Geodetic Survey level, it was but natural that many conferences were had with Mr. Hayford, and thus an acquaintance began which soon ripened into a friendship which lasted for more than twenty-six years.

It was during that winter that Mr. Hayford formed a small class, composed of two Aids (of which the writer was one) and one man from the Computing Division. This class met for one evening each week at Mr. Hayford's home in Northwest Washington for the purpose of studying and receiving instruction in the theory of least squares and adjustments of observations. The writer at the present date wonders if those three men had any conception of what demands they were then making upon the time of a man who was under the heavy burden which now appears to have been his lot at that time, and further wonders if they fully appreciated the greatness in a man who could and would find time to lay aside his larger and more important duties, or his chance for an evening's study or amusement, to assist some of the lesser men in his department. Perhaps if they had thoroughly understood the situation their thanks would have been much more pronounced. To place self in the background when others needed help seems to have been one of the great characteristics of Hayford's nature, for this he was ever ready and willing to do.

BIOGRAPHY (Summary)

For general purposes there is here given a rapid summary of the more important dates and events in the life of Dr. Hayford. Some of these are dealt with at greater length elsewhere in these memoirs.

Born May 19, 1868, at Rouses Point, New York.

Attended country schools, Rouses Point High School two years, Detroit High School two years.

Entered Cornell University, College of Engineering, 1885.

Graduated, degree Civil Engineer, 1889.

Appointed Computer, U. S. Coast and Geodetic Survey, June 22, 1889.

Served in Tidal Division until December 15, 1890.

Transferred to Office of Standard Weights and Measures, and served there until July 20, 1891, when he went as recorder on the Holton, Indiana, base line for three months. Returning to the office of Standard Weights and Measures, he remained there until the end of December 1891, and was then transferred to the position of Aid in the field force of the Survey.

Assistant Astronomer, U. S. and Mexican International Boundary Commission, February 1892 until January 1894.

Returned to the Survey as Aid and was promoted to Assistant in 1894.

Summer 1894 in Alaska on astronomical work in connection with boundary survey.

Married Lucy Stone, October 11, 1894.

September 1895 to April 1898, instructor Civil Engineering, Cornell University.

July 9, 1898, appointed Expert Computer and Geodesist in the United States Coast and Geodetic Survey.

May 3, 1899, became Inspector of Geodetic Work.

Appointed Assistant in the field force, 1899.

Appointed Inspector of Geodetic Work and Chief of the Computing Division in 1900 and served in that capacity until October 1909.

Delegate with O. H. Tittmann, representing the United States at the Budapest meeting of the International Geodetic Association, 1906, and also at the London and Cambridge meeting of 1909.

Elected Director, College of Engineering, Northwestern University, October 1908, to take up the duties in September, 1909.

Elected to National Academy of Sciences, April, 1911.

Chairman, Commission of Engineers, Costa Rica-Panama Boundary Arbitration, October 1911 to November 1913.

Appointed member National Advisory Committee for Aeronautics, 1915.

Appointed member of Commission to study Panama Slides, November 18, 1915.

Granted honorary degree Sc.D. from George Washington University in 1918.

Special war work in Washington on Airplane and Navy instruments.

Awarded Victoria Medal by the Royal Geographical Society of Great Britain, 1924.

Awarded Chanute Medal, Western Society of Engineers, 1925.

Died at Evanston, Illinois, March 10, 1925.

DISTINCTIVE HONORS

1894

Awarded Fuertes Medal of Cornell University for paper in Transactions of the Association of Civil Engineers of Cornell University. "An Account of Certain Field Methods Used on the Survey of the Mexican Boundary in 1892-93."

1918

Degree Sc.D. George Washington University. Awarded for scientific work done in the Government service.

1924

Awarded the Victoria Medal of the Royal Geographical Society of Great Britain for the establishment of the theory of isostasy.

1925

Awarded Chanute Medal by the Western Society of Engineers for superiority of paper published in the Journal during the year 1924.

1925

Name perpetuated by National Geographic Society in the naming of "Mount Hayford" in Alaska.

ANCESTRY

JOHN FILLMORE HAYFORD was born at Rouses Point, Clinton County, New York, May 19, 1868. He was the son of Hiram and Mildred Alevia (Fillmore) Hayford, and a descendant of William Heiford who came from England about 1668 and was an early resident of Essex and Old Norfolk, Massachusetts; from him the line descends through his son John Heiford of Braintree, Massachusetts, who married Abigail Albins; their son John and his wife Lydia Pierce, who lived near Farmersville, New York; their son John (first to spell his surname Hayford) and his wife, Thankful Phinney; thence through their son John who was the great grandfather of the subject of these memoirs. This ancestor with his wife Elizabeth Riley came from Brainbridge, Connecticut, in 1800, built a log house in the dense forest, and commenced clearing to make way for farm crops. This farm has been held by the family since that date, and it was here that John was born. His grandparents were Asel Hayford and Esther Cobb.

John's father's father died at the age of eighty, his father's mother at the age of seventy-two, and his father at the age of sixty. His mother's father died at the age of eighty-seven, his mother's mother at the age of twenty-six, and his mother at the age of seventy-nine.

John had four brothers and three sisters. One brother died in early youth and one sister died in infancy. His other brothers and sisters survived him: Hiram C. Hayford (1930), Rouses Point, New York; Horace Hayford (1930), Pasadena, California; Benjamin Hayford (1930), Waukesha, Wisconsin; Mrs. Emily (Hayford) Coates died in 1928. He lived with this sister during his high school days in Detroit; Mrs. Clara (Hayford) McMurdie (1930), living at Kalamazoo, Michigan.

SCHOOLING

His father died when John was eight years old, and it was necessary for John during his boyhood to help on the farm be-

fore and after school. He received his first schooling in a one-room stone schoolhouse in School District No. 4, in the town of Champlain in which the farm is located. This schoolhouse was in a fair state of preservation when the writer visited Mr. Hayford's brother there in 1907. His brother Hiram, writing in 1930, reports that John ran away from home when he was four years old. The whole neighborhood was out looking for him and he was finally located at the schoolhouse one mile away. He had told the teacher that he would like to come to school. Thus early did he show his desires for mental activity.

When thirteen years old he entered Rouses Point High School, but stayed there only two years, when he went to Detroit to attend high school. While in Detroit he lived with his sister, Mrs. Emily Coates. It is reported that he walked nearly six miles every morning delivering the Detroit Free Press to help pay his expenses. This helped to keep him physically fit and to build up the vigorous body which was to be called upon to stand so much in later life.

Of his life as a student in high school the writer has been unable to obtain much information. Evidently it was of a high order for John was selected to give the Commencement Oration at the graduation exercises of his class held on June 24, 1885, the subject of his oration being "College Influence." It is interesting here to note that another on the same program was Robert P. Lamont who defended the affirmative on the commencement debate, "Should Foreign Immigration be Restricted?" The class consisted of twenty-four girls and seven boys. It is significant that the part taken by Hayford and Lamont in this high school program should point so conclusively to their future lines of work,—Hayford along scholastic lines to become a renowned scientist and educator, and Lamont along political lines to become Secretary of Commerce under President Herbert Hoover.

After graduating from the Detroit High School, Mr. Hayford was awarded a state scholarship at Cornell University from the Assembly District which included Clinton County, New York. He held this scholarship for the four years while he was at Cornell. He entered Cornell in the fall of 1885 and was

graduated in 1889. His brother Hiram is authority for the statement that after the first year John practically worked his way through college by waiting on table in a boarding house in Forest Home, a little town about four miles from Ithaca, and in that way paid his board. He also took care of a horse and the furnace of one of the faculty members of the college. There is among his papers a record of his having obtained financial aid from Cornell University in the form of loans secured by notes which were paid off in 1892.

Of his college life while a student at Cornell the writer is indebted to Anson Marston, Dean of Agriculture and Mechanic Arts of Iowa State College. Dean Marston writes under date of March 2, 1929:

"I became acquainted with Director Hayford in 1885, when we both entered the College of Civil Engineering of Cornell University, Ithaca, New York, as freshmen. He took from the first a prominent place as a student in the Civil Engineering College, and to some extent in university athletics. I remember that in our freshman year he electrified the watching crowds in one of the track events by running from behind under the arm of a tall, lanky senior athlete who was considered to be one of the best runners at Cornell at the time. I remember that Hayford later became interested in fencing, taking part in public contests.

"From the beginning of his college course, Director Hayford showed a great interest in pure and applied mathematics. At that time Cornell University was conducting a 'Lake Survey' every spring for two weeks, in which the juniors and seniors conducted triangulation and did topographic and hydrographic work in surveys of the 'finger lakes' of central New York, one after the other. We did our work on Lake Canandaigua, with headquarters at a summer hotel before the season opened. I remember that at the end of our junior year, Hayford was captain of a stadia party and that he gave a great deal of attention to the methods of adjusting and using the extremely antiquated transit with which the party was supplied.

"At that time the work at Cornell was organized in three 'terms,' fall, winter, and spring, corresponding to the 'quarters' of our present-day university practice in institutions which do not use the semester system. In the spring term of our senior year, Director Hayford inveigled another classmate, now Dean F. E. Turneaure at the University of Wisconsin, and myself into taking an elective course in which the object was the adjustment of the triangulation data obtained in these surveys, accumulated for several years. My own part in the course was mainly to operate a calculating machine, but Director Hayford took an intense delight in planning and directing the work in all its features in detail, and it was a fitting prelude to his after work on various U. S. boundary surveys, and with the U. S. Coast and Geodetic Survey.

"It is my recollection that during the last three years of our work at Cornell, ten engineering students, including Hayford, Turneaure and myself, became the owners of a second-hand sail boat, which afforded us much recreation in patching, painting, and even sailing it occasionally. Professor H. N. Ogden of Cornell University was another of these ten men. He was from Maine and our most accomplished sailor. To this boat we gave the name 'Secant,' and upon one occasion she upset and thus became a 'co-secant'."

In connection with athletics while at Cornell his son Maxwell is authority for the statement that Hayford won the Intercollegiate Mile Championship for 3 years, and placed second in the mile walk. He received many medals for his races, some of which are now in his son's possession.

From other sources it has been gleaned that Mr. Hayford also took part on several occasions in college dramatics and even started to learn to play the violin. Evidently while in college he led the same kind of intense life which was so characteristic of the subsequent years. Judging from the stories which he told, college life and classroom work must have been full of keen enjoyment for him. This was one of his predominating traits, always to get the fullest from every phase of life or activity into which he entered, whether mental, spiritual, or physical.

In addition to his work at Cornell along surveying and mathematical lines, he took great interest in the physical sciences, and under Professor I. P. Church laid the foundation for the great progress he made in later years in his studies and investigations on isostasy and stream flow and other related scientific works.

In Dean Marston's recollections of Mr. Hayford's life at Cornell, mention was made also of Dean Turneaure. The acquaintance of these three men continued throughout Mr. Hayford's life, and they met often and corresponded much, and he spoke of them with highest praise. He had also a close friendship with another classmate of the class of 1889. This was James S. Stone, a brother of Lucy Stone to whom Mr. Hayford was later married. The class of '89 seems to have been a remarkable class. At least four members of it attained "Who's Who in America," three as Deans of Engineering Schools, and one, Professor Carpenter, as Professor of Experimental Engineering, all renowned as scientists and educators.

UNITED STATES COAST AND GEODETIC SURVEY

Tidal Division

It was but natural that on graduation from Cornell he should seek employment along those lines in which he seemed particularly gifted, lines along which he had shown aptitude during his college days; and on June 22, 1889, he accepted service with the United States Coast and Geodetic Survey at Washington, as computer. Thus began his relation with the Survey, a relation which was to bring him such renown, and in a reciprocal way add to the prestige of this bureau of the government. On reporting for duty he was assigned to the Tidal Division. Part of his work in this division was of a general routine nature, and part along special lines of investigation. He made a special study of the Ferrel machine, of Harmonic Analyzers, and frequently discussed with Mr. E. G. Fischer regarding a new tide-predicting machine in the Survey. His work in this division gave rise to his first published works: (a) "Mean Range and

Improvement on the Tidal Machine," (b) "Use of Observations of Currents for Prediction Purposes," and (c) "Comparison of the Predicted with the Observed Times and Heights of High and Low Waters at Sandy Hook, N. J., during the Year 1889," all published by the Survey as shown in the Bibliography at the end of these Memoirs.

Office of Standard Weights and Measures

He served in the Tidal Division until December 15, 1890, when he was transferred to the Office of Standard Weights and Measures, a division of the Survey which was later to become the National Bureau of Standards. Here he served under O. H. Tittmann, who later became Superintendent of the U. S. Coast and Geodetic Survey. His work in the Office of Standard Weights and Measures, as in the Tidal Division, was on the general observing and computing incidental to the routine work of the division, but he also had an opportunity to do some original work, the results of this being given in the Survey Report for 1892, appendix No. 10, "On the Least Square Adjustment of Weighings." In July his work in this Office was interrupted for a few months when he was sent on an assignment to Holton, Indiana, returning upon its completion to the Office of Standard Weights and Measures where he remained until the end of December, 1891.

Holton Base

The first field work in which Mr. Hayford took part was when he was sent to Holton, Indiana, July 20, 1891, to act as recorder on the measurement of the Holton Base Line, under Assistants O. H. Tittmann and R. S. Woodward. He served in this capacity during the measurement of the base until October 12, returning to Washington on October 27, 1891, the intervening time being spent on leave of absence, visiting in Detroit, Rochester, N. Y., and Rouses Point, N. Y.

At Holton Base, Mr. Hayford formed an acquaintance with one of the men of the base party, and between them began a friendship which was destined not only to affect later his reputa-

tion as head of the Division of Geodesy in the U. S. Coast and Geodetic Survey, but in a great measure to affect the geodesy of the United States and of the entire world. This acquaintance with Jasper S. Bilby ripened into an abiding friendship which lasted until the death of Mr. Hayford in 1925. When Mr. Hayford went to the work on the United States-Mexican Boundary, Mr. Bilby was employed as general helper in his party and he has served continuously to date with the Coast and Geodetic Survey, with rare periods omitted, engaged for the most part in the Geodetic Division. Since about 1900 all of the major reconnaissance and signal-building has been in his charge and it was under Mr. Hayford's régime that special recognition was given him by conferring upon him the official title of Signalman, the first to be thus honored. In speed and economy of operation his work has had a distinct bearing upon the phenomenal success attained by the Coast and Geodetic Survey in triangulation and base work. He is the designer of the Bilby Steel Tower now being used with great success. Recently he again received official recognition by being given the title of Chief Signalman, this position having been especially created for him. The writer has had the pleasure of working with Mr. Bilby on many occasions, and believes that as an expert on reconnaissance and signal-building Mr. Bilby stands unrivaled in the world.

In December, 1891, Mr. Hayford was transferred to the position of Aid in the field force of the Survey, and during January, 1892, a considerable part of his time was spent in Washington in preparation for the work on the United States-Mexican Boundary survey to which he had been appointed.

MEXICAN BOUNDARY

Owing to the fact that difficulties had arisen regarding the exact location of the boundary line between the United States and Mexico a convention was concluded between the two governments at Washington, July 29, 1882. Its provisions were not carried into effect before the date of its expiration, and another convention between the two governments to revive and continue the same was concluded February 18, 1889.

In accordance with Article V of this convention, the International Boundary Commission, organized November 17, 1891, was to carry out the provisions of the convention to mark the boundary from the Pacific Ocean to the Rio Grande. The United States commissioners appointed by the President of the United States were Lieut. Col. J. W. Barlow, Corps of Engineers; First Lieut. D. D. Gaillard, Corps of Engineers, and Mr. A. T. Mosman, Assistant, Coast and Geodetic Survey. To carry out the work of the American Commission several parties were organized, and in February, 1892, J. F. Hayford, with the title of Assistant Astronomer, was placed in charge of one of these, namely, the astronomical party for determining latitude and azimuth. Mr. Hayford reported directly to Commissioner Mosman who, also, under the title of Astronomer, had general supervision over the astronomical work along the line.

The work of the astronomical party began in Washington in December, 1891, and on January 22, 1892, Mr. Hayford left Washington for El Paso via New York and Galveston, arriving at El Paso on February 3, and on February 12 the astronomical party went into camp near El Paso, in conjunction with the other survey parties, fully equipped and prepared for work. Mr. Hayford's immediate party consisted of himself as astronomer and observer; James Page, computer; J. S. Bilby, general helper, and a cook and two teamsters. Their equipment consisted of one spring wagon, one baggage wagon, and, when necessary, one water-tank wagon.

All of the observations for latitude, azimuth, time, and magnetic declination on the entire line from El Paso to the Pacific Coast were made by Mr. Hayford in person. He also executed some detached secondary and tertiary triangulation, and ranged out two hundred and thirty miles of line.

So far as the writer knows, this is the first position held by Mr. Hayford where he was essentially chief of a field party and completely responsible for the successful completion of the work assigned. When one considers the magnitude of the work to be done and the difficulties under which the parties worked it

is difficult to realize that this was his first responsible assignment. At this time he was only twenty-four years of age.

The nature of the country traversed had a most important bearing upon the organization of parties and methods adopted for the survey. The whole region is essentially arid, and natural features and conditions were such as arise from its arid character. Volcanic peaks are frequent and in many places the lava had poured in a great flood over the plains, making the desolate region even more desolate and forbidding and furnace-like, as the lava rock catches and throws out again the fierce heat of an unclouded sun.

The greatest difficulty was to secure water, and many times it was necessary to haul water fifteen to twenty miles to camps, sometimes fifty miles, and in one case over one hundred miles. The summer temperature was very severe. During the second summer of the survey, in crossing the Yuma Desert, temperatures rarely fell as low as 90° throughout the night, and reached 104° for four or five hours nearly every day, and on one day indicated 118° in the shade. The only shade in general was that furnished by the tents, vegetation offering none, and the noon day rest found no cooling shade.

To add to the difficulties under which the parties labored in crossing the Yuma and Tule deserts, nearly half of the helpers deserted on this their first experience of the desert, and practically all of those remaining gave out at the end of two or three days, leaving the instrument men to perform their work unassisted.

This work called for the endurance of the most rugged of pioneers, the undaunted courage of the explorer, while the operations involved represent one of the highest types of work demanded from the scientist.

By direction of the War Department the Commission during its operations was provided with a military escort of about fifty enlisted men with three officers to accompany the expedition as a protection against Indians or other marauders.

The determination of each of the three non-parallel sections of the boundary, namely, the meridian position and two western

sections, consisted in the prolongation of the line from its determined azimuth at one end. The tracing of the parallel of latitude sections involved frequent astronomical stations. These were established at successive distances of about twenty miles. Observations were made to determine latitude and azimuth, and tangents to the parallel at each astronomical station were laid out and lines prolonged to the next station. Intermediate points on the boundary were determined by computed offsets.

A detailed report of this work by Mr. Hayford is given in the "Report of the Boundary Commission upon the Survey of the Boundary between the United States and Mexico West of the Rio Grande, 1891-1896," pp. 62-168.

Besides furnishing him much material for his text-book on *Geodetic Astronomy,* it brought to Mr. Hayford the much-prized Fuertes Medal of the College of Civil Engineering of Cornell University, awarded to him about 1894. In regard to this medal Director E. E. Haskell of the College of Civil Engineering in 1911 wrote to Director Hayford saying, "There seems to be no record in this College in regard to the award." On April 20, 1911, Director Hayford replied, "I have no definite record showing the basis of the award of the Fuertes Medal to me. My memory is that it was awarded for the paper entitled 'On Certain Field Methods Used on the Survey of the Mexican Boundary in 1892-1893,' published in the Transactions of the Association of Engineers of Cornell University, 1894, pp. 55-83."

Mr. Hayford was engaged upon the Boundary work from December, 1891, to December 26, 1893.

The Commission, in reporting upon the work to the Congress of the United States, stated in regard to the work of the four principal engineers in charge of divisions (Mr. Hayford being in charge of the astronomical section):

"They all brought to bear upon their duties rare intelligence and excellent training, and throughout the difficult and arduous work devolving upon them were ever willing . . . and to them is due large credit for the successful completion of the survey."

The writer, in his long intimate acquaintance with Mr. Hayford, has listened many times to descriptions of this work, de-

scriptions replete with tales of heroism and endurance of the men engaged upon it and which would constitute an epic if but known to the world, but accepted by them as part of the day's work.

"GEODETIC ASTRONOMY"

Mr. Hayford made use of much of the material gathered on the Boundary Survey in his book on *Geodetic Astronomy,* published in 1898. His own personal copy, in which he had made marginal notes since 1898, is in the writer's possession and needless to say it is a much-prized volume. It contains a wealth of material on observing and computing time, latitude, longitude, azimuth, and least squares, written in such a clear, comprehensive manner as to make it stand near the top of the list of published works on this matter. Unfortunately, it did not have the ready sale which a more popular text-book would have received, and when the plates were melted by the publishers a few years before Mr. Hayford's death, and with his permission, he remarked to the writer that this book had "netted him fifteen cents for each hour spent in its preparation."

On completion of his work with the Boundary Commission, Mr. Hayford returned to his regular duties in the Coast and Geodetic Survey, and was promoted to Assistant in the Survey in 1894.

ALASKA WORK

On April 19, 1894, Mr. Hayford left Washington under an assignment to join the U. S. Coast and Geodetic Survey steamer "Hassler" at Seattle for work in Alaska under Assistant John F. Pratt, commanding the steamer. During the summer he was stationed near Pyramid Harbor, Anchorage Bay and Tanja Inlet, Alaska, and was engaged in making longitude and other astronomical determinations in connection with the survey of the Alaska boundary. He returned to Washington September 8, 1894, to resume his regular work as Assistant in the Survey.

MARRIAGE

On completion of the work at Holton, Indiana, we find that Mr. Hayford spent one week at Detroit visiting with his sister,

after which he went to Rochester and Charlotte, N. Y., to visit at the home of James S. Stone, a classmate of his undergraduate days at Cornell University. It was during this visit that he became engaged to Lucy Stone, the sister of James. Her father was William T. Stone. She also had another brother, Walter King Stone, who has attained fame as an illustrator. This engagement ended in a wedding on October 11, 1894, soon after his return from field work at Anchorage Bay, Alaska. They spent their wedding trip visiting Niagara, Detroit, Chicago, Janesville and Madison, Wisconsin, and arrived in Washington, November 1, 1894.

As to his work during the latter part of 1894 and the first half of 1895, the writer has not been able to learn, but from items that have been discovered it is judged that he was employed in Washington on general work at the Survey office. These items also indicate that it was not a period of all work and no play, for we find evidence that he and Mrs. Hayford made good use of their stay in Washington by making frequent trips to see the nearby points of historic interest; also they took advantage of the many good operas and other forms of amusement afforded by the winter in Washington. Even the lighter forms of entertainment were not neglected, for we find them joining the Mask and Wig Club and participating in amateur theatricals.

INSTRUCTOR AT CORNELL

In September, 1895, Mr. Hayford resigned his position as Assistant in the United States Coast and Geodetic Survey to accept a position as instructor in Civil Engineering at Cornell University. His duties at Cornell were teaching Mechanics, Practical Astronomy, Land Surveying, and Descriptive Geometry, and guiding the laboratory work of certain students in connection with Mechanics and Hydraulics. The statement contained in the previous sentence occurs in a penned copy of a letter written February, 1898, and addressed to Professor William H. Burr, Columbia University, New York City. It is the only reference which the writer has been able to discover in regard to the work at Cornell, and in the twenty-six years of inti-

mate acquaintance he very seldom heard Professor Hayford refer to this phase of his life, and even then the sentiment expressed was such as to lead one to believe that he had not been very happy in his work there and would not care to say much about it. The writer's belief is that his teaching load was so heavy that he could find little time to apply himself to lines of work in research, etc., which were more to his liking. We do know that he responded most enthusiastically to the invitation to return to the Coast Survey.

COAST AND GEODETIC SURVEY, 1898-1909

As stated elsewhere in this memoir, Hayford's correspondence was exceedingly heavy and he was very careful in preserving it. But of his personal correspondence previous to his coming to Northwestern University the writer has not been able to locate much. Evidently it had been packed and placed in some place unknown to or forgotten by his relatives. Among the very few letters preserved in their original envelopes is one on which he had written in red ink, "Letter which brought J. F. H. to the C. & G. S. in 1898," and is dated January 1, 1898. In this letter Henry S. Pritchett, then Superintendent of the Coast and Geodetic Survey, writes to Hayford at Cornell:

"I should be glad to have a talk with you in regard to certain plans which are likely to be carried out in the Coast and Geodetic Survey and which will, if put into execution, give opportunity for permanent work in geodesy along lines which promise results of great interest and value."

Under date of June 2, 1930, Dr. Pritchett wrote to the writer regarding Hayford's entry into the Coast Survey:

"When I went there in '97 and began to study the institution and its organization, one of the first requests I made was for some one who would come as an understudy to Mr. Schott, with the understanding that he would, in a short time, become chief of the division. Mr. Schott was still vigorous but getting quite old. I was led to think of Hayford because of the admirable work he had done in the Survey and because of some of his papers. I never knew him until he came to the Coast Survey.

At that time he was at Cornell. I got him to come down to Washington and talk the whole matter over with me and was delighted at the enthusiasm and interest with which he took up his task."

Evidently the position offered to Hayford at this time was subject to U. S. Civil Service Commission examination, for Hayford took an examination for Expert Computer and Geodesist on June 7, 1898, and on July 6 was rated by the Commission as here shown:

Ability and experience in discussion of geodetic problems and administration of computing work	100
Publications in the line of Geodesy, mathematics and astronomy	100
Positions held in professional life	100
Mathematics	95

It is not known whether he had any competitors in this examination, but it certainly would have been difficult for any one to have exceeded the score made by Hayford. It was a score which practically assured him of the appointment.

As Cornell University was at that time organized on the term instead of the semester basis, we find that Hayford's work at the university came to a close at the end of March, 1898, and he moved with Mrs. Hayford and their son Walter to Washington.

He evidently had been given temporary work in the Survey pending his regular appointment, for on May 11, 1898, he was given instructions by the Superintendent to confer with Professor J. H. Gore of the Columbian University in reference to his proposed pendulum observations at the Survey office and to assist Professor Gore to the extent of observing time for these observations. Also this temporary appointment must have been to the position of Expert Computer and Geodesist, for on July 1, 1898, such an appointment was continued until July 15. On July 9, 1898, the Civil Service Commission certified to his probationary appointment as Expert Computer and Geodesist, and Hayford took the oath of office on that same date.

He was assigned by the Superintendent to report to the Assistant in Charge of the Office for duty in the Computing Divi-

sion, taking the position of chief computer. His duties were to have general charge of the other employees in the division, under the direction of Assistant C. A. Schott. Hayford at this time was only thirty years of age, and comparatively young to have charge of a division in which, at times, there were many men considerably older than he was, and men with considerably more experience. How well he carried on is fully shown by the work of the Computing Division and Geodetic sides of the Survey in the following years, and thus was added one more to the long train of scientists which starting from Hassler did so much to bring the U. S. Coast and Geodetic Survey to its high position in the scientific world.

It was in July of this year that he completed his text-book on Geodetic Astronomy on which he had been engaged since August, 1896, and on which he had put over 1200 hours of work. Although working in the Geodetic and Computing Divisions at this period, Hayford evidently found time to work in other fields than the strictly geodetic, for in December, 1898, he published in *Science* a lengthy article on "The Limitation of the Present Solution of the Tidal Problem," and in March, 1899, *Terrestrial Magnetism* published his monograph, "Is There a 428-day Period in Terrestrial Magnetism?" The latter contains, probably, Hayford's first attempt at utilizing, for purposes of research, the stresses that are set up in the material of the earth.

On July 29, 1898, Hayford was instructed by the Superintendent, by authority of the Secretary of the Treasury Department, to attend the meeting of the American Association for the Advancement of Science at Boston in August, 1898, to officially represent the Coast and Geodetic Survey.

On May 3, 1899, his designation was changed to that of Inspector of Geodetic Work, and in the same year he was given an appointment as Assistant in the field force of the Survey. His rating as Inspector of Geodetic Work was granted upon the recommendation of Charles A. Schott, the "Grand Old Man" of the Coast Survey, and who for more than fifty years was identified with the work of the Coast Survey. At this time Schott was in charge of the geodetic work and of the Computing Divi-

sion; he was reaching an advanced age and realizing that his life's course was about completed, gave up the supervision of the geodetic work in 1899 in order to devote the remaining years to the completion of the transcontinental and eastern oblique arcs of triangulation in the United States. How well he reckoned may be judged from the fact that the Great Transcontinental was published in 1900 and the manuscript for the Eastern Oblique Arc completed in 1901, and on July 31, of the same year Mr. Schott received his "final call" at the age of seventy-five.

In 1900 Hayford, having served as Schott's understudy in the Computing Division for two years, became Inspector of Geodetic Work and Chief of the Computing Division in the Survey. He was the first man to have this double designation granted to him. Schott, as Chief of the Computing Division, was also the directing agent of the geodetic work, but so far as the writer has been able to learn, both titles had never been officially conferred upon him. In this position Hayford had charge, under the Superintendent's direction, of the operations of triangulation, leveling, astronomical determinations and gravity work, from the formation of the plans for field work to the publication of the results, with supervision over the field as well as the office operations.

During 1898-1909 very notable advances were made by the field parties under Hayford's direction in the methods of precise leveling, primary (now called first-order) triangulation, telegraphic longitude determinations, in gravity work, and in the methods of determination of the figure and size of the earth from geodetic operations. In each case a much higher efficiency was secured than formerly, the unit cost of the work being greatly reduced, while in many cases an increased accuracy was obtained. While these were the most important operations carried on under his direction, there were many minor ones in which he had a helping hand in improving, or modifying, so that the operations were carried on more economically or more conveniently. These various phases of his labors will be treated at greater length elsewhere in these memoirs.

During this period Hayford was rapidly improving his mathematical skill and his knowledge of the applications of mathematics and engineering to geodesy. Dr. Pritchett wrote concerning Hayford's work, "In my efforts, during the three years I was Superintendent of the Survey, to reorganize in large measure the scientific work I found Hayford a most practical and willing adviser. He had unusual mathematical ability coupled with the quality of clear judgment—a rare combination."

While still Inspector of Geodetic Work he spent considerable time in the preparation of the Fourth and Enlarged Edition of Coast and Geodetic Survey treatise on "Determination of Time, Longitude, Latitude and Azimuth," which was published in 1899, and which forms the manual for field operations in these subjects. Many important additions were made to the Third Edition, compiled by C. A. Schott, Assistant. The principal additions were (1) an account of the method of determining differences of longitude by transportation of chronometers as used by the Survey, (2) an account of the micrometric method of determining azimuth by means of a theodolite or transit furnished with an eye-piece micrometer, (3) considerable new matter bearing upon the relative magnitude of errors to be expected from various sources, and upon the economics of observing. This manual was published one year later than Hayford's *"Textbook on Geodetic Astronomy,"* from which some of the material for the manual was derived.

Although Hayford was continually at work studying to improve existing methods and devising new methods to make the operations in his departments more efficient, when once these methods proved efficient he proceeded to gather together all the good features and place them in convenient form for use by his office or field force. These collections were then issued in the form of "Standard Instructions" and they constituted the basis on which the work should be carried on. In this way the chiefs of parties had definite goals set them in the results to be attained and they seldom had to grope about for the general methods of procedure. This did not mean that they could not use their own initiative. In case any man thought he had a better way

and would produce evidence, Hayford was always willing to consider such evidence and gladly made the changes in the instructions if evidence warranted it. He was always ready to listen to any proposal from his subordinates in this respect. Results, and these within specified limits of accuracy and with a consideration of economy in expenditure of time and money involved, were the prime factors he considered. This led to a fine *esprit de corps* in his department and the men gladly gave of their energy, both mental and physical.

It is difficult to tell, in an orderly and continuous narrative, of Hayford's activities from 1898 to 1909. In addition to carrying on the routine work of the two divisions of which he was in charge, his many researches led him into so many fields that to portray them in a suitable manner necessitates that they be considered separately, even though there is an overlapping in the time element. Consequently, his various activities are dealt with in the separate accounts which follow, and which bring the story of his life and works up to November 1909, when he resigned from the United States Coast and Geodetic Survey to accept the position of Director of the College of Engineering at Northwestern University, Evanston, Ill.

Precise Leveling

When Dr. Pritchett took charge of the Coast and Geodetic Survey in 1897 the matter of precise leveling was, to quote his words, "in a bad way," and "the instruments we were using at that time had certain drawbacks." He appointed Mr. Hayford chairman of the committee to take up this matter, and largely due to him a régime of precise leveling was introduced which both greatly reduced the expenses of field work and improved the instrumental conditions.

In the winter of 1898-99 the committee made a most exhaustive study of the leveling executed in the United States by the Coast and Geodetic Survey, as well as by other organizations of this government, and also by foreign governments, and of possible errors and of their sources. One of the things discovered was that there existed a systematic error which was traced

to the unequal thermal expansion of the leveling instruments which had been employed. As a result of Mr. Hayford's studies he made recommendations to Mr. E. G. Fischer, at that time in charge of the Instrument Division of the Survey, that a level should be designed which would not be seriously affected by temperature. There is some question as to whom credit should be given for the design of this level. In a letter written April 11, 1911, to Professor W. K. Hatt of Purdue University, Mr. Hayford says, "I was responsible for fixing the general features to be embodied in the instrument and Mr. E. G. Fischer, the Chief of the Instrument Division, made the design." The level which was the outcome of the work by Mr. Hayford and Mr. Fischer and now known as the "U. S. Coast and Geodetic Survey Precise Level" was constructed in the shops of the Survey under Mr. Fischer's supervision early in 1900. The writer had the good fortune to be one of two men to whom was assigned the first field work with these new levels. It has been in constant use for over thirty years by the Coast Survey, to the practical exclusion of all other forms of precise levels, and has been used by other organizations in this country and to a great extent by geodetic organizations in other countries. It is generally recognized as the most efficient instrument for leveling of high precision that has ever been designed. Lallemand, the great French exponent of hypsometry, once made the statement that "with its use practically all of the errors of precise leveling exist *outside* of the instrument."

The most important features of this instrument and methods adopted in the precision leveling organized by Mr. Hayford were (1) Use of invar to as great an extent as possible to minimize temperature changes; (2) Adoption of the dumpy form with low center of gravity, giving relatively few parts to get out of adjustment, and high stability; (3) Single micrometer screw under the eye-piece of the telescope affording rapid manipulation and ease of holding the bubble centered even under difficult conditions; (4) The use of a reading device which enables the observer to see the bubble clearly at any time without moving his eyes from the eye-piece, and (5) A firm mounting of the level

vial nearly in the line of collimation, and in such a position that it is unusually well separated from rapid changes in temperature and, therefore, with the result of securing an unusually stable relation of the vial and telescope.

Before the introduction of this level the rate of progress was less than sixty miles per month. Recent work, which is of a much higher grade of accuracy, shows an average of about one hundred miles, and one observing party recently completed one hundred and forty-eight miles of progress, or more than three hundred miles of single line in one month. The cost of the operations in precise leveling has decreased in about the inverse proportion as the speed per mile of progress.

On January 23, 1906, in an address before the Washington Society of Engineers where he spoke regarding the level, after six years' experience with it, Mr. Hayford said, "This experience shows that such rapid and economical leveling has been accomplished with this instrument and methods as to prove that the same type of instrument and a similar method, if applied to leveling of the grade and accuracy ordinarily done with the wye level, would give much more rapid and much less costly work than the wye level ever can give." And then he issued this challenge, "Any engineer who will consider carefully all the available facts of this experience will find in them a standing challenge to show why he should not consign his wye-level to the junk-heap."

Length of Triangle Sides

In the older schemes of triangulation it seems to have been the practice in selection of stations to obtain practically the longest lines possible. Mr. Hayford's studies led him to the conclusion that this caused the triangulation to become excessively costly and slow. From various considerations he concluded that the extreme lower limit should be about five kilometers, but that this extreme lower limit should be avoided. On the other hand he concluded that from a standpoint of accuracy there was no advantage in using extremely long lines. According to his instructions to parties, the general considerations upon

which they should base their decisions were: (1) The cost of the work, including reconnaissance, signal building, and angle measurements, should be economical, and (2) there should be a sufficient number of accessible stations established to serve the immediate needs of the survey, and also to leave points useful to engineers; they should use the most economical length of line, namely, that length which would give the maximum of usefulness with the minimum of cost.

Strength of Figure Formula

The success of triangulation depends in large measure upon the intelligent investigations made in the reconnaissance. These investigations include the selection of the strongest and most feasible figures for the triangulation as affecting the economy of the operations to follow. The shape of the triangles constituting the figures must be taken into account. As the shape of a triangle is determined by its angles, the angles, therefore, must be taken into consideration.

Up to the year 1903 the general criterion which the man on reconnaissance kept in mind was that no angle should be less than 30° in the main scheme for primary triangulation. This often entailed considerable trouble to the reconnaissance party, and made difficult revision of points already selected, thus affecting the speed and economy of the operations. Mr. Hayford made a study of the strength of figures used in triangulation by applying to them the principles deduced in Least Squares, and among the general conclusions drawn by him was the fact that the 30° criterion was not necessarily a good one in all cases. He propounded the proposition that the triangles of a chain of figures be tested, this test to be based upon the magnitude of the *distance* angles used in computing the lengths from base line to base line and he proposed the now well-known strength of figure formula.

In February 1903, during one of the periods between field seasons when the writer was attached to the computing division of the Coast and Geodetic Survey, this problem was given to him by Mr. Hayford with instructions to study the methods

and to prepare the necessary tables to make it easily applicable to field use. It was first applied in actual field work by the writer in conjunction with Signalman Jasper S. Bilby while engaged on reconnaissance for primary triangulation in South Dakota in 1903; and it proved so successful that practically all reconnaissance is now executed in accordance with this method. By using this method the field officer on reconnaissance can, after having obtained rough angles for the triangulation figure under consideration, in a few minutes of time decide whether the figure is within prescribed limits of accuracy. It is safe to assert that it has very materially helped to produce more rapid and more economical reconnaissance without a lowering of the accuracy of the triangulation.

Base Measurement

Prior to 1900 all of the base lines used on arcs of first order triangulation, with only three exceptions, had been measured by using metal bars. The use of the steel tape had not received full sanction by those engaged in base-line work. There was a division of opinion among scientists as to whether or not the required degree of accuracy could be obtained with the tape. This doubt was natural with the older scientists for they had been trained in the school where bars were recognized as the prime requisite for base apparatus. Immediately after Mr. Hayford assumed charge of the Geodetic Survey he made a study of the measurements with tapes in this country, and with long wires in other countries, and became convinced that the long steel tape could be used in place of bars on base measurements provided these measurements were made at night. The coefficient of expansion of the material of the tapes was so great, and the uncertainty in the determination of the temperature of the tape by means of the attached thermometers was so large that it was believed by Mr. Hayford that the tape measurements should be made at night, as then the temperature of the tape and of the attached thermometers would be practically the same. Tapes had been experimented with at the Holton Base, Indiana, on which work Mr. Hayford had acted as recorder in

1891. He, therefore, had had some field experience in their use and also with base bars of the older type.

Mr. Hayford, with commendable caution, did not at once eliminate base bars, but decided to make a careful field comparison of the results obtained with base bars, 50-meter steel tapes and 100-meter steel tapes. This was done during the measurement of nine bases along the 98th meridian during the latter part of 1900 and early in 1901 with Mr. A. L. Baldwin in charge of the measuring party. A detailed report of this great accomplishment in the comparison of base measuring apparatus is contained in Appendix 3 of the Survey Report of 1901 by A. L. Baldwin, with a preface by Mr. Hayford.

On the base measurements along the 98th meridian there were used the Eimbeck base bars which had been developed for the measurement of the Salt Lake base, and the 50-meter and 100-meter steel tapes. Each base was divided into approximately three equal sections. One section was measured with the base bars, another with the 50-meter steel tapes, and the third with the 100-meter steel tapes. Each part of a base was measured at least twice in opposite directions. A kilometer of each base was used for an intercomparison of all the apparatus used on the base. From this test kilometer a true comparison of the tapes and of the base bars was obtained. The field party was also required to standardize the base apparatus at the beginning and end of the field season by using the iced bar designed by R. S. Woodward. This standardization was done in the field under conditions approaching as closely as possible in every respect those encountered during the base measurements proper.

The results of these tests indicated that the speed with which tape measurements could be made was more than two and one-half times as rapid as the bar measurements and the cost of measuring was about one-third of that with the bars, all work being executed in such a manner as to keep within a requisite degree of accuracy, indicated by a probable error of one part in 500,000. The accuracy with which the bases were measured gave about equal results with the tapes at night and

with the Eimbeck bars, while the operations were carried on much more conveniently with the former.

As a result of these comparisons on the 98th meridian, the Coast and Geodetic Survey adopted the 50-meter tape as the standard length for base work. To the student of the progress of science and of engineering this campaign will be interesting because it was planned and carried out in the spirit of engineering rather than of science, whereas in the past the reverse had been true as a rule. The engineer accepts past experience as his working material, decides upon the results which it is desired to secure, and then selects such methods as will secure those results with the minimum expenditure of time and money. The previous statement seems to embody Mr. Hayford's formula for all of the work planned by him, and to it is due in large measure the success attained by parties working under his direction.

Late in the past century, Professor Charles Guillaume of Paris discovered an alloy of nickel and steel (later called Invar) which has a very low coefficient of expansion. It was found that this could be rolled into wires and tapes, and Mr. Hayford soon recognized the possibility of using invar tapes in the measurement of primary base lines. On his recommendation the Coast and Geodetic Survey purchased a number of 50-meter invar tapes. The experimental work with these tapes, prior to their being taken to the field, was done by Assistant O. B. French, and these tests showed that the invar alloy had sufficient strength and elasticity for base measuring purposes, and so Assistant French was assigned, in 1906, to the measurements of six bases with them.

As in the case with the steel tapes, so here again a good field comparison was made in the case of the invar tapes. Assistant French measured the six bases with both invar and steel tapes, and the results showed conclusively that the invar measurements, made in daylight, frequently in bright sunshine, were even better than the measurements with the steel tapes at night. Since these successful tests of the invar 50-meter tape in 1906, there has been practically no improvement in base apparatus. Invar

tapes are now generally recognized as ideal for the work, and it is difficult to see how any improvement over them could be made.

Triangulation

Shortly before Mr. Hayford took charge of the geodetic work of the Coast and Geodetic Survey, the great transcontinental arc of triangulation along the 39th parallel had been completed, as well as an arc of triangulation along the Pacific Coast from San Francisco Bay to the Mexican boundary. The eastern oblique arc from New Orleans to Maine was practically completed. Their computations were being rushed to completion by Charles A. Schott, "The Grand Old Man of the Coast Survey," as a final and fitting close to his fifty years of service with the Survey. The year 1901 saw the completion of these computations, and in July of the same year Mr. Schott received his "final call."

The data for the stations composing these arcs were found to be of such great value in the surveying and mapping of the interior of the country, and for other purposes, that there was an urgent demand that similar arcs be extended over the whole interior of the country. To do so seemed a formidable undertaking, for the progress of a single observing party on first-order triangulation was approximately from eight to fifteen stations a season of approximately six months, or a progress along an arc of triangulation of from sixty to one hundred miles.

Mr. Hayford carefully studied the triangulation methods of this and other countries, and found that the efficiency with which the work was done here was quite equal to the best that was obtained abroad. However, his studies led him to believe that our methods could be improved upon, and he spent much time in studying methods and apparatus in detail, and consulted with many men on the force, especially with Mr. E. G. Fischer, Chief of the Instrument Division, in regard to apparatus, and with Mr. Jasper S. Bilby, at that time a signalman in the Survey, with the result that a number of radical changes were proposed and tried out in the ensuing years.

Signal Lamps

The development of the heliotrope at the time that Mr. Hayford took charge of the work was well advanced and was admirably suited for observations during afternoons when sunshine was available, but even on the best of days a few hours only could be utilized for observing. Night lamps of several kinds had been used, but with inconsiderable success, especially on moderately long lines. This led to the development of the signal lamp, which was first used in 1902 on the triangulation in Kansas southward along the 98th meridian. This consisted of an acetylene bicycle lamp to which was attached a condenser lens. In the middle west, where the atmospheric conditions are generally favorable, these lamps were effective to distances as great as 35-40 miles. The period of observing was thus increased from two or three hours a day to from ten to twelve hours by the inclusion of night observations, and it was proved that night observations were made more rapidly and with practically the same degree of accuracy as those made in the daytime. A few years later a larger acetylene lamp, such as was used at the time on automobiles, was modified as a triangulation signal lamp. The larger lamp proved to be very effective on lines of triangulation ranging from 30 to 75 miles in length. The writer has often used these larger lamps in tandem, one above the other, during murky weather, where it was impossible to catch the faintest glow from a single lamp, thus saving long, long periods of waiting.

Signal Towers

During this same year (1902) the style of observing tower was radically changed by improvements in design and methods of erection by Signalman Jasper S. Bilby, resulting in a great saving in time and strength of structure. Also the program of operation planned by Mr. Hayford on this work was a rather marked change from the older programs. The principal features of the 1902 organization and methods employed were:

1. Two parties which erected the wooden towers needed to elevate the instrument, heliotrope, and signal lamp to such

heights that the sides of the triangles were clear of obstructions.

2. The employment of two observers, one on each side of the arc of triangulation.

3. The permanent employment of light-keepers who would remain at a station and direct the light from the heliotrope or lamp toward the observers. Communication between observers and light-keepers was effected by employing the Morse Code, flashes of light being used to transmit the signals. Movements of the various groups were thus expeditiously ordered, with a consequent saving of much time.

4. The completion of the observations at a station in the main scheme of the triangulation during a single observing period, afternoon and night, if practicable to do so. Prior to the season of 1902 it was generally believed in this country and abroad, that the angles of the triangles should be observed on a number of different days in order to have varying weather conditions; it was believed that by following this method, the accuracy of the observed angles would be much greater.

The 1902 season was a marked success. While the previous record for a single party during any one season was 15 stations, with a maximum distance along the arc of 70 miles, there were 75 stations in the main scheme completed in 1902 and the progress along the arc was 444 miles. This was a far-reaching and epoch-making accomplishment in triangulation. Following 1902 other parties had greater accomplishments in number of stations per unit of time for a single observer and length of arc completed, yet the 1902 project marked the first great step forward in the application of engineering principles to first-order triangulation.

The great improvements made in the triangulation methods of the Coast and Geodetic Survey gave much promise of extending the first-order triangulation net over the United States in a reasonable number of years, for surveying, mapping, and many other uses. It was rather noteworthy that, up to the 1902 season, there had been accomplished only 5300 miles of

first order triangulation. The first observing had been done under the immediate direction of Ferdinand R. Hassler, the first Superintendent of the Bureau, in 1816, eighty-six years before. Since the beginning of the season of 1902, there have been executed by the Survey nearly 23,000 miles of arcs of triangulation.

The writer hesitates to close this account of the accomplishments of the work of the Survey without a brief sketch of the part played by Signalman Jasper S. Bilby. In the execution of the reconnaissance for triangulation, base-lines, and signal-building, Mr. Hayford and his successor, Major Bowie, were most fortunate in having a man on the Survey of the caliber of Jasper Bilby, a man who in his chosen field stands supreme in the world. Practically all of the reconnaissance and signal-building in first-order triangulation since 1900 has been executed by him or under his immediate direction, and to him is due, in large measure, the phenomenal mileage in first-order triangulation accomplished by the Survey.

Angle Measures

The writer is unacquainted with the part played by Mr. Hayford in instituting changes toward improvements in methods of angle measurements, with the one exception of the ingenious program of observing devised by Mr. Hayford, having for its objective the elimination of the necessity of computing and applying a correction to the observed directions, due to "error of run" in the micrometers of the direction instrument. The program of observing also caused the mean value of any angle to be practically free from errors due to periodic errors of graduation of the circle in the theodolite. This program called for sixteen direct and reverse sets of observations of directions over each line of the main scheme, each direct and each reverse set to be referred to the same initial line wherever possible, and each set to have a varying initial reading on this reference initial line, these varying initial readings to be spaced at definite positions around the circle. This method has been used to the complete exclusion of the older method, where error of run was taken into account, and has greatly facilitated the resulting computations.

It is believed, but of this the writer is not sure enough to make a decided statement, that Mr. Hayford is also responsible for the introduction of the two sets of double parallel lines used in making the backward and forward readings of the micrometers of the microscopes of the direction theodolite, which has so materially aided in making the observations and resulting computations of the triangulation. These double parallel lines in the micrometers were first used in 1903-1904 in Texas and all of the theodolites thereafter have been so fitted.

Primary Azimuth

In order to safeguard and to check the computed azimuths as carried through the triangulation and to control these in the least square adjustment of the net, it is necessary that astronomical azimuths be observed at intervals along the system. Up to 1904 these azimuths were at times observed by an independent astronomical party after the triangulation had been completed. This to Mr. Hayford's mind was productive of extra expense and loss of time, necessitating a second party in the field with the probable chance that the observing tower and azimuth mark tower would have to be rebuilt, or at least repaired if still extant. Also he believed that the resulting azimuth would be more accurate and serve its purpose to better advantage if observed at the same time as the triangulation, under the same conditions, and over one of the actual lines of the triangulation net. This program was first carried out by the writer on the triangulation from Brown's Valley, Minnesota, eastward to Aitken, Minnesota. It proved so successful that subsequent parties have followed this method. By it the regular directions observations on the main lines of the triangulation are temporarily discontinued and the angle between Polaris and one of the lines of the main scheme of the triangulation is observed in exactly the same manner, using the same method of observations as in the main scheme, the only difference being in the number of observations required for the azimuth observations.

Whereas the limit of rejection of observations upon directions in the main scheme was five seconds of angle from the mean of the sixteen direct and reverse observations taken, in the azimuth work the limit of rejection was fixed by the probable error of a single observation, and the observers were instructed to make a sufficient number of observations to make it reasonably certain that the probable error of the mean was within certain specified limits. In order to obtain this required accuracy, it was seldom necessary to take more than the normal set of sixteen direct and reverse measures. The results of this method silenced the criticisms, made before its adoption, that azimuths could not be obtained with a sufficiently high degree of accuracy from the tops of the high towers, and especially without observing on two or more nights in order to introduce varying weather conditions. After the party became accustomed to this work, the delay occasioned by discontinuing the regular observations in order to obtain azimuth observations was seldom over an hour or two, and with but slight inconvenience to the triangulation party.

While the phenomenal success of the triangulation after Mr. Hayford took charge of the geodetic work is due in large measure to the men who accomplished it in the field, to Mr. Hayford should rightly go the credit for the adoption of the methods to be employed and for the manner of selecting the men to carry out the work. Being in responsible charge of the geodetic work, any failure on the part of the field force in carrying out any adopted program would immediately be thrown back as a criticism of Mr. Hayford's régime. On the other hand credit should be given his régime when work was carried on successfully, even though in large measure credit be given to those actually doing the work. Since many of the methods were rather radical changes from the older order, it was inevitable that criticism would arise. Mr. Hayford selected men for the work who had but few years' previous experience on the work and thus were comparatively without prejudice and were therefore free to try out any change proposed. How well this worked out in actual practice is shown by the results.

Astronomical Latitudes

The most important improvement that Mr. Hayford made in the determination of astronomical latitudes was to change the method of observing the same pairs of stars on more than one night. He was convinced from his investigations that the uncertainty in the star positions was greater than the uncertainty in the observations for latitude, hence he concluded that it would be better to use a larger number of pairs of stars and to make all of the observations on a single night, if practicable. In other words, he concluded that single observations on each of many pairs of stars was a more effective method of obtaining a high degree of accuracy than to use a limited number of pairs of stars with each pair observed on two or more nights. The Superintendent approved Mr. Hayford's recommendations in this respect, and that method is still being followed by the Survey.

In 1905 a large campaign of latitude observations was inaugurated by the Coast and Geodetic Survey on which the plan described above was first followed. The writer had the pleasure of being in charge of the field party carrying on this work and between 1905 and 1908 determined the latitudes at 63 stations in the United States, with an average of 1.9 nights of observations at a station in order to obtain the requisite degree of accuracy. In 1908 Assistant William Bowie, now Chief of the Division of Geodesy in the Survey, occupied seven stations and at only one station were observations made on more than one night. The instructions under which the parties operated called for a sufficient number of pairs of stars to be observed at one station to make it reasonably certain that the probable error of the result should not be greater than $\pm 0''.10$.

Another decided advancement in the operations of determining latitude was in regard to computing the micrometer value. Previous to 1905 the general method in use was to turn the micrometer box 90° and observe upon close circumpolar stars near culmination. Such observations consume time both in observing and in computing, and experience showed that they were subject to errors. A careful study was made by Mr. Hayford

of this part of the work and the Survey decided to adopt the method of computing the micrometer value from all of the latitude observations at a station, for it seemed quite evident that the value obtained in this way was more accurate than that determined from even three or four sets of circumpolar observations, each requiring an hour or more of time, and since the beginning of the 1905 latitude campaign no observations have been made on close circumpolar stars for that purpose.

The Transit Micrometer

A short time previous to the beginning of the present century Repsold, the great designer and maker of astronomical and other instruments, had designed what was called the "impersonal micrometer" for making observations of star transits by means of a movable transit line in the eye end of the observing telescope. Such a micrometer driven by clock work had been used many years before, but with little success. Repsold's design called for a hand driven movable line, and tests by the Prussian Geodetic Institute proved its superiority over the other methods of observing star transits. The prime object of the attachment was to eliminate the effect of the personal equation in making observations for time.

After Mr. Hayford assumed charge of the geodetic work he made a careful study of the possibility of using the impersonal micrometer on the transits of the Coast and Geodetic Survey for longitude work. While it had proved successful on the instruments at fixed observatories, the question to be decided was whether it could successfully be applied to the lighter portable transits in use by the Survey. At his request, Mr. E. G. Fischer, Chief of the Instrument Division of the Survey, purchased an impersonal transit micrometer from Repsold. He made certain modifications, simplified the apparatus, and made it more effective for use.

Very exhaustive tests of this improved impersonal micrometer, or "transit micrometer" as it is now known were made at the office of the Coast and Geodetic Survey under Mr. Hayford's direction. These tests were made on eighteen nights be-

tween March 15 and May 3, 1904, sixteen different observers taking part. These observers ranged from observers having much experience on longitude work to those having had no previous experience on any kind of field work. The results of the test showed that the relative personal equation between any two observers with the transit micrometer is so small as to be masked by the accidental errors of observation, and, therefore, it would be unnecessary to have exchange of observers on longitude work, a procedure that had up to this time been followed. The transit instruments of the Survey were accordingly fitted with transit micrometers of this improved type, and when used in actual longitude work proved to be most successful in facilitating field operations and in reducing the time and cost involved in making longitude determinations.

Standard Datum

Toward the close of the last century there had been completed in this country a number of arcs of triangulation, principally the great transcontinental arc along the 39th parallel of latitude and the eastern oblique arc. While all of these arcs had been computed on the same spheroid of reference (Clarke 1866), there was, owing to the detached character of many, no harmonious correlation between them. It was apparent, if these arcs were to serve their highest purpose, that they must be brought into close correlation with each other.

In the United States this was accomplished by the adoption of an initial point to which all of the connected arcs then existing were referred. Not only was an initial point selected (station Meades Ranch in Central Kansas), but a latitude and longitude for that station were adopted which would make the sum of the squares of the differences between the triangulation and astronomical latitudes and longitudes of a number of astronomical stations a minimum.

Upon examination of the data, however, Mr. Hayford found that the datum used for the triangulation in New England agreed so closely with the chosen ideal datum, that upon his recommendation the Superintendent of the U. S. Coast and Geodetic Sur-

vey in 1901 approved the adoption of the latitude and longitude of station Meades Ranch, as computed through the triangulation from the New England datum. By selecting this position for Meades Ranch a large amount of recomputation could be avoided. The foundation thus having been laid, Mr. Hayford, as Chief of the Computing Division of the Survey, started several members of this force on the long labor of recomputing and adjusting the triangulation of the United States upon this, the then designated United States Standard Datum.

This was a geodetic movement of far-reaching influence, not only to the United States, but also one of great importance to the North American continent. It placed the geodetic work of the survey upon one datum for the correct coordination of the geographic latitudes, longitudes, distances, and azimuths. From the scientist's point of view it furnished accurate correlation of data for a study of the figure of the earth, of isostasy, and for other related sciences. Since that time all of the triangulation of the United States has been computed on that datum.

Owing to the fact that the triangulation of Canada and Mexico coincided with that of the United States at many points along their common boundaries, the United States Standard Datum was adopted by those countries in 1913. It thus became a matter of international importance, and consequently its designation was changed to that of North American Datum, an event of great importance in the history of geodesy.

Dr. William Bowie, now chief of the Geodetic Division of the Coast and Geodetic Survey, in writing to Professor Hayford in regard to some publications of the Survey, on December 6, 1913, wrote the following: "The foundation for most of these publications was laid when you extended the U. S. Standard Datum throughout the triangulation net of the country."

The Standard Datum, as finally adopted, assigned to the station Meades Ranch the following position on the Clarke Spheroid of 1866:

Latitude	39°13′26″.686
Longitude	98°32′30″.506
Azimuth to Waldo	75°28′14″.52

Gravity at North Tamarack Mine

In 1902 President F. W. McNair of the Michigan College of Mines, in an interview with the Superintendent of the U. S. Coast and Geodetic Survey, indicated that if matters could be arranged he would like to have the Survey furnish the necessary instruments and an officer skilled in their use to make some determinations of the value of the intensity of gravity at the North Tamarack Mine near Calumet, Michigan.

Such an arrangement was made with the Survey and with the mine owners, and Mr. Hayford was given the assignment to carry on the work with President McNair.

The regulation standard set of quarter-meter pendulums were used on this work. They were standardized at the base station in Washington in August before being taken to Calumet and standardized again in October after their return.

The observations were made at the North Tamarack Mine between September 9 and 20. Three stations were occupied. One was upon the surface. One was in the same vertical line as the surface station, and about 4600 feet below it. The third station was about 1200 feet below the surface station, and a few hundred feet out of the vertical.

The purpose of the observations was to determine the difference between the value of gravity at a point on the surface at the mine and two points beneath the surface, with a view to studying the vertical gravity gradient. Such a determination of the gravity gradient in connection with an estimate of the density of the materials between and near the stations would furnish a new determination of the mean density of the earth. It would be still more valuable, however, as furnishing a means of testing various theories as to the formation and present condition of the earth.

An account of this work was made by Mr. Hayford in an unpublished report to the Superintendent of the Survey in February 1904, and contains a most splendid discussion of errors and their effects upon the value of the intensity of gravity. In so far as the writer knows, this is the only case where Mr. Hayford was actually engaged in a field determination of the value

of the intensity of gravity, although he had engaged in pendulum work at the base station in Washington. It was probably one of the contributing causes which crystallized his efforts in starting the long campaign of gravity observation which in a few years was destined to add so many new determinations to the list of those executed in this country.

Deflection of the Vertical

After Professor Hayford had placed the triangulation of the United States on the United States Standard Datum, as explained elsewhere in this memoir, he was in a position to make a comprehensive study of the deflections of the vertical at many of the triangulation stations of this country. It is not known when this problem was first brought to Hayford's attention, but the following, quoted from a letter to the writer by Mr. O. H. Tittmann, formerly Superintendent of the Coast and Geodetic Survey, may solve the question. Writing under date of June 24, 1930, Mr. Tittmann says:

"It may be of interest to you to know that Helmert suggested to me the desirability of computing the osculatory surface fitting our extensive and homogeneous triangulation rather than to discuss meridians and parallels. When, as Superintendent, the opportunity came to me, I submitted to Hayford the problem of doing it, and of correcting the triangulation for deflection of the zenith. How well he solved the problem is known to all geodesists, and Helmert told me, after the publication of his results that he himself would have hesitated to undertake so extensive a computation."

As is well known, there is a lack of harmony between latitudes and longitudes determined by direct measurements of triangulation and those determined by astronomical means. These discrepancies were generally recognized as being due to the effect of the irregular surface of the earth on the direction of the plumb-line at the points where the astronomical observations were made, the astronomical observations being referred to the direction of the plumb-line at the point of observation. Any

disturbance of this direction necessarily affects the resulting latitudes and longitudes.

The problem of the deflection of the vertical is so intimately related to Hayford's two other monumental works, Isostasy and the Figure of the Earth, that it is almost impossible to separate them. Hayford attacked the stupendous work of computing the deflections of the vertical only after most careful study and consideration of the difficulties involved. His plan was approved by the Superintendent of the Coast and Geodetic Survey, who permitted the research work to be carried on in the Computing Division of the Survey. The rate of progress was mainly fixed by the fact that only a small amount of time was available in the Division, for the major duty of the Division was taken up in the general work of the Survey, and research work of this type could be but a small part of the activity of the Division.

Upon these three works, i.e., deflection of the vertical, figure of the earth, and isostasy, Hayford was engaged for more than ten years. As he states, "Attention has been given to the problem during hundreds of short periods of a few hours each, or even of a few minutes each, in the intervals between other duties."

In the first study of the deflection of the vertical reported upon to the International Geodetic Association at Copenhagen in 1903 there were available 246 station errors in latitude, 76 in longitude, and 152 in azimuth, all expressed on the United States Standard Datum and therefore comparable with each other. Hayford made computations to show what should be the theoretical values for the deflections of the vertical at the many astronomical stations that were connected with the triangulation, and devised methods for rapidly reading from maps what effect each topographic feature had upon the deflection of the vertical at any station. While studying the relation between the general features of the topography and the direction of the vertical in 1901, he reached the conclusion that one very efficient means of investigation would be the graphic method, and accordingly such a method was devised. By it the effect of all topographic irregularities within 4,126 kilometers of each astronom-

ical station were taken into account in studying the deflections.

An examination of tabulated deflections showed that there was a strong tendency for the deflections of the vertical over various regions of considerable magnitude to be of one algebraic sign. In other words, there was rather conclusive proof that there exist regional deflections common to large areas of the United States, as well as local deflections about a station. The most salient fact brought out by a study of the list of deflections was that there is a decided tendency for the deflections on both the Atlantic and Pacific slopes to be in such a direction as to indicate that they are due to an excess of mass beneath the oceans or to a defect of mass in the continent, or to both.

These facts led Hayford to a consideration of the theory of Isostasy which had been advanced some years before by geodesists and geologists, and also to a consideration of the Figure of the Earth.

Figure of the Earth and Isostasy

Mr. Hayford began the study of the figure of the earth about 1903. The report made to the Fifteenth General Assembly of the International Geodetic Association, held in Budapest, Austria, in 1906, gave an outline of the methods which he devised and was following in his investigations of the figure of the earth. In that report a statement was made as to the data used and how the computations of the topographic deflections were made. Topography was considered by Mr. Hayford to be the masses of the earth's material above sea-level and the deficiency of mass in tidal waters.

Professor Hayford's methods of attacking the determination of the figure of the earth formed a notable contribution to geodetic science. His use of the area method rather than the classic arc method was especially noteworthy. In the 1906 report to the Conference at Budapest the subject of isostasy was given consideration and it was shown that isostasy must be considered in connection with the determination of the figure of the earth. In this investigation reported upon, 507 astronomical determina-

tions were used, 265 of which furnished that component of the deflection of the vertical which lies in the meridian, and 231 stations furnished the prime vertical components.

The figure of the earth investigations and also the investigations in isostasy, involving the deflections of the vertical, were continued by Mr. Hayford, and again in 1909 he reported to the Sixteenth General Conference held at Cambridge and London the results of this further investigation involving 765 astronomical observations, this being an increase of more than 50 per cent over those used in the 1906 report. A complete report of this later investigation was published in "The Figure of the Earth and Isostasy, from Measurements in the United States," published by the Coast and Geodetic Survey, 1909, and in "Supplemental Investigations in 1909 of the Figure of the Earth and Isostasy," published in 1910. These two epoch-making reports of Professor Hayford were well received by the scientific world and led to his being elected a member of the National Academy of Sciences, the greatest honor that this country has to offer a scientific man.

Up to this time Mr. Hayford had been engaged for more than ten years in developing the ideas concerned in these investigations. While the work was in progress, various preliminary statements had been made by him in papers before scientific gatherings. A summary of the noteworthy features of the investigations, as given by Mr. Hayford, follows:

1. The investigation of the figure of the earth and of the reality of the condition called isostasy is based entirely upon observed deflections of the vertical in the United States.

2. No use was made in the investigations of determinations of gravity, for it was believed best to deal thoroughly with one phase of the investigation before taking up the other.

3. The area treated extends over a wide range in latitude and longitude—18°50′ in latitude and 57°07′ in longitude.

4. A large number of astronomical observations have been used.

5. All of the astronomical determinations are connected by a

continuous primary triangulation. The triangulation does not consist of separate and distinct belts of triangulation or arcs.

6. Unusual methods of computation have been used.

7. The effect of all topographic irregularities within 4,126 kilometers of each astronomical station have been taken into account.

8. The effect of possible distribution of densities beneath the surface of the earth corresponding to the condition called isostasy has been carefully taken into account and the existence of said condition established.

9. The investigations lead to values of the equatorial and polar dimensions of the earth, based on observations in a single country, the United States, which are of a very high degree of accuracy.

As stated by Mr. Hayford, every known device was utilized for reducing the time required for the computation of topographic deflections without allowing the accuracy to fall below the necessary high standard, and several new methods were devised by him to further the work. Very early in the investigation it was realized that it would be necessary to compute the topographic deflection for each station, and that the computation to serve its full purpose must extend to a great distance from the station. It was also realized that to make such computations by any method known to have been used before would be impossible on account of the great expenditure of time and money involved. It was necessary, therefore, to devise some new method of computation, or to modify old methods, so as to make these computations feasible. An ingenious method by the use of templates was devised by Mr. Hayford, and served the purpose admirably. By the method of computation used in this investigation, one computation for either a meridian or a prime vertical component of the deflection at a station, taking into account all the topography within 4,126 kilometers (2,564 miles) of the station, was found to take on an average the equivalent of 9.4 working hours for one computer.

Before proceeding to a study of the possible relation of the distribution of the sub-surface densities to observed deflections of the vertical, a secondary study was made to develop the extent to which the observed deflections of the vertical are related to the topography. This investigation was made by constructing contour lines of the geoid (or actual earth) graphically, starting with the observed deflection of the vertical as a basis. The problem was one of constructing the contour lines which will represent the relation of the irregular geoid to the regular ellipsoid of revolution known as the Clarke Spheroid of 1866, which is supposed to be in the position fixed by the adopted United States standard datum.

In order to carry on the investigation of the possible relation between the theory of isostasy and the deflections of the vertical, Hayford assumed that isostatic compensation is complete and uniformly distributed with respect to depth from the surface down to some unknown depth of compensation, which it was desired to find from the observations. He developed a series of mathematical equations showing the relation which he believed should exist, introduced the observed values of deflections, etc., and proceeded to make least-square solutions on several basic assumptions as to depth of isostatic compensation. A number of solutions were made assuming various depths of compensation, each successive assumption being influenced by the previously determined values. For Solution E (depth of compensation 162.2 Km.), solution H (120.8 Km.), and solution G (113.7 Km.), the sum of the squares of the residuals changed but very little, solution G giving the smallest, and it was considered the closest to the truth.

The two major results of this investigation are those given in Nos. 8 and 9 of the list of noteworthy features already stated in this article, namely, (1) the existence of the condition called isostasy was established and that the United States is not maintained in its position above sea-level by the rigidity of the earth, but it is, in the main, buoyed up, floats, because it is composed of material of deficient density, and (2) values of the equatorial and polar dimensions of the earth derived.

In 1910, Mr. Hayford published a continuation of this investigation, "Supplementary Investigations in 1909 of the Figure of the Earth and Isostasy" in which more observations were used than in the previous work. In this work he again derived values for the dimensions of the earth which were slightly different from those derived in the previous work. These values have been accepted by the scientific world as probably the most accurate which can be derived without an undue amount of further time and money spent in collecting more data and in the resulting computations.

Probably no work of any man within a century has attracted more attention from geodesists, geologists, and geophysicists, than has this work of Mr. Hayford's. It brought to him international fame, and has placed him in the front ranks of the world's great geodesists. R. S. Woodward, President of the Carnegie Institution of Washington, and an eminent scientist himself, in a letter to Mr. Hayford characterized the work as one of the most important contributions made to geodesy since the time of Gauss, and he predicted "that the verdict will be that you have succeeded in pushing knowledge one step beyond the point attained by Gauss, Bessel, Clarke, and all the rest."

Colonel Sir Sidney G. Burrard writing in 1925 says, "When we consider that the conclusions which he originally put forward in 1909 have never had to be modified, we have to acknowledge that the stamp of genius rests upon his work."

These and many other quotations from well-known geodesists and scientists all bear evidence of the high value placed on his work. But they all pay tribute to the courage of the man in attacking such a stupenduous piece of work.

Previous to Mr. Hayford's publication Colonel Burrard had the view that the geodetic results deduced from observations in the outer Himalayas and in the plains at their feet were not in accord with the theory of isostasy. Investigations made by him along the lines suggested in Mr. Hayford's treatise caused him to change his views. The very evidence which formerly seemed to be unfavorable to the theory of isostasy proved an unexpected support for it, and in a most able treatise issued in 1919, he

showed that the condition of isostasy exists also for India, and confirms the general deductions made by Mr. Hayford.

In general it is inevitable that opponents will arise to question the validity of any new revolutionary scientific theory. In this, Mr. Hayford's work on isostasy has been no exception.

One able scientist has criticized Mr. Hayford's work on isostasy and points out what he considers a rather serious defect in the work. His contention is that Mr. Hayford was in error by building his method around the untenable theory of complete local compensation, involving an unnecessarily complex mathematical treatment, and ignoring regional compensation. In his summary he states that "the isostatic compensation of the topographic features of the earth's crust must be regional to some extent. Perfect compensation is inconceivable; it could only be obtained if the material were so plastic that no surface irregularities would remain. The departures from complete local compensation are sufficient in their effect to require that they be considered in a complete reduction of gravity observations." In a letter to the writer under date of February 14, 1929, this scientist states, "The work on this subject which he planned was so impressive in magnitude and results, and is so really important, that the above has passed practically unnoted for twenty years."

In reviewing, however, the comments and discussions regarding his work, one is struck by the unanimity with which all accept it, and by the expressions of accord, indicating that Mr. Hayford's work is one of the outstanding pieces of research along geodetic, geophysical, and geologic lines.

In addition to bringing to him international fame through the award of the Victoria Medal, and by the adoption of the Hayford Spheroid, his theory of isostasy also brought to him local honors. His paper before the Western Society of Engineers at Chicago on "The Establishment of Isostasy," presented May 26, 1924, won for him the Chanute Medal of the Society as one of the three best papers read before the Society during the year 1924. The date of reading this paper was chosen by the Western Society in celebration of the occasion of the presentation of the Victoria Medal, which presentation was made on this same date

before the Royal Geographical Society of England and at which Mr. Hayford was not able to be in attendance. Formal presentation of the Chanute Medal was made on June 3, 1925, at the annual banquet of the Society. As Mr. Hayford's death had occurred the preceding March, the medal was received by his son, Maxwell Hayford.

International Spheroid of Reference

At the Constitutional Assembly of the International Geodetic and Geophysical Union (supplanting the former International Geodetic Association) held at Brussells in July, 1919, the question of an international ellipsoid of reference was brought to the attention of the delegates. This was brought up again at the First General Assembly of the Union held at Rome, May, 1922, when it was recommended that a spheroid should be fixed upon as early as possible so as to insure uniformity in geodetic work and computations. In accordance with this recommendation the section of Geodesy of the Union directed its Executive Committee "to fix, and, as early as possible, to recommend for cartographic calculations a spheroid of reference common to all countries on one continent." A serious study was made of this question by the executive committee, and reported upon to the Madrid Assembly of the Union held in October, 1924. After long discussion the proposals were ratified by the Section of Geodesy, at which some fifty members, representing twenty-five nations, were present. (1) Almost unanimously it was agreed to adopt an international ellipsoid common to all the continents; (2) almost unanimously it was agreed to adopt the flattening given by Hayford in his work, "Supplementary Investigations in 1909 of the Figure of the Earth and Isostasy." p. 77; (3) by the majority it was agreed to adopt the semi-axis given by Hayford in the same work. It was, therefore, recommended and adopted that the International Spheroid of Reference should be the one characterized by the following:

Semi-Major Axis 6,378,388 meters $\pm$ 18 meters
Flattening 1/297.0 $\pm$ 0.5

as given by Hayford in "Supplementary Investigations in 1909 of the Figure of the Earth and Isostasy."

It was recommended to scientific men for use in all scientific investigations where the shape and size of the earth were involved, and it was also recommended to those countries which, at the time, had not adopted a spheroid of reference for their triangulation, surveys, and maps, and to those countries which, having adopted one of the older spheroids, desired to make a change to a more accurate one. Hayford's Spheroid was chosen as the one which represented with the greatest precision all of the land surface of the earth. The values computed by him have about four times the weight of the others. These values, though deduced from observations made in the United States, have been shown to apply equally well to other regions.

This spheroid of reference is now generally known among scientists as the "Hayford Spheroid" and Americans may well be proud of this signal honor conferred upon one of its scientists.

It is interesting to note that General Georges Perrier, Secretary of the Section of Geodesy of the International Geodetic and Geophysical Union, has had tables computed and published for the Hayford International Spheroid. Furthermore, it is understood by the writer that Finland has already started computing its geodetic work on this spheroid.

When Dr. William Bowie, President of the Section of Geodesy and delegate to the Madrid Meeting, notified Professor Hayford of the adoption of the 1909 spheroid, he wrote, "This is a fine tribute to you."

In this as in many other cases Hayford's reply was very characteristic: "I am not unmindful of the fact that I was merely the leader of the team when this work was done. In this as in other cases, the leader gets a large part of the credit for work done by the team."

Intensity of Gravity and the Figure of the Earth

After making tests of the isostatic condition of the earth's crust and the figure of the earth by means of triangulation and astronomical observations, as already described in this memoir,

Professor Hayford decided that he was now in a position to make a further test by the use of values of the intensity of gravity, determined at many places in this country. This problem he had had in mind for some years and had laid plans for and carried out a campaign of gravity work in order to have data on hand, storing up the material gathered to be ready for use when he had finished his work on the deflections of the vertical.

The opinion was formed about 1900 that in order to secure the highest efficiency in the geodetic work of the United States, in the effort to increase the knowledge of the figure and size of the earth, it was advisable to postpone gravity determinations until the existing triangulation in the United States had been fully supplied with astronomical observations, and the resulting deflections of the vertical had been carefully studied. It would then be possible to utilize the information given by these observed deflections of the vertical in selecting such locations for the gravity stations that a given number of stations would furnish a maximum of valuable information. For it appeared that the deflections of the vertical would probably furnish valuable indications in regard to points in the United States at which the intensity of gravity might be expected to be normal, to be abnormally small, or to be abnormally great.

In accordance with this opinion few determinations of gravity were made during the years, 1900-1908. In 1907 Professor Hayford turned his attention seriously to a proposed gravity campaign. Methods of observing and computing were carefully gone over, and he suggested a number of changes. His studies led him to believe that control of temperature should be most carefully considered, as therein lay one of the greatest possible sources of error. Also he came to the conclusion that the static method of correcting for flexure of the pendulum case under the influence of the swinging pendulum could be improved upon. This latter conclusion led to the adoption of the interferometer method of measuring the flexure, an account of which is given elsewhere in this memoir.

On his recommendation the Superintendent of the United States Coast and Geodetic Survey approved Hayford's plan to have a number of additional gravity measures determined at selected points in this country. The writer, then in the field force of the Survey, began a gravity campaign in January, 1909, using the half-second pendulum, and continued on this work until he severed his connection with the Coast and Geodetic Survey in September, 1910. The gravity campaign was, however, continued for several years thereafter.

A new method of computation of the effect of topography and of isostatic compensation upon the intensity of gravity at a station was developed by Hayford and tested at a number of stations. A statement of the method and of the results of the test was given by him at the Sixteenth General Conference of the International Geodetic Association held at London and Cambridge, England, in September, 1909. On his return to the United States Mr. Hayford resigned from the Coast and Geodetic Survey to accept the position of Director of the College of Engineering at Northwestern University.

Dr. William Bowie was made Assistant Chief of the Computing Division and Assistant Inspector of Geodetic Work early in 1909, and served in the office as Hayford's understudy until the latter left the Bureau in October, 1909. During that year the two worked together on the application of isostasy to gravity determinations, and they continued their cooperation after Professor Hayford left the Survey. The result of their joint work was a report by the Coast and Geodetic Survey which appeared in 1912 and which was entitled, "Effect of Topography and Isostatic Compensation upon the Intensity of Gravity."

This investigation is based upon determinations of the intensity of gravity made at 105 stations, 16 selected stations being in foreign countries. In the principal computations full account is taken of the effect upon the vertical component of the attraction of gravity at a station, of all the topography of the world, and of the isostatic compensation of that topography assumed to be complete and uniformly distributed to the limiting depth of compensation, 113.7 kilometers, the value derived in his study of

deflections of the vertical. Use was made of the template method of computation, which materially speeded up the work. By this method a computer in an average of seventeen hours of work obtained the effect of all the topography of the world and its isostatic compensation upon the vertical component of the attraction of gravity at a given station.

For comparison purposes, the gravity anomalies for these same 105 stations were computed by the two methods of computation most generally accepted in recent years—the Bouguer method, and the free-air method. The "free-air" method ignores topography as if it had no effect whatever, or as if it were compensated for at zero depth. The Bouguer method takes into consideration the topography near the station, but ignores the distant topography and the curvature of the earth in computing the effect on the intensity of gravity. Hayford's methods are based on the assumption that the earth's crust is in a state of approximate equilibrium called isostasy. Besides the correction for topography to the theoretical value of gravity at any station there is also applied a correction of opposite sign to account for the effect of the compensation. The effect of the topography and its compensation for the whole earth is considered at each station.

The general result of this investigation was that isostatic compensation was found to be very nearly complete under all parts of the United States. Also that Hayford's method of reduction gave a closer approximation to the truth than either the free-air or the Bouguer method.

It may be stated that, as a result of the work of Professor Hayford while with the Coast and Geodetic Survey, it was proved that isostasy was probably a universal condition of the earth's surface. His conclusions in regard to isostasy were not, however, generally accepted by students of the earth, largely because it was a new subject and did not fit into generally accepted theories regarding structural and dynamic geology. The second reason was that Hayford had based his conclusions on rather scant evidence, that is, the triangulation used in the figure of the earth investigation formed a mere skeleton over the coun-

try, and that in the gravity investigation too few stations were involved. Investigations made since by officers of the Coast and Geodetic Survey in which more data were used, and the data involved were for stations in other countries in addition to those in the United States, have proved that isostasy is a scientific principle. There are few today who will deny the existence of isostasy for any considerable portion of the earth's crust.

The work of Dr. Vening Meinesz in determining the values of gravity at sea from observations on a submarine has proved that isostasy exists in ocean areas to as marked a degree as has been found true for land areas. The pioneer work of Hayford in attacking so vast a problem as the isostatic condition of the earth's crust, stands out as one of the notable accomplishments in the entire history of geodesy. Not only did his isostatic investigations lead to his election as a member of the National Academy of Sciences, but they brought to him the award of the Victoria Medal.

"For more than a century observers have been patiently determining the variation in the force and direction of gravity in all parts of the earth; observations are still being multiplied, new regions are being tested, the surface of the ocean and even its depths are being tested. What is the aim of this enthusiastic army of workers? It is to accumulate a world-wide series of results, until the rare man arises who can interpret their meaning. Hayford interpreted the gravity results; it was he who discovered their meaning.

"The foundations of Hayford's work were the 'observed facts'; he never allowed his imagination to lead him astray, he utilized mathematics as an instrument for dealing with his observed facts. When he had eventually discovered conditions in the earth's crust which had not been foreseen by either geologists or mathematicians, he presented his conclusions to the scientific world in the simple language of an engineer: 'Here are the observed facts, and here are the conditions of the crust that explain them.'

"The conditions that have arisen in the discussion of Hayford's Theory of Isostasy have not been due to his methods, but

to our inability to comprehend the conditions which have been shown to be existing. Conditions have been discovered of which we had had no experience at the earth's surface, and which were beyond the range of our imagination."—S. G. Burrard, in *The Geographical Journal of the Royal Geographical Society,* July, 1925, London.

Mechanism of Isostasy

In Hayford's work on isostasy he dealt mostly with the mathematical and geological sides, with but little consideration of the mechanics or physical interpretation of isostasy. This was a phase of the subject upon which he had spent considerable thought, but as shown by the following extract from a letter to Colonel Sir S. Burrard, September, 1920, he was not fully prepared or inclined to undertake researches regarding the physical explanation of isostasy:

"I have at various times studied a good deal on this particular part of the matter. I feel confident that, given sufficient time, I can show a good first approximation to the mechanism, a first approximation in accordance with a great mass of facts known to the physicist, chemist, engineer, geologist, and geodesist. I believe that the mechanism is simple in essence, but rather varied in the manner of its action under the great variety of conditions surrounding various cases in different parts of the earth and at different times. However, I have found such extreme difficulty in getting my views across into the minds of other men that I do not care to make any further attempt unless, and until, I can attempt it with such ample time at my disposal as to make the effort effective. I find that the greatest obstacle to progress is that most men persistently look at one factor in a problem at a time, whereas, especially in such a case as the one under consideration, one must keep a considerable number of factors in mind simultaneously to get a true understanding."

Interferometer Applied to Gravity

As noted elsewhere in this memoir, Mr. Hayford had assisted Professor Gore on pendulum observations for determining the

intensity of gravity, and in conjunction with Professor McNair had utilized the pendulums in similar work at the North Tamarack Mine, Calumet, Michigan, in 1902. Also, in his official capacity, he was very well informed regarding the apparatus and methods in use at the Survey for such work. One of the points which he considered weak was the method of determining the flexure of the pendulum case and its effect upon the resulting value of the intensity of gravity. The method employed was the static method of applying a known pull and from the flexure of the case compute what it would have been under the effect of the swinging pendulum, the correction to the period of the pendulums having been determined experimentally for various degrees of stability of the support of the case.

Professor Albert A. Michelson about this time had published his splendid monograph on "Light Waves and Their Uses," in which the Michelson interferometer and its use for measuring exceedingly small displacements was described. This was closely studied by Mr. Hayford and his keen mind soon grasped its possibilities in connection with gravity work.

In October, 1907, the writer was stationed at Barnegat Light House, N. J., engaged in making observations for primary azimuth, latitude, triangulation, and magnetics. Here he was joined on October 15 by Mr. Hayford, who as Inspector of Geodesy was making a field inspection trip to several of the field parties. He remained with the writer at Barnegat for five days watching the progress of the work at hand and assisting in observing and computing. Part of the time, however, he could be found under the lee of a neighboring hedge studying and computing and making notes. The night before leaving, he turned over to the writer the computations and notes upon which he had been working, together with a copy of Michelson's "Light Waves," with verbal instructions to go over the whole carefully before the field season ended, as the matter contained therein would probably be the writer's next assignment. Between this date and November 5, when the field season closed, the writer spent all of the time which could be spared from his other duties in studying the material handed over to him by Mr. Hayford.

These notes and computations proved to be a study on the possible use of the interferometer as a means of directly measuring the flexure of the pendulum case during the swinging of the actual pendulum, and showed mathematically the magnitude of the fringe displacement which could be expected in the interferometer, and other related but necessary points.

The problems confronting him were: (a) could the then existing instrument be so remodeled as to be used under the new conditions; (b) could such a remodeled instrument be used under the varying conditions incident upon field stations as to temperature, vibration, etc., without undue expense or loss of time to the field party; (c) could the correction to the period of the pendulum be obtained accurately in terms of the half-second shift of fringes in the interferometer due to the flexure of the pendulum case under the influence of the swing of the half-second pendulums used in gravity work.

The writer reported to the Washington office of the Survey and under instructions dated November 5, 1907, was assigned to the Division under Mr. Hayford. Preliminary experimental work was carried on at the Bureau of Standards, where a Michelson interferometer and the facilities of the Bureau were kindly placed at the disposal of the writer by Dr. S. W. Stratton. By December 10 the preliminary tests were carried far enough to satisfy questions (b) and (c) and the matter was laid before Mr. E. G. Fischer, Chief of the Instrument Division of the Survey, who solved question (a) by designing the modified form of interferometer now used for many years by the Survey.

In the fall of 1908, after returning from an extended field trip, during which time the modified forms of interferometer had been constructed, the writer was again assigned to the work with a view to perfecting the methods of, and computation incidental to, its use as an actual field instrument. This was successfully accomplished, with the result that the static method is now in practically all cases superseded by the interferometer or direct method.

This rather lengthy discussion of the interferometer is here given to show to what great length credit should be given to

Mr. Hayford. However much credit is given to the writer for his part in this work, since it was under his name the monograph on this subject was published by the Survey, it was Mr. Hayford's keen mind which conceived the idea; it was his power of abstract analysis which proved it theoretically possible; and it was his courage in backing the work which made it actually a success.

INTERNATIONAL GEODETIC ASSOCIATION

Dr. Hayford was twice honored by being sent to Europe as one of the two delegates selected to represent the United States at the General Conference Meetings of the International Geodetic Association, Mr. O. H. Tittmann, Superintendent of the United States Coast and Geodetic Survey, and Member of the Permanent Commission, being the other delegate.

The first of these meetings attended by Dr. Hayford was that held in 1906 at Budapest, and was the fifteenth General Conference of the International Geodetic Association. The report to the conference by the delegates from America is contained in a publication by the Department of Commerce and Labor and gives a summary of the geodetic operations in the United States, 1903-1906. In addition to a report upon the general operations of the Coast and Geodetic Survey, a second report was made by Hayford regarding his investigations of the figure of the earth based entirely upon observed deflections of the vertical in the United States. The first report of these studies was made by Mr. Tittmann to the fourteenth General Assembly of the Association held in Copenhagen in 1903, a work which reported upon later in 1909 was to bring to Mr. Hayford international fame. The meeting at Budapest is of special interest because it was the subject of his last talk to the engineering students at Northwestern University on December 19, 1924, when at the annual engineering banquet Professor Hayford gave a most interesting talk on the court reception at Budapest at which the delegates to the Geodetic Association were the honored guests.

Again in 1909, Tittmann and Hayford were the American delegates to the sixteenth General Conference of the International Geodetic Association held at Cambridge and London, at which a report was made upon the geodetic operations in the United States 1906-1909. At this meeting Hayford gave a further report of his investigations on the figure of the earth, and submitted his newly computed values for the dimensions of the spheroid, values which were later adopted by the Conference of 1924, assembled at Madrid, as the dimensions of the International Spheroid of Reference and now designated as the "Hayford Spheroid."

READINGS AND STUDIES

Previous to 1900, while in the Coast and Geodetic Survey, Mr. Hayford's readings and studies were extraordinary in scope of subjects and in number of publications read. He has left a list, on the Survey computing paper, of over six hundred such publications read, the latest recorded one being in 1900. This seems to have been the period when he was making himself conversant with the many lines of work and gathering information so necessary in his work. It must be remembered that this study and reading was mostly done at the time when a prodigious amount of labor was demanded of him in taking over the work of Mr. Charles A. Schott as Chief of the Computing Division and in carrying on the work of his newly created position as Inspector of Geodesy. The range of his studies during this time is best shown by the index to the one hundred and one pages of these studies:

Tidal theory, tidal observations and discussions, waves, seiches, earthquakes, physical hydrography, computing machines, mathematics, geodesy, least-squares, electricity and magnetism, astronomy, thermometry, density, weighing, meteorology pressure measurements, important numerical results, base measurements, variation of latitude, triangulation, leveling, station errors, and mean star places.

For each book or article read there is given the complete reference as to publication and author, and a brief summary of the

contents. To have kept this running account of his studies and readings was in itself a great task, and only the most methodically minded man could have done it. Evidently the burden became too great, for nothing similar to it is found in any other of his papers with the exception of one pocket-notebook dealing exclusively with geologic studies made, apparently, during the time he was working on the figure of the earth and isostasy.

While he kept no such list as above, he nevertheless did a vast amount of reading and study along engineering lines, in education, and in the physical sciences.

After taking up his work at Northwestern University his time was so fully occupied by his administrative duties, his teaching, and his researches, together with many outside activities, that there was left scant time for such a large range of reading. He kept up with the general current literature, however, to some extent through the medium of his class in "Journals." This class was composed of senior and fifth-year students and met one afternoon each week. It was conducted by having the students spend part of the time in the library making selections of articles in current engineering periodicals, then about three-quarters of an hour was given over to the study of these articles, after which the remainder of the afternoon period was devoted to reports by the students on their selected topics with discussions of the same. During the study period of this course, Professor Hayford usually devoted his own time to reading and study of selected articles in the current periodicals or other readings that he had on hand for the purpose. Each student was required to abstract his article on 3 x 5 cards and turn them over to the Director. Thus he accumulated a very great amount of information regarding the important engineering topics of the day. Practically no other reading was done by him during the school week, and as he usually had important engagements to take up his evenings, little time was granted him for reading, excepting at odd moments and during Sunday. How he managed to keep himself so well informed on the many subjects at his command is one of the marvels in connection with his program of life.

UNITED STATES COAST AND GEODETIC SURVEY DIRECTORSHIP

In 19— Mr. Hayford was approached by a man very high in the scientific life at Washington in regard to his becoming a candidate for Director of the United States Coast and Geodetic Survey. Hayford took this matter up with another man, also prominent in Washington, in order to get his view on the matter. Correspondence kept by Hayford indicates that these two men are the only ones having knowledge of the subject, but they were so high in scientific circles that there is little doubt but that their recommendations would have carried considerable weight in regard to the appointment. Concerning this Hayford wrote: "The position as head of the Coast and Geodetic Survey appeals so strongly to my professional ambition, because I have so great an admiration for the Survey and for its possible future, that if the appointment ever came to me at an adequate salary, a security of tenure for at least ten years, and a security against political interference with my administration as Director, I should expect to accept it and go into the work with a vim.

"I should feel in duty bound to accept on the above basis . . . especially as I have had an experience which qualifies me especially for the position. The Coast and Geodetic Survey has an excellent past record. I believe the future possibilities are great for rendering efficient service to the people of the United States in making good surveys, in producing excellent charts, and in making valuable fundamental scientific work.

"I see definite attainable possibilities of decided improvement in the geodetic work, in its hydrographic work, in surveys of the coast from airplane, in new instruments, in its tidal work, in the precise leveling, in the character of its charts, and in the way its charts are used to promote safety in navigation.

"I believe I have the proper background of training and experience to enable me to succeed under favorable circumstances in making these possible improvements a reality. For all these reasons I would enter the position of Director of the United States Coast and Geodetic Survey with great enthusiasm, *pro-*

vided I entered it under conditions favorable to success, i. e., adequate salary, freedom from fear of short tenure, and freedom from fear of political interference."

Evidently these conditions were not possible in their fulfilment, for the name of Hayford does not seem to have become publicly listed for the position, or at least Mr. Hayford thought they could not be met. In setting forth the advantages of this position one of the two scientists wrote him: "It is a great institution, with a record of achievement of which one may well be proud. It would be an honor and a privilege to guide its destinies to still greater achievements. I am satisfied that you can do this better than any other man. You have the background from long years of intimate contact with the work, world-wide recognition as an authority in geodesy, executive experience, and vision, energy, and enthusiasm. Where else can these attributes be found? I say these things judicially, untempered by my admiration and affection for my friend."

For obvious reasons the writer has omitted dates and the names of the two who were interested in this matter.

In the foregoing the endeavor has been made to give a report of the contributions which Hayford made to geodesy. Most of these contributions were made while he was a member of the Coast and Geodetic Survey, hence, in a way, they also tell of the progress which the Survey made while he was at the head of the geodetic work and of the computing division. These divisions and Hayford are so closely related that what may be said of the one should be said of the other. The glory of the one becomes the glory of the other. While the work of the Survey before Hayford was of a very high degree of excellence and worthy of much praise, under his leadership the strides that were made in geodesy attracted the attention of the world. It is generally recognized today throughout the scientific world that Professor Hayford laid the foundation for the great progress that the Coast and Geodetic Survey has made in both its scientific and engineering work and in the field of isostasy during the past thirty years. The Survey is universally recognized as the

leading geodetic organization in the world not only in its practical work but in the interpretation of the geodetic data collected. This advance has since been ably carried on under the leadership of his successor, Dr. William Bowie, until the United States in its geodetic work stands, probably, unrivalled today. A test of the greatness of the geodetic work of the Survey may be had in a review of the comments of prominent men in other organizations and countries, and by men who are qualified to judge. They all accord to the Survey a very high place in the geodesy of the world. Commandant Perrier, the French Geodesist, says:

"There is no example in the history of geodesy of a comparable collection of measurements, made with so much determination, such rapidity, and such powerful means of action, and guided by such an exact comprehension of the end to be attained."

While living in northwest Washington, Hayford's home was too far away to permit of his taking noon luncheon with his family at home. Consequently he took his lunch at places near the office of the Survey, usually in the company of one or more congenial friends. Noteworthy among luncheon groups was the one which usually left the Survey at noon to partake of the midday meal at the Library of Congress Cafe. This group usually consisted of Hayford, R. L. Faris, Assistant, and now Assistant Director of the Survey, George R. Putnam, Assistant of the Survey, and later First Commissioner of Lighthouses, William Bowie, Assistant, and now Chief of the Division of Geodesy. It was a merry, congenial group and many were the scientific problems discussed during the noon period.

RESIGNATION FROM THE U. S. COAST AND GEODETIC SURVEY

In 1908 the Trustees of Northwestern University extended an invitation to Mr. Hayford to become the head of the newly established College of Engineering at Evanston, Illinois. This offer

was accepted and he was officially elected Director of the College in October, 1908, with the understanding that he would take up his duties at Northwestern in September, 1909. Owing to the fact that he was detained in his position at Washington and sent as one of the delegates to represent the United States at the Conference of the International Geodetic Association held at London and Cambridge, England, September 21-29, his formal resignation from the U. S. Coast and Geodetic Survey was not handed to O. H. Tittmann, Superintendent of the Survey, until November 12, 1909. In tendering his resignation he wrote:

"I thank you for the strong support and hearty sympathy which you have uniformly given me in my work in the Coast and Geodetic Survey. I leave the Survey with regret and only because I am convinced that as Director of the College of Engineering at Northwestern University, which position I have accepted, I have a greater opportunity for usefulness than it is possible for you to give me in the Survey."

In accepting Mr. Hayford's resignation to take effect at the close of business on November 23, 1909, Superintendent Tittmann wrote:

"I fully share the expression of regret with which the Secretary has accepted your resignation, for no one is more fully conscious of the loss which the Survey has sustained than I am.

"The signal ability with which you have served the government, your industry and loyalty, have established a standard which will always be pleasant to refer to and to look back upon."

In reference to Mr. Hayford's resignation from the Survey, Mr. Charles Nagel, Secretary of the Department of Commerce and Labor, expressed himself as follows:

"The terms of commendation with which the Superintendent of the Coast and Geodetic Survey has transmitted to me your letter of resignation, make it a pleasant duty to take more than passing notice of your resignation, which I accept with deep regret, because your going is a distinct loss to the government. On the other hand, the evidence of the unusual ability, the zeal and the wisdom with which you have served the government for a long period, warrant the assumption that a multitude of stu-

dents, and through them the country at large, will benefit by the same qualities which have distinguished your service to the Government."

THE COLLEGE OF ENGINEERING AT NORTHWESTERN UNIVERSITY

Mr. Hayford was elected Director of the College of Engineering at Northwestern University in October, 1908, to take up his duties in September, 1909. He entered into this work with enthusiasm because he felt that here was a field for unlimited service to the engineering and scientific world. He had long held strong views as to the kind of training an engineer should have and in the type of curriculum to be adopted at Northwestern he had vision of the fruition of his views.

The motto of the College of Engineering of Northwestern is "Culture for Usefulness." In order to realize to the fullest extent the import of the motto it was decided that the usual four-year course was too short a time in which to give the necessary technical training for engineers, and at the same time to broaden his education by the inclusion of many of the more cultural subjects. Hence, the adoption of a five-year program leading to the professional degree. It called for an effort to obtain for the student the broadest culture attainable in five years in order to equip him, as a man and an engineer, for the greatest possible usefulness in the world in the united struggle of man for progress. It was the aim to train future engineers for the greatest average effectiveness in a lifetime rather than for the greatest effectiveness in the first years after graduation.

Only two curricula were offered—one in Civil Engineering, and one in a combined Mechanical-Electrical Engineering course. Up to the time of Director Hayford's death only slight modifications were made in these curricula. The engineering training in the narrow sense commenced in the freshman year and continued throughout each of the five years, occupying a large portion of the curriculum in the last two years, and a relatively small proportion in the first three. The general education, represented by the courses normally given in the College of Liberal

Arts, extended throughout all of the five years. This arrangement was based upon the idea that a liberal arts education is an essentially inseparable part of an engineering education—not a matter separate and apart, to be secured first; that it is in part essential to fit the engineering student into the world's work, to enable him to use his technical knowledge effectively, and to live a richer and more contented life.

While the engineering students were under the continuous control of the engineering faculty during the five years, they merged with the liberal arts students in classrooms and in campus, social, and athletic activities. It was believed that this control from the start by the engineering faculty, combined with the close contact with the liberal arts faculty and with students having other ambitions than his own, would give the engineering student early orientation and unusual breadth of view.

In his appointment at Northwestern University, Director Hayford held the title of Director of the College of Engineering and Professor of Civil Engineering. As professor he was supposed to do a small amount of teaching. This teaching consisted of two courses, "Public Relations of Engineers" and "Journals," both courses being required for all students before graduation and taken in their senior or fifth year.

These two courses were virtually of his own invention and showed him as a man keenly alive to what kind of a training an engineer should have. His belief was that the purely technical side of engineering was not sufficient for the best type of engineer and that the student should early learn about the human side of engineering through contact with men, through a study of men as made evident by their success or failure, and in a study of them and their works through their writings.

In the course of Public Relations he was well fitted to guide the young engineer for he was closely in touch with many of the great men of the scientific world; he knew a great many of them very intimately and many more through their writings. He was thus able at all times to supply the needed factors to make clear to the class why success or failure had come to the person

in question. His fund of information along these lines was most astounding.

As given in his initial lecture to this class, the purpose was to study the relations of human beings with reference to success, of the best kind of success; true success that is worthwhile as measured by accomplishment, by the degree to which a task is accomplished. Biographies of the more successful men were studied and analyzed, the ethics of the profession taken into consideration, how to work in organizations and with administrations and officials.

His varied life as student, computer, teacher, field observer, and administrator and educator made him an ideal teacher; to the classroom he brought a knowledge of the sciences and of contact with scientists, engineers, and educators given to but few men. His analytical thought, breadth and depth of knowledge made him a most wonderful teacher. He not only possessed the requisite knowledge, but he took great interest in his teaching and had that most important ability of being able to impart the knowledge he possessed. His students respected him not only as an instructor, but because of his sterling character. The more mature his students, the more mature they were in their praise.

Director Hayford thoroughly believed in having his faculty keep each other informed regarding their work, especially along the lines of research and studies outside the classroom, and also that they themselves keep in touch with engineering and the scientific world in general. Partly to meet this need he organized the Faculty Colloquium, which met normally every two weeks and at which each faculty member, acting in rotation, was responsible for the hour devoted to the meeting. A member at his own discretion could talk regarding any research problem he was engaged upon, or on matters relating to the college, or review some question of importance in the scientific or educational world. The dates for the entire year were assigned for each meeting and speaker, the assignments extending throughout the scholastic year.

His contact with the student body was a close and intimate one, especially in the earlier years of the régime at Northwestern, and before the students had increased to a number too large to permit of this close intimacy. When he assumed the position of Director he constituted himself the student adviser for all students, and regularly twice each year, every student was called to his office for conferences in regard to his work in college; programs of studies for the coming year were studied, and at registration he personally supervised the schedule of course for practically every student registering. His office hours were from 9 A.M. to nearly 5 P.M., and his door was always open to any student who wished to confer with him. Never did the writer know of a case where a student was forced to apply to a secretary or clerk before being admitted to the Director. Practically at all times the students had free access to Director Hayford; this, of course, led to serious interruption, but he did not seem to mind it very much. He would simply make a notation or mark regarding his work, turn to the student and pay strict attention. When the conference was ended he would take up his line of thought or work again as though no interruption had occurred. If the matter was important enough he would carefully write out a detailed statement regarding the conference and file for reference. He trusted little to his memory.

Usually his office was the working shop for the computers who helped him on his researches. In this way he was always close at hand to take account and direct their work with a minimum loss of time to himself.

In his relations with his faculty he was invariably fair, just, consistent, and considerate of all interests and seldom exercised with authority his official position. The only thing which he seemed to hold in contempt was bad work in pupil or professor. He did not apparently care for display of any kind, and it seemed that no desire of approbation influenced his actions, though he always seemed pleased to inform his intimate friends of any honors that came to him.

His standards of work and accomplishment were high. His influence as Director, and his commanding position as a scholar

and a scientist, were naturally great and were always exerted in the direction of progress in the education of the engineering student.

He was an earnest worker on the faculty, especially in the furtherance of a rigid and broad scientific training and development of the mind. His motto seemed to be "train to think" and thus produce leaders in thought—in order to obtain the greatest development for later life rather than for the years immediately following graduation.

His long experience as a scientific man and scientific educator in this country, together with his wide scientific knowledge, gave him a very clear perception of a school of engineering which should train men capable of meeting the professional calls of the future. His ideals were that there should be no specializing until the broad fields of study in engineering and the humanities had been covered.

In his own college life he apparently laid the solid foundation of success, and wished to carry such a foundation onward.

Sincere he was, and truthful to the point of being unable to allow the shadow of deceit in his ways. In reporting on conditions within the College he always gave the *facts,* whether to his disadvantage as Director or otherwise. As one of his colleagues once remarked: "Hayford was so upright, he leaned over backward." This sometimes worked to his disadvantage, for it sometimes furnished opponents with ammunition to criticize his régime. Perhaps, sometimes it would have been more to his advantage had he glossed over some of the facts.

It was noticeable in his Directorship, as in the work at the Coast and Geodetic Survey, that more than one subordinate felt the cheer of his sympathetic appreciation.

As head of the College of Engineering his aid was much sought for as an adviser in matters involving scientific questions along engineering lines, especially those relating to his chosen fields of geodesy or geologic matters, and he was called upon several times to give expert court testimony in questions where solution demanded technical skill and knowledge. He had a fine grasp upon the true use of the calculus method of approaching

a problem, and his methods of approximate solutions of an intricate mathematical problem astounded all with whom he worked. President McNair of the Michigan College of Mines, himself a mathematician and scientist of no mean ability who had worked with Hayford in solving many intricate problems, once remarked to the writer that in his opinion Hayford had no equal in the world in handling mathematical problems, for when the ordinary calculus solutions failed Hayford's methods of approximation usually found a way.

The tasks of his position in the College, the preparation of scientific papers and lectures, the researches and computations in his favorite fields of geodesy, geology, evaporation and stream flow, and his large correspondence with scientific men and educators—these filled his time and seemed to employ all his time. No doubt he realized that his time was too fully taken up and that he would have liked to have more leisure for pure research. In a spirit far from boasting, but stating it merely as a matter of fact, he once remarked to the writer that if he could be sure of uninterrupted time for one hour a day, he could make a name for himself once a year.

The problems which he had in mind and upon which he would have liked to carry on research were many, especially in the later years of his life when stream-flow and evaporation were his important investigations. But his life proved all too short and only notes are left to show the lines along which he expected to progress.

Hospitality was a keen delight to him and to his family and his home was ever a place of entertainment to visitors from out of town or intimate personal friends. It was always a delight to visit them in their home. An atmosphere of good cheer was always present.

In conversation Director Hayford was most apt, because of a remarkable range of information on general and scientific topics, and with anecdote ready for the entertainment of guest or associate. He was ever cheerful and ever inclined to look upon the bright side of life, hopeful and sanguine of success where others might be discouraged. His keen sense of humor often carried

him over disagreeable obstacles, but he had a tremendous spirit when roused to just anger. Usually he had great control over himself in this respect and seldom did he allow anger to overcome him.

He was no recluse, but was most human in his associations with mankind. When traveling he never failed to associate himself with some man, whether of high or low degree, and in this way he put in practice his motto "Study Men." In a way he was not fond of "society," or social distinction, but did not shun it and usually was the life of a party at which he was present.

In his moral life Professor Hayford was almost without a peer. The writer has had a most varied experience with men in many walks of life, traveling on trains and boats, in camp life on surveys, in college life as student and professor, and in his association with men he can truthfully say that Hayford is one of the exceedingly few men of his intimate acquaintance whom he has never heard give voice to a "shady" joke or tainted story. Whether this was due to strict inhibition or to natural cleanliness, the writer cannot say, but it always appeared as though such thoughts were not a part of him.

As in his moral life, so was Hayford in regard to minor vices and appetites usually found in men. The use of tobacco and liquor was not a part of his make-up. While he did not use them himself, he was seldom heard to preach against them, and evidently they detracted little from his estimate of men with whom he associated. However, he was very severe in his censure of delinquent students who appeared before him with cigarette-stained fingers, and they usually received sharp reprimands on this account.

He was not a "gossip," unless it was something good or worth-while which he could speak of regarding another person. In this he was very careful. Dean Marston, referred to in another part of this memoir, wrote in 1929, "I find it impossible to tell why or just how Director Hayford made such a strong personal impression on me, or why we formed such an endearing friendship, continuing until the day of his death. I do not re-

call, at this time, a single mean thing he ever did, yet he was no sissy." His moral and mental cleanliness were noticeable to all his intimate friends and associates, and were a source of generous comment when he became the subject of discussion.

COSTA RICA-PANAMA BOUNDARY COMMISSION

The boundary between the Republics of Costa Rica and Panama in Central America had been a matter of dispute for many years. It was the subject of an arbitration in 1900 by President Loubet of France, but the award was not accepted by the two countries. In 1910 a new treaty between the countries was negotiated which provided for a new arbitration of the boundary dispute. Under this plan, the arbitrator was Chief Justice White of the United States Supreme Court. A boundary commission of engineers was provided for, of which each of the two countries would have one representative, and Chief Justice White would appoint two impartial American representatives.

The Chief Justice appointed as his representatives Director John F. Hayford of Northwestern University College of Engineering and Professor Ora M. Leland of the College of Civil Engineering, Cornell University, Ithaca, New York. Frank W. Hodgdon of Boston, Massachusetts, was appointed by Panama, and Percy H. Ashmead of New York was selected by Costa Rica as their respective representatives. These appointments were made in the fall of 1911. Director Hayford in his letter of acceptance as commissioner made the following conditions: that he should "not be required to leave Evanston before September 30, nor to be continuously absent from Evanston for more than twelve weeks at any one time" to "protect the University against the danger that this service might interfere, improperly, with the performance of my duties as Director of the College of Engineering."

The Commission was organized October 6, 1911, by electing Director Hayford as its Chairman and Professor Leland as its Secretary. It organized a large body of engineers and operating staff and sailed from New York on January 13, 1912, for

Panama, and arrived on January 24 at Bocas del Toro near the disputed territory, and the same day the party with all equipment reached the houses on the Sanchez farm, which had already been prepared for use as the field headquarters, on the bank of the Sixaola River near the end of the railroad. The survey parties left headquarters to commence field work on January 25-29. Surveys and explorations of the region involved in the boundary dispute were carried on under the direction of the Commission for the greater part of 1912 when the force was returned to the United States and disbanded. A tabulated statement in the report of the Commissioners shows that Director Hayford was present in the region of the field work from January 24 to March 19, May 14 to July 29, visiting the engineering parties and studying the topography of the country.

The Commission held twenty-six meetings from October 6, 1911, to February 19, 1912, and eight meetings July 22 to 27, 1912. Between February 19 and July 22, 1912, though no meetings were held the Commission was virtually in session continuously, for the members kept in touch with each other by mail or by cable. In all forty-one meetings were held, including those after completion of the field operations. Throughout the period Director Hayford adhered strictly to the "twelve weeks" condition of his acceptance, and this necessitated his doing considerable traveling to be at the various meetings, and to and from Panama.

The conditions under which the field work was done were very difficult, in a region where rainfall is heavy even during the dry season, in part through tropical jungle where cutting was practically necessary at every step, and in part where all supplies had to be carried on men's backs. Especially difficult was it to obtain astronomical observations on account of the dense growth of trees.

Director Hayford's portion of the work was the duties which fell to him as Chairman of the Commission, and during a part of the time as the only Commissioner present in the region of the field work. The writer has had the privilege of inspecting his personal diaries which he kept on all of the work and they

proved intensely interesting reading, kept as they were with his usual infinite detail.

The survey parties were disbanded gradually in San Jose after their return from the field work, the last one leaving for New York on November 20.

The preparation of the final Report of the Commission, including its collection of maps and photographs, was made at Evanston, Illinois, between October 25, 1912, and July 5, 1913, under the direction of Mr. Hayford, assisted by two transitmen of the field force and the disbursing officer who acted as stenographer. Four meetings of the full Commission were held in Evanston. The final report was submitted to the Arbitrator on July 14, 1913, and the work of the Commission was brought to a close.

Formal notice of the termination of the services of the Commissioner was sent under date of November 22, 1913, in which Chief Justice White stated: "And I say with perfect candor that the zeal, the character, and the high professional qualities displayed by the Commission have won my profound appreciation of their great merit, and entitle them to the gratitude of both governments who are parties to the treaty."

The opinion and decision of Edward Douglass White, Chief Justice of the United States, acting in the capacity of arbitrator in the boundary dispute between the Republics of Costa Rica and Panama, provided for by the Convention between these two governments under date of March 17, 1910, was formally rendered on September 12, 1914, and the work of actually marking and delineating the boundary was authorized September, 1921.

EVAPORATION FROM THE GREAT LAKES, STREAM-FLOW AND RELATED PROBLEMS

In the fall of 1909, when Mr. Hayford moved from Washington to Evanston, Illinois, to become Director of the College of Engineering at Northwestern University, he established his family in a delightful home on Ingleside Place, only one house

removed from the bluff overlooking beautiful Lake Michigan, and about one mile from the College. It was his usual practice, excepting in the most inclement weather, to walk to and from the College along the bluff or lake shore rather than use the walks. His active mind soon realized that before him, in the form of Lake Michigan and the rest of the Great Lakes, there existed a wealth of scientific problems of astounding interest. The first of these to receive more detailed notice was the problem of the seiches occurring in the lake, and often he would be engaged in studying them by actually measuring their magnitude and times of occurrence. He coupled this with a wide range of the study of the literature on the seiches.

Soon a much larger problem began to take form in his mind, and by the summer of 1911 had taken rather concrete form. He saw at his very door a most gigantic "Evaporation Pan," and visioned many of the intensely interesting scientific studies which lay therein. The first of these which he attacked was the problem of evaporation and of the wind and barometric effects upon the level of the Great Lakes, which soon broadened out to larger problems, the ultimate object of this larger investigation being to obtain a better formulation of the laws governing evaporation, rainfall and run-off, and in deriving therefrom better formulas governing the amount of stream flow. These problems continued to enlist his attention for the remainder of his life and, with the exception of his work as Director of the College, occupied the greater part of his time. The work was of such magnitude that he found he could not handle the mass of computing necessary and so placed the matter before the Carnegie Institution of Washington. They designated him a Research Associate of the Institution and awarded him grants of money to enable him to hire computers on the work.

These computers were for the most part advanced students in the College of Engineering, and they worked continuously during the various school vacations and at various periods during the school year. One student, Julius A. Folse, worked on the computations almost from their beginning and attained such proficiency that after graduation he accepted work as chief as-

sistant to Professor Hayford in carrying on these investigations, and to him was awarded the work of completing the second volume, as is shown later on in these memoirs. The help of these computers was especially needed in the long, involved least-squares solutions incident to the work. The first direct result of the work was given to the world in the volume, "Effect of Winds and of Barometric Pressures on the Great Lakes," published in 1922 by the Carnegie Institution as Publication No. 317.

This was followed by a second publication which Professor Hayford was not able to complete before his death, but upon which he was working when stricken in December, 1924. The work was, however, brought to such a state that it was completed in 1929 by Julius A. Folse and was published by the Institution as Publication No. 400. This second volume deals with "A New Method of Estimating Stream Flow, Based upon a New Evaporation Formula."

These two volumes, together with his work on Isostasy, are tangible evidence of the wonderful brain which could conceive a method of attacking such difficult problems, and the almost unbelievable courage of the man in facing the gigantic task of trying to work through such a mass of intricate and difficult computations. Only a man grounded thoroughly in the theory of the method of least squares, with a concise grasp upon the interpretation of results obtained, and with much practice in the solution of indefinite problems by this method would have the temerity in attacking them. In this kind of scientific research Professor Hayford probably had no equal. In his hands least squares was a most wonderful tool.

In the investigations of "Effect of Winds and Barometric Pressures," 74 complete least-squares solutions and the corresponding studies were made. In one of these solutions each observation equation contained 40 unknowns, and there were 619 observation equations in the set. More than 22,500 man-hours of time were spent on the routine part of the computations and studies connected with the broad investigation of evaporation, and of wind and barometric effects.

This investigation considers the lake-chain Michigan-Huron and Erie as a great "evaporation pan." The principal data used include hourly and daily observed elevations of the surfaces of Erie and Michigan-Huron at five gage stations, observed hourly wind directions and velocities at five points near these lakes, and the observed barometric pressures twice a day at six points, for periods from 1909 to 1913 as observed by the U. S. Weather Bureau, the U. S. Lake Survey, and the Corps of Engineers of the U. S. Army.

A summary of the results obtained in this research includes:

1. Reasonably accurate numerical expressions for the effects of barometric pressures at five stations.

2. General method developed for finding numerical expression at any station on any body of water from observations of the water elevation and the forecast maps of the Weather Bureau.

3. General expression, including numerical constants, for effect of winds, of any given velocity and direction, affecting elevation of the water surface at any given station, on any body of water, anywhere in the world.

4. The relation between seiches and the uncertainties in daily mean elevations at gage stations discerned.

5. Accuracy with which the elevations of mean surfaces of any one of the Great Lakes may be determined for any given day decidely increased.

The possible applications of the results of the investigations as summarized by Professor Hayford are:

a. Application to a study of the laws of Evaporation.
b. Application to regulation of the Great Lakes.
c. Application to determination of mean sea-level and to precise leveling
d. Application to determination of tilting of the Great Lakes region.

The second volume on the study of evaporation concerns itself with "A New Method of Estimating Stream-Flow, Based upon a New Evaporation Formula" as previously mentioned.

In it Professor Hayford (and as completed by Mr. Folse)* makes use of the evaporation formulæ derived in the first part and applies them to two specific streams for which stream-flow and meterological data were available. These two streams were in Wagon Wheel Gap, Colorado, and data were available through the kind permission of the Weather Bureau and the Forest Service.

A general summary of the outcome of the investigation shows:

1. Approximate quantitative expressions of the fundamental law of flow of the two streams in Wagon Wheel Gap.

2. Development of general method by which such expressions can be derived for any streams anywhere in the eastern two-thirds of the United States where annual rainfall is twenty inches or more and data of stream-flow and meterological observations are available.

3. The relation of the above to:
   - *a.* Problem of increasing length of record of flow of a stream, the hydrograph, as a basis for greater accuracy in the design of works for power, irrigation, sanitation, and navigation.
   - *b.* Problem of forecasting flow of a stream as a basis for increasing the economy of hydro-electric power plants.
   - *c.* The problem of determining effects of forest cover on the run-off from a watershed.

While he was at work on the larger investigation of stream-flow and evaporation, he had a number of related problems in mind, and some of these were investigated as engineering theses by advanced students in the Fifth Year of the College of Engineering, working under the direction of Professor Hayford. It is worth while to consider here a few of these because they had a direct bearing on his proposed line of future work and studies.

* Mr. Folse states in the preface to this second volume that he resumed work on this study "primarily with the object of rounding out in form for publication the work already accomplished by Dr. Hayford."

Having developed the theories and formulas for evaporation and stream-flow, it was necessary to justify the expenditures of time and money in showing that they could be applied successfully in general practice in hydraulic work.

In 1924, Alva B. Simons, under the direction of Professor Hayford, made a study of a "Proposed Control of the Elevations of Lake Huron-Michigan and Erie by a Dam with Moveable Parts at the Head of the Niagara River." On the supposition that a desirable elevation to be maintained in Michigan-Huron as one-half foot above its mean annual stage, and similarly for Erie, the investigation showed that the proposed method of regulation would practically destroy the loss on Michigan-Huron of the 10,000 c. f. s. withdrawn by the Sanitary District of Chicago. It would entirely destroy the losses on Lakes St. Clair and Erie, due to the diversion, and in addition would appreciably raise the levels of these lakes.

In 1924, T. B. Stitt, working under Professor Hayford's supervision, began a study of "Probability of Floods in Streams in Humid Climates." In this work the investigation applied the laws obtained by Professor Hayford in his stream-flow, and through these found the relation of the actual discharge-frequency curves of each of four streams selected to their theoretical probability curves. On account of the sickness and death of Professor Hayford this investigation was not brought to a complete conclusion. Note is here made of it because this field of work, namely, prophesying stream-flow, was the field in which Professor Hayford was planning to do much work. He often discussed with the writer concerning the practical use of the proposed methods in their application to hydro-electric plant installation and operation. He had already applied his formulas for stream-flow to the streams in Wagon Wheel Gap with much success and was planning a further application to the Cumberland and Delaware Rivers.

In the fall before his death the writer made a trip with him to the hydro-electric plant of the Mississippi River Power Commission at Keokuk, Iowa. While there Professor Hayford made tentative arrangements with the management to obtain their rec-

ords of stream-flow and hydrological data on the Mississippi with a view to testing the accuracy of his laws on one of the largest projects in this country. His untimely death, however, brought an end to this work.

In 1924 Professor Hayford, J. A. Folse, and B. J. Fisher collected data on the Kankakee River, Illinois, and Mr. Fisher, under the supervision of Professor Hayford worked on the problem of estimating stream-flow on this river, and its application in the hydro-electric field. The results indicated very clearly the value of the method in prophesying stream-flow.

His publications and lectures soon brought him general recognition as an authority on the problems affecting the waters of the Great Lakes and his services were increasingly solicited in connection with these problems.

In the case of the United States versus the Sanitary District of Chicago, which was argued before Judge Landis in 1923, in which the United States sought to restrain Chicago from taking as much as 10,000 cubic feet per second of water from Lake Michigan, Professor Hayford was called in by the United States as an expert to establish the degree of accuracy and reliability of the gaging of the Niagara River. This was the crucial point in establishing the fact that there had been a lowering of Lake Erie, Lake Huron, and Lake Michigan, by the diversion of water through the Chicago drainage canal, below the levels which these lakes would have had under natural conditions.

Not only was Director Hayford keenly interested in the problems concerning the Great Lakes, but he also spent much time and study on the related problem of the St. Lawrence Waterway, in the value of which he was a firm believer as is made evident by many letters which he wrote regarding it. In one of these, addressed to Hon. C. R. Chindblom, House of Representatives, Washington, D. C., he writes, "I hope that the St. Lawrence Waterway will be built, the power along that river gradually developed, and certain other relatively minor improvements made for the benefit of navigation on the Great Lakes. Such action would bring large returns to the people of the United States by lowering the cost of transportation between the great

middle west and the seaboard and Europe, and by helping to relieve the inevitable congestion on the railways which is bound to occur occasionally for a quarter of a century."

When he was invited November 24, 1923, to become a member of the Committee of the Western Society of Engineers on the St. Lawrence Waterway he accepted with pleasure for he believed "such improvements to be very important to the people of both the United States and Canada, because it will bring vast returns in comparison with what it will cost."

On January 29, 1924, he was appointed and accepted membership on the Rivers and Harbors Committee of the Chicago Association of Commerce, and on many occasions was invited to address various meetings on topics relating to the Lake Diversion and Waterways. One of these addresses, "The Best Use of the Waters of the Great Lakes," was given before various groups in and around Chicago and was productive of much comment.

As a humorous side-light on his researches and addresses on the subject of the diversion of waters from the Great Lakes and his other activities, the honorary degree of S. G. (Steam Generator) was conferred upon Director Hayford at the December 13, 1923, meeting of the Chicago Club of Northwestern Men. The degree was appropriately conferred with the following tribute:

"John Accelerator Hayford"

"Beloved of all the poker players in the Cosmos Club of Washington, D. C.; discoverer of the cut-throats who are stealing waters from Lake Michigan, thus preventing navigation of schooners across the bar; a professor of engineering who knows more about aeroplanes than Dean Kendall knows about microbes; a consistent rooter at foot-ball games, win or lose."

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

In the law establishing the National Advisory Committee for Aeronautics it is stated that "The President is authorized to appoint not to exceed twelve members, to consist of two mem-

bers from the War Department, from the office in charge of Military Aeronautics; two members from the Navy Department, from the office in charge of Naval Aeronautics; a representative each of the Smithsonian Institution, of the Weather Bureau, and of the United States Bureau of Standards; together with not more than five additional persons who shall be acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied science." President Woodrow Wilson appointed Professor Hayford a member as one of the "five additional persons" on April 2, 1915, when the Advisory Committee was first formed, and he served continuously in that capacity until his voluntary resignation in 1923. This duty caused him often to be absent from Evanston to attend the various meetings of the Committee held at Washington or at the several flying fields where tests of airplanes or airplane equipment were in progress. He took keen interest in this work and so far as the writer is able to judge from his correspondence he was never absent from any of these meetings. Judging from several passages in his correspondence, these meetings often occurred at the same time as meetings of other organizations in Washington and vicinity in which he was interested, and thus only one trip from Evanston was made necessary. Perhaps these coincident meetings were graciously arranged to favor Professor Hayford in this respect.

Personnel of National Advisory Committee,
April 20, 1922.

Dr. Charles D. Walcott, Secretary, Smithsonian Institution, Chairman.
Dr. Joseph S. Ames, Johns Hopkins University, Chairman, Executive Committee.
Dr. S. W. Stratton, Secretary, Director, Bureau of Standards.
Major T. H. Bane, Chief, Engineering Division, Army Air Service.
Dr. W. F. Durand, Professor of Mechanical Engineering, Stanford University.
Dr. John F. Hayford, Northwestern University.
Professor Charles F. Marvin, Chief, United States Weather Bureau.

Rear Admiral Wm. A. Moffett, Chief, Bureau of Aeronautics, Navy Department.
Major General Mason M. Patrick, Chief of Army Air Service.
Dr. M. I. Pupin, Columbia University.
Rear Admiral D. W. Taylor, Chief Constructor, U. S. N.
Orville Wright, Dayton, Ohio.

When Dr. S. W. Stratton resigned from the position of Director of the Bureau of Standards to become President of the Massachusetts Institute of Technology, and his successor, Dr. G. K. Burgess, had been appointed, it was apparent that Dr. Burgess should become the representative of the Bureau of Standards on the National Advisory Committee for Aeronautics, and unless Dr. Stratton could be appointed from private life he would necessarily have to be dropped from the Committee of which he had been the Secretary. There now occurred one of the finest examples of self-effacement which could possibly be conceived when, on May 21, 1923, Professor Hayford tendered his resignation from the Committee to take effect at whatever date the President should designate, in order to provide an opportunity for Dr. Stratton to continue on the Committee. In his letter of resignation he states:

"It is very important to keep Dr. Stratton on the National Advisory Committee for Aeronautics. . . . He has a continuing special interest in aeronautics on account of the advanced courses in that line at the Massachusetts Institute of Technology. He can render the Committee especially valuable service in connection with various governmental relations. My interest in the Committee work is as keen as ever, but my value to the Committee is necessarily small as compared with that of Dr. Stratton. . . . There is not the slightest hesitation on my part to withdraw from the Committee, in order to provide a place for Dr. Stratton, even though I have greatly enjoyed my association with the Committee for eight years, have greatly prized the honor of being on the Committee, and even though I shall have a keen sense of a personal loss to me as I drop out."

Professor Hayford's resignation from the Committee was formally accepted by President Warren G. Harding under date of May 26, 1923. President Harding wrote:

"I desire especially to commend your fine spirit of public interest in sacrificing your membership in the National Advisory Committee for Aeronautics in order to promote the Committee's welfare by making possible the continued membership of Dr. S. W. Stratton, who is Secretary of the Committee.

"In accepting your resignation, I wish to express to you the thanks of the Government for your patriotic service without compensation as a member of the National Advisory Committee for Aeronautics since its organization in 1915."

Dr. Charles D. Walcott, Chairman of the Committee, wrote to Professor Hayford on May 24, 1923, expressing regret for

". . . the situation that is the cause of the severance of our official relations, which have been most cordial and delightful since the organization of the Committee in 1915. I know that this action has caused you regret that can be overcome only by the satisfaction that comes from doing the big thing—from making a personal sacrifice for the general good, a sacrifice not unlike that which has always characterized your service on the Committee during the past eight years."

As might be expected, Professor Hayford's connection with the National Advisory Committee for Aeronautics and with the Bureau of Standards on aviation problems soon brought him to the attention of the public at large and he was invited often to address various scientific or civic bodies on subjects connected with aviation, and his services were often employed on committee work in engineering societies. A partial list of these is given here:

Chairman of the Aviation Committee of the Western Society of Engineers, 1920.
Representative of Western Society of Engineers on Air Board of Chicago, appointed April 19, 1922.
Member of the Aviation Committee of Western Society of Engineers, appointed June 17, 1922.
Address—"What American Science is Doing for Aviation."
Chicago Academy of Science, January 25, 1918.
Sigma Xi at Northwestern University, February 4, 1918.
Western Society of Engineers, February 5, 1918.
Address—"The Future of the Airplane."
Cosmos Club of Washington, January 5, 1920.

Address—What Should Be Done to Develop the Civil Use of Airplanes?"
Western Society of Engineers, 1920.

VISITING COMMITTEE OF THE BUREAU OF STANDARDS

On February 26, 1912, Professor Hayford was appointed by the Secretary of Commerce and Labor as a member of the Visiting Committee of the National Bureau of Standards at Washington, D. C., the appointment to be for four years. He was absent from Evanston on this duty about one week each year.

In accordance with Section 10 of the Act of Congress, approved March 5, 1901, to establish the Bureau of Standards, "The Visiting Committee shall consist of men prominent in the various interests involved and shall visit the Bureau at least once a year, and report to the Secretary of the Treasury upon the efficiency of its scientific work and the condition of its equipment."

The other members of this committee, besides Professor Hayford, were Professor Elihu Thomson, Professor Henry M. Howe, President R. S. Woodward, and Professor A. G. Webster.

Under date of June 9, 1917, Professor Hayford was reappointed a member of the Visiting Committee of the Bureau of Standards. The appointment was signed by Hon. William C. Redfield, Secretary of the Department of Commerce, and was for the period beginning June 9, 1917, and ending June 30, 1921.

WAR WORK AND THE BUREAU OF STANDARDS

When the United States entered the Great War it was but natural that Director John F. Hayford of the College of Engineering at Northwestern University should be called into service at Washington because of his former connections there in various capacities and because of the fact that he had been a member of the National Advisory Committee for Aeronautics since 1915. He responded to the call in June, 1917, immediately after Commencement at the University. He maintained close touch with

the College of Engineering by coming back to Evanston more than twenty times during the extent of the war, for periods varying from one to six weeks. The University was thus able to help in the war work by lending his services and without losing his help at Evanston.

His Washington work was the result of a close cooperation between the National Advisory Committee for Aeronautics and the Bureau of Standards, as both supported the investigations which were carried on.

In June 1917, when he entered the work, he was given a roving commission to help, anywhere he saw fit, in the investigations connected with aeronautics which were then in progress at the Bureau of Standards. His appointment to this work was in the nature of a temporary one as Associate Engineer Physicist, Bureau of Standards, and was to continue for a period not to exceed three months. Under dates of October 11, 1917, and January 8, 1918, respectively, this temporary appointment was extended by a similar three months' temporary appointment.

He soon reached the conclusion that the particular field in which he could be of most value was in the development of the necessary instruments and methods for making tests of full-sized airplanes in free flight in the normal manner. Nothing was then being done toward the development of such tests as were contemplated.

At that time airplanes, airplane propellers, and airplane engines were designed mainly on the basis of tests made on the ground. Full-sized engines were used on these tests, but some of the conditions which the engines meet in the air could not easily be duplicated on the ground. In so far as the airplane propellers and wings are concerned, the designs were based mainly upon information gained from observations upon small models usually not more than thirty inches in the longest dimension. These models were tested in an artificial wind in a wind tunnel, and from them conclusions drawn as to the probable performance of full-sized propellers and wings in the air.

It was recognized to be extremely important to secure the exact information as to the performance of the full-sized machine

in the air. Such tests as had been made in the air were either very incomplete or the accuracy much lower than was recognized to be necessary. The reason that the free-flight tests of the required kinds had not been secured was simply that the difficulties in the way were so great that but few persons had attacked the problem, and these few had necessarily made but small progress. It was recognized, however, in June 1917 that the importance of such tests was so great that they should be made at any reasonable cost, and both the Advisory Committee and the Bureau of Standards were prompt in offering support to the project. The proposed tests would furnish decisive evidence as to the strong and weak points of a given airplane, including its engine and propeller, and so would furnish a firm basis for progress in making improvements.

To make the desired tests in a satisfactory manner it was necessary to devise six new instruments which would record autographically and continuously in the air the following six quantities:

(1) The number of revolutions per minute of the engine,
(2) The torque of the engine (this being the quantity which, multiplied by the revolutions per minute, furnishes the horse-power),
(3) The thrust of the propeller,
(4) The inclination of the airplane wings to the true horizon as it flies,
(5) The speed of the machine through the air, and
(6) The inclination of the actual path of the machine.

Such records would show continuously the power developed by the engine and its efficiency, the efficiency of the propeller, the efficiency of the wings, and they would show under what conditions the performance of the airplane and of its separate parts was best and under which it was poorest during the flight.

It was necessary that each record should be autographic, that is, that the instrument should draw a continuous line on a moving sheet of paper to indicate the fact at every instant. Most of the instruments to this date were instruments which the observer or pilot necessarily read by eye, by looking at a

pointer against a dial. If the attempt was made to secure the free-flight tests with such dial-reading instruments the results would not be satisfactory, for though an observer made a reading every ten seconds, the airplane would probably have traveled more than a mile before one reading of each of the six instruments had been made. During that time the conditions would probably have changed so that the readings of the different instruments would have been made under different conditions. With the autographic instruments all of the six records might be read at leisure on the ground for the same instant of flight, so that corresponding values of the different quantities could be obtained.

As the work progressed, Dr. Lyman J. Briggs of the Bureau of Standards and Professor F. W. McNair of the Michigan College of Mines were associated with Professor Hayford in the creative part of the work. At various times many others were helping in the work. An English officer in Washington who had made tests in England which were then the nearest approach to the required free-flight tests furnished valuable advice.

A new, original design was found to be necessary for each of the six instruments. At the outset four of the six appeared to be nearly impossible. One of the instruments has proved to be a new invention which was patented in favor of the United States. This was a gyroscope apparatus, and was patented under date of September 19, 1922, with John Fillmore Hayford and Lyman James Briggs as assignors to the Government of the United States. All of the six were finally completed and were built in five different shops, three in Washington, one in Brooklyn, and one in Champaign, Illinois.

Early in April, 1918, it was recognized that one of the six instruments, which had then been demonstrated, had several war applications other than the application to free-flight tests. As a result Mr. Hayford and his group were required to turn aside and design modified forms of the instrument for two or more war applications. Though these modified instruments were not finished before the Armistice was signed, the military authorities decided to have them completed, which was done after the

Armistice. Thus eight new instruments were the outcome of the work by Mr. Hayford and those associated with him. The material that Director Hayford left regarding these is marked "Confidential," and though war conditions no longer prevail, the writer, for obvious reasons, does not divulge the nature of these instruments. It may be that this precaution is no longer necessary.

On July 19, 1919, Professor Hayford, together with Professor McNair and Dr. Briggs, his associates in the development of these special instruments as modified for the War and Navy Departments, left Hampton Roads, Virginia, with the Pacific Fleet enroute to San Diego, California, by way of the Panama Canal for the purpose of carrying on tests of the instruments for the Navy under actual sea conditions. These tests were made on board the U. S. S. Mississippi. Commander W. R. Furlong, U. S. N., of the Bureau of Ordnance, accompanied the party, made all arrangements with the officers of the Mississippi, and took an active part in all tests. Captain Moffett and the officers of the Mississippi furnished the party with every facility desired, and Admiral Hugh Rodman in command of the Pacific Fleet gave the Mississippi permission to drop out of the fleet formation every day on much of that part of the trip which lay in the Pacific. The tests were carried on during practically the entire trip which ended at San Diego, California, on August 5, 1919. From ten thousand tests made on this trip it was proved that the instrument was a practicable, convenient, reliable instrument for indicating the position of a ship with reference to the true horizon, regardless of the visibility conditions of the sea-horizon.

Letters of appreciation for the services of Director Hayford during the war were received by President Lynn Harold Hough of Northwestern University from the Navy Department and from the Bureau of Standards. Dr. Stratton, of the Bureau of Standards, wrote:

"Professor Hayford and his associates have not only solved to the satisfaction of the Navy Department the problems pre-

sented, but have secured data and developed devices which we now see will have many important applications in aviation, in navigation, and in the industries."

Similarly, in expressing its appreciation of the services of Professor Hayford, the Bureau of Ordnance of the Navy Department stated that the work done was a great contribution to the efficiency of the gunnery of the United States Navy and that the Bureau "particularly appreciates the generosity and patriotic spirit of the officers of your institution (Northwestern University) in allowing Dr. Hayford to give considerable time and effort to the government. You may be recompensed in knowing that the time of Dr. Hayford thus given has resulted in efficiently solving a very important scientific problem for the United States."

ROCKAWAY POINT

In 1921 Mr. Hayford was called to New York City to serve as Expert Witness in the case of the Rockaway Pacific Corporation against the State of New York. It was an interesting case of a point of land which in eighty years had extended itself more than three miles into an area formerly covered by the waters of the ocean from depths of ten to thirty or more feet, and is probably the most rapidly growing point anywhere on the shores of the United States. Mr. Hayford's function was to help establish the facts as to how Rockaway Point near New York City had grown. He spent considerable time gathering information at the Coast and Geodetic Survey and other places, and finally testified before the court at Utica, New York, January 22-26, 1921.

THE SLIDES OF THE PANAMA CANAL

In 1915, and for some time before, the use of the Panama Canal was badly affected, due to the occurrence of sliding or caving in of the banks at several points along the Canal. At the request of President Woodrow Wilson on November 18, 1915, the National Academy of Sciences appointed a committee of thirteen persons "to consider and report upon the possibility of

controlling the slides which are seriously interfering with the use of the Panama Canal."

In 1912 Professor Hayford, while in Central America in connection with the Costa Rica-Panama Boundary Survey, had the pleasure of spending five days at the great Culebra Cut with Col. Gaillard, accompanying him through the cut on his regular inspection trips each day, climbing three of the slides which were then active, and hearing him discuss the nature and cause of the slides. Also in that year he became well acquainted with Mr. Donald F. MacDonald, the geologist employed especially to study the slides.

During the four years, 1912-1915, as he states, he "read with avidity" everything he saw in regard to the Panama slides and his voluminous scrap book bears ample evidence that this was no idle statement. Therefore, when the invitation came to be one of the Committee to study this great question he responded most heartily, his acceptance being dated November 26, 1915.

The Committee as originally appointed consisted of thirteen persons, as follows:

C. D. Walcott, Scientist, Secretary of the Smithsonian Institution.
G. F. Becker, Geologist, in Charge of Division of Chemical and Physical Research, U. S. Geological Survey.
R. S. Woodward, Scientist, President, Carnegie Institution of Washington.
Arthur L. Day, Physicist, Geophysical Laboratory.
C. R. Van Hise, Geologist, President, University of Wisconsin—Chairman of the Committee.
H. L. Abbott, Army Officer and Engineer. Long record as investigator in connection with the Mississippi River and Panama Canal.
J. C. Branner, Geologist, recently President of Stanford University.
Whitman Cross, Geologist, U. S. Geological Survey.
R. C. Carpenter, Professor, Mechanical Engineering, Cornell University.
A. P. Davis, Chief Engineer, U. S. Reclamation Service. Twice before called into service in connection with the Canal.

J. R. Freeman, Consulting Engineer, Providence, R. I. Once before called into consultation on Panama Canal Problems.
J. F. Hayford, Civil Engineer, Director, College of Engineering, Northwestern University.
H. F. Reid, Professor of Geology, Johns Hopkins University. Eminent student of glaciers and earthquakes.

For various reasons the first three were unable to visit the Canal and participate in the deliberations of the Committee leading to the preliminary report; the fourth declined service on the Committee.

The remainder of the Committee sailed from New Orleans, December 11, and arrived at Panama, December 19. All spent two weeks in the Canal Zone, and three of them several days longer, working upon the problems submitted to them. The Committee saw the Canal from end to end, but directed its main attention to the slides and hills of the Culebra District, where the engineers encountered the most serious difficulties. The work of the Committee in the field was facilitated in every way by Major General George W. Goethals, and many officers and engineers connected with the Canal work, and by the work and services of Mr. MacDonald, Canal Geologist from 1911 to 1913.

It was desirable that President Wilson and Major General Goethals should have the general conclusions of the Committee as early as possible; and, accordingly, a preliminary report was prepared, which was placed in the hands of the President on February 3, 1916. It was published in the *Proceedings of the National Academy of Sciences,* 1916, Vol. II, pp. 193-207, and in the *Annual Report of the Isthmian Canal Commission* for the fiscal year 1915-16, pp. 587-98.

Meetings of the Committee were held in Washington, D. C., April 22, 1916, and in Boston, November 11, 1916, to discuss and formulate the final report which was signed by Professor Hayford March 24, 1917. On consideration of all available data the Committee modified some of the conclusions and tentative recommendations presented in the preliminary report. Although

presented too late to be of much use in the "control" of the active Culebra slides, it was hoped that this final report of the Committee would lead to a more thorough understanding of the slide phenomena and more complete future protection for this great thoroughfare of commerce.

The final report is contained in Volume 18 of the Memoirs of the National Academy of Sciences, published in 1924.

At the time of activity of the slides they were a problem of great interest to the general public as well as to the scientific men of the world. As might be supposed, Professor Hayford was besieged from all sides for information regarding them, and organizations of various kinds invited him to address them on the subject. It was not, however, until after the report was placed in the hands of the President in February, 1916, that he consented to talk or write for public use regarding the slides. He had prepared from official photographs a large number of slides and these were used to illustrate his address on "The Great Land Slides at Panama."

A BUSY MAN

During the war extra burdens were taken over by Hayford. It must have been, indeed, a busy time for him. On November 2, 1917, he writes:

"It is important to the success of the United States in war, if it is to be a long war, to keep the universities going, and still more important to the United States in the reconstruction period after the war that the supply of trained thinkers should not be allowed to diminish any more than is absolutely necessary. My belief in these propositions is shown by the determination with which I am sticking to my work as Director at the same time I am trying to do my part in Washington."

And again on September 8, 1920, he says:

"I am now thoroughly immersed in my college duties plus original researches in connection with gyroscopes, aeronautics, and evaporation and stream flow. This is a heterogeneous list which is a result of following where duty and opportunity both lead. I spent much of my time for three years in Washington

on war duty while still carrying my responsibilities at Northwestern University. Incidentally, during these three years I have travelled about 40,000 miles, including twenty-one round trips between Evanston and Washington."

ROTARY GRAVIMETER

Among the many scientific problems in which Professor Hayford was interested was that of determining the intensity of gravity at sea. It was one of the outstanding problems, as he saw it, whose solution was needed in order to complete satisfactorily the studies of gravity and isostasy. He was continually issuing a challenge for some one to invent a device by means of which the intensity of gravity at sea could be determined with an accuracy commensurate with those made on land, and he, himself, pondered long on the possibility of such a device.

In 1921 he was confined to a hospital in Evanston for a minor operation. On the occasion of one of the visits which the writer paid him during his convalescence, he found Professor Hayford in a very jubilant mood, and was shown the preliminary studies of a device which seemed to have promise of solving this important gravity problem. The device was an adaptation of the principle of the rotating governor and the displacement of the arms was to be a measure of the force of gravity. For this reason Professor Hayford termed it "the rotary gravimeter," and for a year or more the study of this took up much of his spare time.

In December of that same year he wrote to Lyman J. Briggs: "I am still finding nothing wrong with the scheme and am accumulating evidence in favor of the probable success of the instrument."

He deduced a complete theory for the instrument and made computations as to its accuracy and possibilities.

In a letter to William Bowie written in February, 1922, he wrote: "After studying more than one hundred and thirty hours on the problem I found that my proposed instrument will not serve the purpose. I have killed my own bright idea by proving that it will not work." Under date of February 13, 1922, he

abandoned its further study and marked the seventy-five pages of the study with these words: "The Rotary Gravimeter is not feasible for determining gravity at sea," and then proceeded to give a complete summary of the reasons therefor.

This must have been a severe blow to him, for it was a problem whose solution was so ardently desired. It is the only case known to the writer where Professor Hayford failed to arrive at his goal within a brief period. The studies which are contained in the seventy-five pages constitute a masterpiece of intrinsic reasoning and mathematical analysis, and the instance is here cited because it shows very clearly his method of attack and his mental processes in carrying out a specific line of investigation. Although failure was the reward for his many hours of work, this study shows the truly wonderful research qualities of the man and the splendid analytical powers he possessed.

COLORADO SCHOOL OF MINES

On May 31, 1915, the Board of Trustees of the Colorado School of Mines, Golden, Colorado, extended an invitation to Professor Hayford to consider himself as a candidate for the Presidency of the Colorado School of Mines. This invitation was extended by Mr. H. C. Parmlee of the Board upon recommendation of Dr. Richard Maclauren, President of Massachusetts Institute of Technology. On June 4, Director Hayford wrote that he did not care to be considered as a candidate for the position, stating that "Northwestern University is treating me so well and there is so much need for my continued presence here in this young College of Engineering that I do not care to consider leaving." Upon being informed of this decision of Professor Hayford, Dr. A. W. Harris, then President of Northwestern University, expressed himself by writing: "Your letter with its enclosures pleased me immensely, first because of the compliment to you and the reflected compliment to Northwestern, and second, because of the great compliment to Northwestern contained in your decision. To lose the Hayfords from Northwestern would be a loss so serious that I do not find it easy to characterize it."

SOCIETY FOR THE PROMOTION OF ENGINEERING EDUCATION

Long before he became Director of the College of Engineering at Northwestern University, Mr. Hayford showed great interest in the Society for the Promotion of Engineering Education, and joined with the group of teachers and workers in the engineering field who were active in studying the possibilities of improving engineering education. He became a member of the Society in 1905, and throughout the following twenty years was a most ardent worker in this cause, and very markedly so after his appointment to Northwestern.

While still in the government service he gave two talks before the Society, one "Opportunities for Engineering Graduates in Government Service," and the other, "Why not Teach About Men, the Most Important and Difficult Tools an Engineer Uses?," published in Volumes XIII and XIV of the Bulletin of the Society.

He seldom was absent from any of the annual meetings of the Society and usually took part in some way, either by presenting a paper or by entering into the discussion of papers presented. At the Ames, Iowa, meeting in 1915, he presented the paper, "Reflections of a Director," and at the Baltimore meeting, 1919, "Reflections of an S. P. E. E. President," and was coauthor on "Fifteen Years' Experience with a Five-year Engineering Curriculum at Northwestern University," presented by the writer at the Boulder, Colorado, meeting in 1924.

He served the Society in many capacities; was on its Council in 1909, in 1916, and again in 1921, was Vice-President in 1917-18, and President in 1918-19. During 1918-19 he was a member of the Program Committee, in 1918-19 and 1919-20 a member of the Publication Committee, and in 1918-19 a member of the Executive Committee. These were added to the heavy duties which he had in connection with his work in Washington during the War, and to his duties as Director of the College of Engineering.

Through his invitation Northwestern University was host to the Society in 1918. Due to the fact that President Ketchum

was not able to be present, Director Hayford served as President during that meeting and was at that time elected President for the ensuing year.

In December, 1917, he was appointed by President Ketchum as a member of a committee of eighteen to secure a ruling from the Provost General of the United States Army in regard to enlisting engineering students in the Enlisted Reserve Corps so that they might finish their course before entering active service. This was one of the prime factors in the organization of the Engineer Enlisted Reserve Corps during the World War.

In December, 1918, Director Hayford presided and gave the address of welcome on behalf of the Society for the Promotion of Engineering Education at the joint meeting of the Society and the British Educational Meeting of the American Council on Education, held at the Massachusetts Institute of Technology, Cambridge, for a discussion of engineering education in relation to the war.

In his address as retiring President, given at Baltimore in 1919, he called attention to the rare opportunity he had had of presiding over three successive meetings, an opportunity not given to any of his predecessors.

At the request of the President of the Society, he represented the Society for the Promotion of Engineering Education at the Congress on Public Information held at the Congress Hotel, Chicago, in February, 1921, and acted as Chairman during one session of the Congress.

He was one of the Deans of Colleges of Engineering, men with long experience in engineering education, men proud of the progress already made and imbued with the desire to make still further progress in improving engineering education, who met by appointment for a conference in Chicago in May, 1922. These deans, in conference assembled, passed the now famous resolution:

"Resolved, that in order to meet the constantly enlarging responsibilities of the engineering profession we favor an advance in engineering education at this time that shall provide for five years of collegiate training for those engineering students whose

aim is to be qualified to take positions among the creative leaders in the profession."

During the time that engineering education was being studied by C. R. Mann, under a grant from the Carnegie Foundation, and later by Mr. Wickenden, Director of the Board of Investigation and Coordination, Mr. Hayford took a keen interest in these studies, and many times called his faculty together informally to discuss the various phases of engineering education brought to light by these studies and investigations.

In regard to Director Hayford's work in the Society for the Promotion of Engineering Education, Dean F. L. Bishop, Secretary of the Society, wrote to the writer under date of January 30, 1929:

"He was always ready with advice, and could be depended upon to do whatever job was handed him. His clear mind and direct way of thinking was of great value to all members of the Society who had the pleasure of knowing or hearing him. His organization of the Baltimore meeting in 1919 was one of the outstanding features of the work of the Society immediately following the war. He was of great assistance during the war in keeping the work and activities of the Society on a going basis."

HAY-FEVER

In general Professor Hayford enjoyed abounding good health, but he had one affliction which bothered him very much at times, so much so indeed that it was a most pitiful sight to see him trying bravely to bear up under it. This was hay-fever. In regard to this he wrote under date of December 19, 1919:

"Ordinarily I have had a form of asthma each year as a climax to the hay-fever. Ordinarily this asthma is so severe for two weeks or more as to make it difficult or impossible to sleep continuously except in a sitting position rather than lying down. I have had hay-fever every summer since 1895, in some summers in a very severe form, have never run away from it, have been in various parts of the United States during the hay-fever season and have studied the disease carefully."

To the writer's knowledge he did bear up bravely under it, and was usually found at his desk or at whatever work he was engaged in, keeping regular hours, and striving by frequent use of menthol or other aromatic unguents to minimize the discomforts attendant upon this irritating affliction.

PERSONALITY

During the early years of the writer's acquaintance with Mr. Hayford, the most impressive characteristic was his apparent happiness. His jovial, hearty laughs would ring out merrily along the halls of the old Coast and Geodetic Survey building. He had a generous fund of humor and this was one of the ways he expressed it. His aptitude for seeing the humorous, and the shrewd turning of a phrase, or the "cracking of a joke" was noticeable to all.

This characteristic remained for some time after he became Director of the College of Engineering, but gradually a change became apparent. It may be the advancing years were causing him to be more sedate, but it is more likely that the load he was carrying as Director, administrator, teacher, research investigator, student advisor, his many addresses—all added their part to make him more sedate and less inclined to laugh.

In later years his brain must have been called upon for an abnormal amount of work and from the records that he has left in his voluminous correspondence one is lost in wonder that he could have so successfully kept the many strands of thought from becoming hopelessly entangled.

In gathering the material for this memoir nothing has impressed the writer more than the enormous amount of work which he accomplished and of which little was known, even to those who were closely in touch with him. The fields in which he labored were so diversified that his friends and associates and colleagues, each knew only a small part of the activities in which he was engaged. In looking over his correspondence one could easily gain the idea that his list of correspondents included nearly every man in *Who's Who* in engineering and the related

sciences and engineering education. It was a tremendous task for one man to accomplish.

He seemed to have an unfailing fund of energy upon which he constantly drew, and an industry which never seemed to need periods of idleness to refresh him. An inextinguishable fire of energy and enthusiasm was his, and even to the last his mind was on some scientific problem. But he had that most happy faculty of being able to lay aside his work when quitting time came and taking his relaxation in the form of a walk along the lake shore, or in a good game of volley ball or a game of "cow-boy" at the club, and in play he always put the same abounding energy and enthusiasm as in his scientific work. In nothing he undertook did he do half-hearted work, but drove himself forward along his adopted course with a vim and vigor which astounded all who knew him.

His activities penetrated into practically every field of the physical sciences and he was keen to travel along new paths of exploration. The list of learned and civic societies to which he belonged is a long one and in these he gave to the fullest of his time and energy. The list could have been lengthened several times had he responded favorably to the many invitations offered him, but it was a firm conviction of his that he did not care to join an organization for the sake of the mere honor, and unless he saw that he could prove worthy of the membership by giving to it a worthwhile service, he politely but firmly declined to have his name considered for membership.

CHURCH

The writer does not know the strength of Hayford's religious convictions. He was a member of the Unitarian Church at Washington, and later affiliated with All Souls Unitarian Church when he moved to Evanston. Evidently, as in everything else into which he entered, he took a very active part in the work of the church, for the church in Evanston has honored his memory by dedicating one of the rooms of the church as "Hayford Hall." He was also head of the Layman's League of the Church.

Though devoted to his work, he did not live aloof from his fellow citizens, but always took a keen interest in matters affecting the welfare of the city. This extended to political questions, as well as civic improvements and civic organizations.

PERSONAL APPEARANCE

In personal appearance he was of medium height, but strong and compactly built, and in later life rather heavy in build and slow in motion. His pictures taken at Anchorage Bay, Alaska, in 1894, show him with a full beard. He wore a full beard up to about the summer of 1905, after which he remained smooth-shaven.

EDUCATION

When asked to tell of his education he responded in 1923 with the following:

"To the present time my education has been that represented by the degree of C.E. from Cornell University, and Sc.D. from George Washington University, supplemented by seventeen years of education received from students, three years while acting as instructor at Cornell University (1895-1898), and fourteen years (1909-1923) while acting as Director of the College of Engineering at Northwestern University; and extended by seventeen years in the service of the United States. The majors, so to speak, in that education have been an investigation of isostasy for thirteen years, and an investigation of evaporation and stream-flow for nearly twelve years, and which is still in progress. There is still hope that my education is advancing to a perceptible degree."

DOCTOR OF SCIENCE

On June 5, 1918, Director Hayford was granted the honorary degree of Doctor of Science by George Washington University at Washington, D. C. The statements made when the degree was conferred indicate that it was intended as a recognition of the scientific work that he had done in connection with the United

States Coast and Geodetic Survey and in other parts of the government service.

In an alertness test, conducted at the Rotary Club of Evanston, March 20, 1924, by L. B. Hopkins, Director of Personnel at Northwestern University, Hayford obtained a score of 71. Of the 75 men tested by Professor Hopkins at the Club the average was 46.

VICTORIA MEDAL

It is somewhat difficult to pick out the most significant honor which came to Professor Hayford. Standing among the highest, however, should be listed the award to him of the Victoria Medal of the Royal Geographical Society of Great Britain. Notification of this award was sent to Hayford under date of March 5th, 1924, just one year before his death.

The Secretary of the Society, Arthur R. Hinks, in conveying the notification wrote: "I am happy to inform you that the Council have awarded you the Victoria Medal of this Society for your establishment of the theory of Isostasy. The medal will be presented at the Anniversary General Meeting on May 26. It is, I suppose, too much to hope that you will be in England at that time, but I shall be glad to hear from you whether you would wish to nominate any personal friend to receive the medal for you or whether we shall ask one of the Embassy.

"May I take the opportunity of expressing to you the great pleasure which it gives me personally of being the medium of conveying to you this decision of the Council."

As Mr. Hayford was not able to be present on May 26th to receive this medal, it was awarded in his absence. As stated in the Geographic Journal (V. 64, p. 83) "The Victoria Medal was presented to Mr. Boylston Beal—in the unavoidable absence of Mr. Hayford himself and of His Excellency the American Ambassador." Announcement of the King's approval of the award was made in the April issue of the Geographic Journal (V. 63, No. 4, April 1924, p. 361). In so far as the writer has been able to find out this signal honor has been granted to

but two other Americans in recent years—Commodore Peary * in 1910, and Alexander Hamilton Rice * in 1914.

MOUNT HAYFORD

About two years before the death of Dr. Hayford, Colonel E. Lester Jones, as American Commissioner on the International Boundary, submitted to the United States Geographic Board through the State Department the proposal that the name "Mount Hayford" be given to one of the peaks in southeastern Alaska, with the hope that the Board would waive the rule against naming geographic features for living persons in this instance because of the eminence of Dr. Hayford in the scientific world.

At this time the Board did not concur in the recommendation, but on May 6, 1925, shortly after Dr. Hayford's death, the recommendation of Colonel Jones was formally and unanimously approved, and the name "Mount Hayford" was inscribed on the map of the world for all time.

In a letter to Mrs. Hayford apprising her of this action of the Board, Mr. James W. McGuire, Member of the U. S. Geographic Board, states, "The peak itself rises in grandeur, one and one-quarter miles toward the heavens, its snowy summit only six miles from the seashore; a monument raised by the hand of the Creator."

Mount Hayford is six thousand four hundred and forty feet high, and is located about six miles west of Portland Canal, southeastern Alaska, near latitude 55°44′.

STUDY MEN

Of his non-technical writings few attained the recognition accorded to "Study Men," originally given as an address deliv-

* In 1898 Commander Peary was awarded the Patron's Medal of the Society and in 1910 was awarded a Special Gold Medal. Dr. Rice was awarded the Patron's Medal in 1914. The Gold Medals of the Royal Geographical Society, the Founder's Medal, and the Patron's Medal, are not identical with the Victoria Medal received by Mr. Hayford. (Geographic Journal, V. 64, 1924, pp. 81-83.)

ered on Commencement Day, June 14, 1907, at the Thomas Clarkson Memorial School of Technology, Potsdam, New York, and published in the Clarkson Bulletin, July, 1907, and later incorporated in *Addresses to Engineering Students* by Waddell and Harrington.

Some of the thoughts contained therein are worthy of note here.

"One of the prominent characteristics of the average engineer is that he is so wrapped up in his work as to see only its immediate results and to fail to see its much great indirect effect. He fails to realize fully that he is working through men and for men, that the most important effect of his work is its influence upon the onward and upward progress of man."

He urges the engineering student to study men "because much of your learning is done through other men, because you will do your work through men, and because men are so difficult to understand. Men are the most important objects of interest that will come within your sphere of knowledge. I urge you to study men because I am safe in saying that there are some of you who will fail to be useful in the world simply because you will fail to understand men until it is too late. The effectiveness with which you will use your engineering knowledge depends very, very intimately upon your knowledge of men. You are urged to pay attention to all phases of men around you, to see and appreciate them as literary and artistic men as well as technical men, as men of feeling as well as men of thought, as incarnated motives as well as thinking and working machines."

The thoughts embodied in this address seemed to be one of the guiding forces in his life. He was not a recluse, a solitary man, a man hiding himself in a cloister. He delighted in the exchange of thought whether with the highest scientist of the land or the humblest workman on the surveying parties. At meetings of scientific societies he considered the time well spent if he could get in close touch with some new personality, even though the business of the meeting seemed to have little of profit in it for him. And these "touches" were no passing, idle contacts for him. They generally contained some pertinent fact

which his wonderful memory would bring to light and make use of in the future.

"Study Men" was probably at the foundation of his organization of one of the courses taught by him at Northwestern University. This was the course in "Public Relations of Engineers," which is discussed in another part of these memoirs.

LAST DAYS

As mentioned before, the last public appearance of Professor Hayford was at the Annual Banquet of the Engineering Society of the School of Engineering held at Evanston on the evening of December 19, 1924, at which he gave a most interesting talk of the court reception given by the King to the delegates to the Fifteenth general conference of the International Geodetic Association held at Budapest in 1906. So far as the audience could tell, he was apparently in good health, for he stood up all of the time during his talk and gave no evidence of any illness. The next morning, however, he came to the writer's office at the Engineering Building and said that he had been ordered to the hospital for several days' examination. This he did after clearing up some important matters on his desk.

When he made the above announcement it was told in such a way that the stay at the hospital was probably to be only a few days. The examination at the hospital, however, showed that the case was very serious and soon after he was ordered to his home and to have complete rest for some time. Only the family and a small number of close friends were allowed to see him. His condition gradually became worse, and in the early hours of March 10, 1925, Director Hayford passed to the Great Beyond, his death occurring as he slept at his home, 1124 Judson Avenue, Evanston, Illinois. The affliction causing his death was principally dropsical in character, and he suffered quite a bit during those last weeks of his life. In accordance with his will the body was cremated and his ashes spread on Beautiful Lake Michigan, beside the shore of which he had spent so many years and regarding which he had studied so much.

Before going to the hospital he had been under the doctor's care, but to the outside world he gave little indication of this. Evidently his condition had gradually crept upon him, for he continued his daily walks to and from home. But it had been noticeable that he moved less sprightly and vigorously than previously, and seemed to want a more quiet existence.

On the occasion of his death, the tributes received by the family were many, and came from all parts of the country, and some from foreign countries. The writer believes that some of these are so important in showing an estimate of Professor Hayford's life and character that excerpts are here given. Also there have been added a few, some written to Professor Hayford during his lifetime and some written to the writer only recently. Some of these tributes are scattered throughout the memoir, the remainder being given in a group.

TRIBUTES

"I was very proud of his ability as a scientist, a scholar and administrator, but I loved him for himself, so simple and wholesome in his tastes, so kindly and just in his relations with other men and with his students. He was wholesome in everything he did. He had the fun of the boy, and yet the wisdom of a sage.

"I never knew him in all my relations to ask for favors for his school or his own work in the school. Having known the conditions when he took up his work, he accepted them.

"He was a great teacher, because of his scholarship, his clearness."

(Ex-President A. W. Harris, Northwestern University, March, 1925.)

"On behalf of the body generally of Northwestern University the deep and sincere sympathy which they feel at the loss of Dean Hayford. Both because of his very lasting services to the University and his contributions to the sum of the world's knowledge he had endeared himself to the University at large. Because of a peculiarly lovable personality, he was dear to those students who came into contact with him."

(By order of the Student Council of Northwestern University, March 10, 1925.)

"Other graduates of the Engineering School with whom I have talked feel as I do, that all of us have lost a true friend and that the University has lost one of the greatest men that has ever been on its faculty."

(C. D. Hale, March 11, 1925.)

"There is this however that endures, the memory of the inspiring contact that we have had with Professor Hayford and the inspiration of his high standard for the profession."

(Edgar S. Nethercut, Secretary, Western Society of Engineers, April 23, 1925.)

"I am sure that the loss of such an outstanding figure in the field of geodesy is a most serious one and will be very keenly felt."

(Noel Ogilvie, Director, Geodetic Survey of Canada, March 23, 1925.)

"We express our sympathies with the loss which the American Geophysical Union has suffered in the death of this eminent scientist."

(President and Secretary, Norwegian Geodetic Commission, April 27, 1925.)

"He was an active and enthusiastic worker, with great faith and persistence in any idea he took up. His influence was strong in systematizing, and placing on an economically sound basis, the government geodetic work, and in developing important results from it."

(G. R. Putnam, Director, U. S. Light House Service, February 4, 1929.)

"Among us, his friends, there will be cherished in our memories those qualities that won for him a place of unstinted affection. The sparkling eyes, the smiling countenance, that contagious laugh, the kind sympathetic disposition, these all made him so human. Clean-minded, self-controlled in imputing evil to others, he was one of whom it can truly be said that he was master of the greatest of all sciences, how to live among his fellow men."

(Rotary Club of Evanston, March, 1925.)

"I have learned to admire his wonderful attainments and ability, and to look forward to the accomplishment of the splendid

work in science that he has been conducting for so many years. It is impossible to estimate the loss that will result from the sudden termination of his activities."

(C. F. Marvin, Chief of Weather Bureau, U. S. Dept. of Agriculture, March 10, 1925.)

"His going is a great loss to the engineering and scientific work of America, in both of which he did such outstanding work and signal service. He did all things well and the world is better for the useful part he took in it."

(R. L. Faris, Acting Director, U. S. Coast & Geodetic Survey, March 11, 1925.)

"Hayford was a man for whom I had not only a high regard but an affection. I never knew him until he came to the Coast Survey. When I went there in '97 and began to study the institution and its organization . . . one of the first requests I made was for some one who would come as an understudy to Mr. Schott, with the understanding that he would, in a short time, become chief of the division. I was led to think of Hayford because of the admirable work he had done in the Survey and because of some of his papers. At that time he was at Cornell. I got him to come down to Washington and talk the whole matter over with me, and was delighted at the enthusiasm and interest with which he took up his task. The work he did in the Survey not only reflected his admirable ability as a mathematician, but he took up many cognate problems because he was interested in the application of mathematics as well as with mathematical theory.

"During my time in the Survey, Hayford was rapidly improving his mathematical skill and his knowledge of the application of mathematics to geodesy. When Mr. Schott finished the work on the 39th Parallel he gave way very willingly as Head of the Division to Hayford, and from that time on Hayford was the scientific authority of the Survey in all geodetic operations. . . . In my efforts, during the three years I was Superintendent of the Survey, to reorganize in large measure the scientific work I found Hayford a most practical and willing adviser. He had unusual mathematical ability coupled with the quality of clear judgment—a rare combination. I saw nothing of him after he left the Survey but I will always remember him as one of the most able and devoted men with whom I have ever been associated."

(Henry S. Pritchett, President, Carnegie Foundation, June 2, 1930.)

"Five years has not been long enough to reconcile me to his loss."

(A graduate of the School of Engineering writing in 1930.)

"In my administration at Northwestern . . . I think my selection of men was perhaps the most satisfactory part of my service. In no case do I feel more confident than in your own. All this I might be able to say even though the satisfaction were only in a professional and official way, but in your case it is very much more. You have helped to make me satisfied during all the years we worked together and since, as well. I have known many good men and successful men. I put you with a very small group who seem to me to deserve the highest congratulation."

(Ex-President A. W. Harris, Northwestern University, November 21, 1923.)

"Not often is opportunity granted to the engineer to take direct part in unlocking the larger mysteries of nature. Hayford was fortunate enough to find such an opportunity in his work and he was prepared to meet it. Already the truths he developed have had a guiding influence on the work of the geologists in their attempts to decipher the ancient record of the earth's long-past changes, and there is little doubt that the future understanding of the growth and development of our planet will be related very closely to the facts which Hayford brought to light."

(Editorial. *Engineering News-Record,* March 19, 1925.)

The writer had more than a quarter of a century of close association with Professor Hayford, an association which began in the United States Coast and Geodetic Survey in 1899. In these years he found the following characteristics to be uppermost in the life of Director Hayford: intense energy of body and mind, strict honesty of thought and purpose, and a hatred of all show and pretense. He had the great faculty of making and holding friends, and he took especial delight in these friendships. He seldom entered into anything without giving to the fullest of his energies; he got the fullest enjoyment out of life; was a keen lover of all sorts of healthy outdoor sports and indoor games; enjoyed a brisk walk along the lake shore, or an exciting game of "Cowboy" at the Club in company with congenial associates; took an immense amount of pleasure in sitting with the family or

friends reading tales and poems of the old colonies of northern New York and Canada; and withal he had the happy faculty of being able to drop official duties when necessary.

On the scientific side, the ideal set before us by Hayford—his energy, adaptiveness, perseverence, both intellectual and physical, and mathematical precision, are to be held as his most precious characteristics.

He is sadly missed by those who enjoyed his friendship. To the world of science his loss is keenly felt. Those who knew him best esteemed him most, and he has left with them those precious memories of a worth-while life.

On the occasion of the death of Director John F. Hayford, a resolution by the Faculty of the College of Engineering of Northwestern University was adopted March 17, 1925.

WHEREAS

Director John F. Hayford has been the main guiding spirit of this College from its beginning in 1909 to his untimely death one week ago:

Through many years of intimate association the members of this Faculty have come to know him as a man of the following characteristics:

1. He was a believer in the ultimate triumph of truth. He was not a retailer of ready-made opinions and he did not seek to influence others by personal persuasion or by clever statement. On important problems, whether of physical phenomena or of social relations, he sought to find the fundamental facts; to disentangle these facts from matters of emotion and prejudice; and to give these facts clear and forceful statement. He sought to be a leader of men by giving them better views of truth.

2. In mental work he had habits of unusual accuracy, and in industry he was almost indefatigable. In reading he formed the habit of never leaving an article with a hazy notion of its contents; he formulated a statement of its meaning when reduced to simplest terms, and he retained this meaning as a permanent addition to his stock of reliable information. The most of his researches have made successful use of data whose volume and heterogeneity have appeared to other men too forbidding for systematic treatment. His studies of the data of engineering education have been of a thorough and painstaking character.

3. He was thoroughly democratic. In matters of educational policy he had opinions which he believed right because he had

reached them after careful consideration of the facts. But if any question was decided in opposition to his views, he accepted the decision wholeheartedly and carried it into effect with perfect loyalty.

4. He was honest, just, and generous. In college legislation he insisted that every rule should be an accurate statement of policy, and in administration, he undertook to carry out every regulation to the letter of its statement. In the absence of established fact, his opinions were always tempered with extreme generosity; he was not only generous but even prodigal in giving his time and labor to his students and to his friends; in the apportionment of funds to his faculty members he was generous, even self-sacrificing.

5. In manner of life he was modest and unassuming. In general attitude he was genuinely sociable, genial, frank, cheerful, optimistic, loyal, and in important matters aggressive; he had a keen sense of humor; he was slow in the expression of criticism, but prompt in the expression of deserved commendation.

Because of the above characteristics of Director John F. Hayford, the members of this Faculty have great confidence in the general policies which he has advocated for this College.

RESOLVED THAT

This University, this College, and its individual members have suffered a great loss in the death of our friend and director, John F. Hayford, the magnitude of which loss we have hardly begun to appreciate.

The members of this Faculty hope that means will be found not only to continue unabated our efforts in improving engineering education as heretofore directed by John F. Hayford, but so to reinforce our work as to bring to fruition his complete ideal of an engineering college.

It is fitting that these statements of fact in appreciation of our first Director be made a matter of record in our minutes, be transmitted to the family of the deceased, and be transmitted to proper officials of the University for such dissemination and publicity as may be appropriate.

(Signed) WILLIAM H. BURGER, *Secretary.*

In the fall of 1925 funds were collected by the students and faculty of the College of Engineering, and a bronze tablet to commemorate Director Hayford's memory was placed on the

west wall of the lecture room of Swift Hall of Engineering. The tablet reads:

IN MEMORY OF

JOHN FILLMORE HAYFORD

1868-1925

DIRECTOR OF THE COLLEGE OF ENGINEERING OF NORTHWESTERN UNIVERSITY 1909-1925

ESTABLISHER OF THE THEORY OF ISOSTASY

AUTHOR OF THE INTERNATIONALLY ACCEPTED HAYFORD SPHEROID OF REFERENCE

DEDUCER OF THE CONDITIONS WHICH GOVERN THE LEVELS OF THE GREAT LAKES

AN INSPIRING TEACHER—SKILLFUL IN THE USE OF THE SOCRATIC METHOD; DISCIPLE OF ACCURACY AND DEFINITENESS OF KNOWLEDGE; IMPARTIAL INTERPRETER OF FACTS; FIRM BELIEVER IN THE COLLEGE STUDENT; A GENIAL AND MODEST MAN; A GOOD CITIZEN

THIS TABLET IS ERECTED BY HIS STUDENTS

CHILDREN

Besides his wife, he was survived by his four children:

Walter Stone Hayford, born at Ithaca, New York, January 14, 1896. Graduate C.E. degree, College of Engineering, Northwestern University, 1921. Now (1930) in the Research Department of the Bell Telephone Laboratories, New York.

Maxwell Fillmore Hayford, born at Washington, D. C., May 27, 1898. Graduate C.E. degree, College of Engineering, Northwestern University, 1923. Now (1930) Ticket Manager, Athletic Department of Northwestern University, Evanston, Illinois.

John Bryant Hayford, born at Washington, D. C., October 20, 1900. Graduate E.E. degree, College of Engineering, Northwestern University, 1924. Now (1930) Business Manager, Museum of Science and Industry, Chicago.

Phyllis Hayford, born at Washington, D. C., May 18, 1904. Graduate B.S. in Engineering degree, College of Engineering, Northwestern University, 1926. Now (1930) Computer at Lick Observatory, temporarily released and completing work for Ph.D. degree at University of California, at Berkeley, where she has a Teaching Fellowship in the Department of Astronomy.

Mrs. John F. Hayford went to live with her daughter, Phyllis, at Berkeley, California, and died in that city August, 1932.

SCIENTIFIC AND OTHER ORGANIZATIONS

Professor Hayford was a firm believer in the development of a man through contact with men and men's activities. To this end he became a member of numerous organizations and in each of these he gave to the fullest of his powers by presenting papers or in service. His correspondence contains numerous refusals to accept membership in organizations in which he did not see his way to contribute to the welfare of the organization. This stand on his part is clearly indicated in the following quotation taken from a letter (1920) in which he declined accepting membership in a society to which he had received an invitation. "I do not care to belong to any organization in which I cannot do my part. I am already in, and committed to help in so many organizations, that I must restrict my energies to them."

There is given here a list of scientific, educational, and civic organizations with which he was identified. No doubt there are others which have not been listed. The list shows that he was, in truth, "committed to help" in many organizations, and how well he helped is shown by the statement of his activities in so far as could be learned. It is not known whether he continued holding membership in them all up to the time of his death; no correspondence was found among his papers indicating any withdrawals of membership. Perhaps some of them were allowed to lapse.

1. *New York Mathematical Society.*
   Elected to membership, 1891.

2. *Mask and Wig Club of Washington.*
   Member, 1895.

3. *American Society of Civil Engineers.*
   Elected Associate Member, May 6, 1896; member, April 2, 1907.
   Appointed with A. N. Talbot to represent the Society in the Council of the American Association for the Advancement of Science, August 17, 1920.

4. *American Association for the Advancement of Science.*
   Elected member, 1897; fellow, 1898.
   Represented U. S. Coast and Geodetic Survey at Boston meeting, August, 1898.
   Represented U. S. Coast and Geodetic Survey at New York meeting, July, 1900.
   Represented U. S. Coast and Geodetic Survey at Boston meeting, December, 1909.
   On Council, 1910.
   Vice-President, 1910.
   Served as Secretary Section A, Secretary of Council and General Secretary.
   Papers presented:
   "It is not necessary to place geodetic arcs in various latitudes." December 29, 1908.
   "The ellipticity of the earth is not a proof of its former liquid state." December 30, 1908.
   "Relation of isostasy to geodesy, geology, and geophysics." Vice-President's address, Minneapolis, December 29, 1910.

5. *Cosmos Club of Washington.*
   Elected member, December 10, 1898. Non-resident member after 1910.
   Served at times on various committees.
   Made the Cosmos Club his home during his frequent trips to Washington.
   Address—"Future of the Airplane." January 5, 1920.

6. *Philosophical Society of Washington.*
   Elected member, February 11, 1899.

One of the signers of the Articles of Incorporation, May 15, 1901.
Elected Secretary, December 21, 1901.
President, 1907.
Papers presented:
"A new treatment of refraction in height computation." April 29, 1899.
"Recent progress in geodesy." February 3, 1900.
"Determination of the difference of elevation of two given points on the earth's surface." March 31, 1900.
"Corner's apparatus for determining zenith distance of stars that culminate near the zenith." January 5, 1901.
"The new Coast and Geodetic Survey precise level." January 5, 1901.
"Recent progress in geodesy." February 16, 1901.
"What is the center of an area, or the center of a population?" November 23, 1901.
Discussion of "Longitude by wireless telegraphy." January 4, 1902.
"Gravity at North Tamarack Mine, Michigan." October 11, 1902.
"Novel principles applied in rapid primary triangulation." May 6, 1903.
"Telegraphic determinations of longitude of Honolulu." October 10, 1903.
"A test of the transit micrometer." May 21, 1904.
"Computation of the deflections of the vertical from topography." December 10, 1904.
"Geodetic evidence of isostasy." 1906.
"The earth as a failing structure." December 7, 1907.
"The part taken by the Philosophical Society in the development of geodesy."
"The earth from a geophysical standpoint." 1910.
"Relation of isostasy to geophysics." 1911.

7. *American Astronomical and Astrophysical Society.*
Elected member, 1902.

8. *Society for the Promotion of Engineering Education.*
Elected member, 1905.
On Council, 1909, 1916, 1921.
Vice-President, 1917-1918.

President, 1918-1919.
Member Program Committee, 1918-1919.
Member Publication Committee, 1918-1919; 1919-1920.
Member Executive Committee, 1918-1919.
Represented S. P. E. E. at Congress of Public Information, Chicago, February 25, 1921. Chairman, one session.
Papers presented:
"Opportunities for engineering graduates in government service." June 28, 1905.
"Why not teach about men?" 1906.
"Reflections of a Director." Ames, Iowa, June 22, 1915.
"Welcome to British delegates at Cambridge, Mass." December, 1918.
"Reflections of an S. P. E. E. President." Baltimore, 1919.

9. *Washington Academy of Science.*
Elected member.
Vice-President, 1906.
Paper presented—"Geodetic evidence of isostasy." April 14, 1906.

10. *Western Society of Engineers.*
Elected member, December, 1909.
Committee on increase of membership, 1911.
Elected 3rd Vice-President, January 8, 1913.
Chairman, Aviation Committee, 1920.
Member, Student Branch Committee, 1920.
Chairman, Joint meeting with Chicago Section A. I. E. E., November 21, 1921.
Representative of W. S. E. on Airboard of Chicago, April 19, 1922.
Member, Aviation Committee, June 17, 1922.
Member, Committee on St. Lawrence Waterway, November 24, 1923.
Awarded Chanute Medal of Society (posthumous, 1925).
Papers presented:
"Measuring the earth." November, 1913.
"The Great Slides at Panama." March 20, 1916.
"What American science is doing for aviation." February 5, 1918.
"The establishment of isostasy." 1924.

11. *Engineering Society, Northwestern University.*
Member, 1909.
Faculty adviser on several occasions, 1909-1925.
Papers presented:
"Is it advisable to make large expenditures for the improvement of our waterways?" March 10, 1910.
"Measuring the earth." April 22, 1913.
"The urgent need for more engineers." October, 1917.
"Keeping engineering education going at Northwestern University." October 31, 1918.

12. *Washington Society of Engineers.*
Elected member.
Served as Treasurer.
Member, Committee on meetings, 1906.
Papers presented:
"Present methods of precise leveling." January 23, 1906.
"Stream flow." October 15, 1924.

13. *Society of Sigma Xi of Cornell University.*
Elected member.

Society of Sigma Xi of Northwestern University.
Elected member, 1909.
President, 1914-15.
Paper presented:
"What American science is doing for aviation." February 4, 1918.

14. *Chaos Club of Chicago.*
Elected member, November, 1910.
Papers presented:
"Measuring the earth." March 18, 1911.
"The Great Slides at Panama" March 25, 1916.

15. *National Academy of Sciences.*
Elected member, April, 1911.
Appointed member, Panama Slides Committee, 1915.
Papers presented:
"The importance of gravity observations at sea on the Pacific." April 17, 1916.
"Effects of winds and of barometric pressures on the Great Lakes." 1922.

16. *University Union.* (Northwestern University.)
Elected member, 1909.
President, 1914-1915.

17. *University Club of Evanston.*
Elected member, 1909.
Member, Entertainment Committee, June 16, 1910.
On Board of Direction, 1923-1925.
Paper presented:
"What should be done to develop the civil use of airplanes?" November 19, 1919.
"The Great Slides at Panama." March 25, 1916.

18. *Illinois State Academy of Science.*
Elected member, 1909.
On Council, 1910.
Paper presented:
"Relation of pure and applied science to progress of knowledge." February 18, 1910.

19. *Math Club of Northwestern University.*
Elected member.
Paper presented:
"Measuring the earth." January 11, 1922.

20. *American Philosophical Society.*
Elected member, April 24, 1915.
Paper presented:
"The earth from a geophysical standpoint." 1915.

21. *American Physical Society.*
Elected member.

22. *Astronomical Society of America.*
Elected member.

23. *Chicago Astronomical Society.*
Elected to life membership without fees, July 7, 1921.

24. *Rotary Club of Evanston.*
Elected member.
Paper presented:
"Best uses of the waters of the Great Lakes." April 17, 1924.

25. *American Geophysical Union.*
Elected member.
Vice Chairman, Section Geodesy, for two years. 1920.
Member, Executive Committee, Section Geodesy, 1921.
Chairman, section of Geodesy, 1924.
On Executive Committee, 1924-25.
Paper presented:
"Isostasy." April 19, 1921.

26. *Chicago Association of Commerce.*
Appointed member, Rivers & Harbors Committee, January 29, 1924.

27. *Illinois Society of Engineers.*
Appointed judge to pass upon written paper competition, November 23, 1921.

28. *Chicago Academy of Science.*
Paper presented:
"What American science is doing for aviation." January 25, 1918.

29. *National Research Council.*
Member of Geography Committee, 1917.

30. *U. S. Board of Surveys and Maps.*
Member, Committee on Control.

31. *Evanston Academy of Cum Laude Scholarship Society.*
Elected member, June 13, 1916.

MISCELLANEOUS ADDRESSES AND PAPERS:

Detroit High School, commencement oration.
"College Influence." 1885.
Clarkson School of Technology. Founders' Day Address.
"Study Men." 1907.
Dedication Address. Swift Hall of Engineering, Northwestern University.
"The New College of Engineering, An Opportunity." 1909.
Engineering Society, University of Iowa.
"Precise leveling." April 25, 1910.
Engineering Society, State University of Iowa.
"Precise leveling." April 28, 1910.
Engineering Society, University of Wisconsin.
"Measuring the earth." March 10, 1911.

Miscellaneous Addresses and Papers—*Continued*

Men's Club, La Grange, Illinois.
"Panama-Costa Rica Boundary." 1912.
Sigma Xi of Chicago University.
"Measuring the earth." May 22, 1913.
Geographic Society of Chicago.
"Measuring the earth." May 23, 1913.
Michigan School of Mines, class day address.
"The great landslides at Panama." April 14, 1916.
Structural Engineers, Chicago.
"The Great Slides at Panama." October 26, 1916.
Central Association of Science Teachers.
"The Great Slides at Panama." December 1, 1916, Chicago.
Radio Broadcast, WMAQ Chicago.
"Engineering, an occupation which arouses enthusiasm." November 14, 1923.

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1885

College Influence. Commencement Oration. 29th Graduation Exercises, Class of 1885. Detroit High School, Michigan.

1890

Mean Range and Improvement on the Tidal Machine. Coast and Geodetic Survey Report for 1890, pp. 100-138.

1890

On the Least Square Adjustment of Weighings. Coast and Geodetic Survey Report, 1890, Appendix 14.

1890

On the Use of Observations of Currents for Prediction Purposes. Coast and Geodetic Survey Report, 1890, Appendix 14, pp. 691-703.

1890

Comparison of the Predicted with the Observed Times and Heights of High and Low Waters at Sandy Hook, N. J., during the Year 1889. Coast and Geodetic Survey Report, 1890, Appendix 15, pp. 705-14.

1892

On the Least Square Adjustment of Weighings. Coast and Geodetic Survey Report, 1892, Part 2, Appendix 10, pp. 515-27.

1894

An account of Certain Field Methods Used on the Survey of the Mexican Boundary, 1892-1893. Transactions, Association of Civil Engineers of Cornell University, Vol. II, pp. 58-83.

For this paper Professor Hayford received the award of Fuertes Medal, College of Engineering, Cornell University.

1895

The Rueprecht Balance Belonging to the United States Office of Standard Weights and Measures. Coast and Geodetic Survey Report, 1895, Part 2, Appendix 9, pp. 383-92.

1896

The Problem of the Tides, and the Limitations of the Present Solution of that Problem. Transactions, Association of Civil Engineers of Cornell University, 1896, Vol. IV, pp. 31-50.

1898

Limitations of the Present Solution of the Tidal Problem. *Science,* N. S., Vol. VIII, No. 206, Dec. 9, 1898, pp. 810-14.

1898

Geodetic Astronomy. John Wiley & Sons. 351 pp. (a text book) with numerous plates.

1898

Determination of Time, Longitude, Latitude, and Azimuth. Coast and Geodetic Survey Report, 1897-1898, Appendix 7, pp. 261-409. 4th Edition.

1898

Report of the Boundary Commission upon the Survey and Re-Survey of the Boundary between the United States and Mexico West of the Rio Grande, 1891-1896 (pp. 62-128 contain report of the Astronomic Work by John F. Hayford). Government Printing Office.

1898

The Geographic Work of the Coast and Geodetic Survey. *Engineering News,* Vol. XL, No. 22, Dec. 1, 1898, pp. 340-42.

1899

Is There a 428-Day Period in Terrestrial Magnetism? *Terrestrial Magnetism,* University of Cincinnati, March, 1899, pp 7-14.

1899

Precise Leveling in the United States. Coast and Geodetic Survey Report, 1898-1899. Appendix 8, pp. 347-886.

1899

A New Treatment of Refraction in Height Computation. Paper presented before Philosophical Society of Washington, April 29, 1899. Abstract *Science,* May 12, 1899, N. S., Vol. IX, No. 228, p. 686.

1900

The Transcontinental Triangulation Along the Thirty-ninth Parallel. Bulletin, University of Wisconsin, No. 38, Engineering Series, Vol. 2, No. 5, pp. 173-96, plates 1-5.

1900

Recent Progress in Geodesy. Paper presented before Philosophical Society of Washington, February 3, 1900. Published in Bulletin, Vol. XIV, pp. 1-20. Also in *Science,* N. S., Vol. XI, March 9, 1900, pp. 369-92.

1900

The Determination of the Difference of Elevation of Two Given Points on the Earth's Surface. Presented before the Philosophical Society of Washington, March 31, 1900.

1901

A New Connection Between the Gravity Measures of Europe and of the United States. *Science,* N. S., Vol. XIII, No. 330, April 26, 1901, pp. 654-59.

1901

Test of the Massachusetts Institute of Technology Base Apparatus. *Technology Quarterly* Vol. 14, June, 1901. (Co-author with Alfred E. Berton.)

Reprint, *Engineering Record,* Vol. 45, No. 4, January 25, 1902.

1901

Preface to Appendix on the Measurement of Nine Base Lines Along the 98th Meridian. Coast and Geodetic Survey Report, 1901, Appendix 3.

1901

Triangulation Northward Along the 98th Meridian in Kansas and Nebraska. Coast and Geodetic Survey Report, 1901, Appendix 6, pp. 357-423.

1901

Extension of Tables for the Computation of Geodetic Positions to the Equator. Coast and Geodetic Survey Report, 1901, Appendix 4.

1901

Discussion on Precise Spirit Leveling. *Transactions, American Society of Civil Engineers,* Vol. XLV, pp. 135-175.

1901

Description of Corner's Simple and Ingenious Apparatus for Determining the Zenith Distance of Stars that Culminate Near the Zenith. Presented before the Philosophical Society of Washington, January 5, 1901.

1901

The New Precise Leveling Instrument of the Coast and Geodetic Survey. Coast and Geodetic Survey Report, 1903, Appendix 3. Paper presented before Philosophical Society of Washington, January 5, 1901.

1901

What Is the Center of an Area, or the Center of a Population? Paper presented before the Philosophical Society of Washington, November 23, 1901.

1901

Recent Progress in Geodesy. Read before Philosophical Society of Washington, February 16, 1901. Philosophical Society of Washington, Bulletin XIV, pp. 139-43.

1902

Discussion of Paper by D. B. Wainwright on "Longitude by Wireless Telegraphy." Philosophical Society of Washington, January 4, 1902.

1902

Specifications for Triangulation, etc. Coast and Geodetic Survey Report, 1902.

1902

Adjustment of Lake Survey Triangulation and Its Adaptation to the United States Standard Datum of the Coast and Geodetic Survey. Annual Report, U. S. Engineers, Appendix EEE, 1902, pp. 2883-3032. (Co-author with Thomas Russell.)

1902

The Base Line Measurements for the 98th Meridian. *Engineering News,* Vol. XLVIII, No. 10, Sept. 4, 1902, pp. 162-64.

1902

Account of Recent Gravity Observations at the North Tamarack Mine, Michigan. Paper presented before the Philosophical Society of Washington, October 11, 1902.

1902

Discussion—Some Devices for Increasing the Accuracy or Rapidity of Surveying Operations, by W. L. Webb. *Transactions, American Society of Civil Engineers,* Vol. XLVIII, 1902, p. 98.

1902

Triangulation in Kansas. Coast and Geodetic Survey Report, 1902, Appendix 3.

1903

Triangulation Southward Along the 98th Meridian. Coast and Geodetic Survey Report, 1903, Appendix 4, pp. 811-930.

1903

Opportunities in the Coast and Geodetic Survey. *Technology Review,* Vol. 5, No. 1, January, 1903, pp. 52-57.

1903

Novel Principles Applied and Results Obtained in Recent Rapid Primary Triangulation on the 98th Meridian. Paper presented before Philosophical Society of Washington, May 6, 1903.

1903

The New Coast and Geodetic Survey Level; a Possible Successor of the Wye Level. *Engineering News,* Vol. L, No. 1, July 2, 1903, pp. 2-4.

1903

Report on Geodetic Operations in the United States to the 14th General Conference of the International Geodetic Association. Government Printing Office, 1903, by O. H. Tittmann and J. F. Hayford.

1903

Precise Leveling in the United States, 1900-1903, with a Re-adjustment of the Level Net and Resulting Elevations. Coast and Geodetic Survey Report, 1903, Appendix 3, pp. 189-801.

1903

Recent Telegraphic Determinations of the Longitude of Honolulu, and the Older Determinations from 1555-1903. Engineering News, Vol. L, No. 19, November 5, 1903, pp. 414-15. *Science,* N. S., Vol. XVIII, No. 462, Nov. 6, 1903, pp. 589-93. Paper presented before Philosophical Society of Washington, October 10, 1903.

1904

Determination of the Value of Gravity at the North Tamarack Mine, Calumet, Michigan, from Observations by John F. Hayford and Pres. F. W. McNair, Michigan School of Mines. Unpublished Report, dated February 8, 1904, to the Superintendent of the Coast and Geodetic Survey.

1904

Report on Transit Micrometer Tested During March, April, and May. Coast and Geodetic Survey Report, 1904, 1 page.

1904

A Test of a Transit Micrometer. Coast and Geodetic Survey Report, 1904, Appendix 8, pp. 451-487.

1904

A Test of the Transit Micrometer as a Means of Eliminating Personal Equation. Paper presented before the Philosophical Society of Washington, May 21, 1904.

1904

Precise Leveling from Red Desert, Wyoming, to Owyhee, Idaho, in 1903. Coast and Geodetic Survey Report, 1904, Appendix 6, pp. 403-430.

1904

Precise Leveling from Holland to New Braunfels, Texas, in 1903. Coast and Geodetic Survey Report, 1904, Appendix 7, pp. 433-50.

1904

Recent Practise in the Coast and Geodetic Survey in Primary Triangulation, Base Measurements and Precise Leveling. Eighth International Geographic Congress, September 9, 1904, pp. 531-34.

1904

The Computation of Deflections of the Vertical from the Surrounding Topography. Paper presented before the Philosophical Society of Washington, December 10, 1904.

1904

Surveying. (Co-author with Officers of the Coast and Geodetic Survey.) Part of Proceedings, International Engineering Congress held at St. Louis, Missouri, 1904. Subject No. 35, Paper No. 1. Published by the American Society of Civil Engineers.

1905

A Connection by Precise Leveling Between the Atlantic and Pacific Oceans. *Science,* N. S., Vol. 21, No. 539, pp. 673-74, April 28, 1905; also *Engineering News,* Vol. LIII, No. 11, p. 279 March 16, 1905.

1905

Opportunities for Engineering Graduates in the Government Service. Proceedings, Society for Promotion of Engineering Education. Vol. XIII, 1905, pp. 87-95.

1905

Triangulation Along the 98th Meridian, Lampasas to Seguin, Texas. Coast and Geodetic Survey Report, 1905, Appendix 5.

1905

Precise Leveling from Red Desert, Wyoming, to Seattle, Washington, in 1903-1904. Coast and Geodetic Survey Report, 1905, Appendix 4, pp. 195-241.

1905

The Form of the Geoid as Determined by Measurements in the United States. Report of Eighth International Geographical Conference, 1905, pp. 535-540. Government Printing Office.

1906

The Adjustment of Observations by the Method of Least Squares. 1906. 298 pp. (Joint author with T. W. Wright, and sole author of Chapters VII and IX.) D. Van Nostrand Company.

1906

Present Methods of Precise Leveling. Paper presented before the Washington Society of Engineers, January 23, 1906.

1906

The Geodetic Evidence of Isostasy with a Consideration of the Depth and Completeness of the Isostatic Compensation and of the Bearing of the Evidence Upon Some of the Greater Problems of Geology. Proceedings, Washington Academy of Sciences, Vol. VIII, May 18, 1906, pp. 25-40. Paper presented before the Academy, April 14, 1906.

1906

Geodetic Operations in the United States, 1903-1906. Vol. I of Report of the 15th General Conference of the International Geodetic Association, pp. 192-234. (Joint author with O. H. Tittmann.)

1906

The Budapest Conference of the International Geodetic Association. *Science,* N. S., Vol. XXIV, No. 623, December 7, 1906, pp. 713-19. (Joint author with O. H. Tittmann.) Also *Engineering News,* Vol. LVI, No. 21, November 22, 1906, pp. 540-41.

1906

Why Not Teach About Men, the Most Important and Difficult Tools an Engineer Uses? *Proceedings, Society for the Promotion of Engineering Education,* Vol. XIV, 1906, pp. 198-207.

1907

Report of General Secretary, 57th Meeting of the American Association for the Advancement of Science, Columbia University, December 1906-January 1907. *Science,* N. S., Vol. XXV, No. 628, January 11, 1907, pp. 46-50.

1907

Study Men. Clarkson Bulletin, Vol. IV, No. 3. Commencement Day Address at Clarkson School of Technology. Reprinted in *Electric Journal,* Vol. IV, No. 10, October 1907.

1907

The Earth, a Failing Structure. Bulletin, Philosophical Society of Washington, No. 15, pp. 57-74. Retiring Presidential Address. Read before the Society December 7, 1907.

1907

Study Men, Incorporated in "Addresses to Engineering Students," by Waddell and Harrington.

1907

Geodetic Measurements of Earth Movements. California State Earthquake Investigation Commission Report, Vol. I, Pt. 1, 1908, pp. 114-159. Published by the Carnegie Institution. (Joint Author with A. L. Baldwin.)

Also published as Appendix 3, Coast and Geodetic Survey Report, 1907, pp. 67-104, under different title.

1909

The Figure of the Earth and Isostasy, from Measurements in the United States. Separate Publications, Coast and Geodetic Survey, 1909, 178 pp.

1909

The Effect of Topography and Isostatic Compensation Upon the Intensity of Gravity. Vol. I, Report 16th General Conference of the International Geodetic Association, pp. 365-89.

1909

Geodetic Operations in the United States, 1906-1909. Report to 16th General Conference of the International Geodetic Association, London and Cambridge, Coast and Geodetic Survey. (Joint author with O. H. Tittmann.) 11 pp.

1909

Precise Leveling in the United States, 1903-1907, with a Readjustment of the Level Net and Resulting Elevations. Coast and Geodetic Survey, 1909. 280 pp. (Joint author with L. Pike.)

1909

Report on the Triangulation of Greater New York. New York Board of Estimates and Apportionments, part of report by J. F. Hayford.

1909

The New College of Engineering, An Opportunity. *Engineering News*, Vol. 61, No. 20, May 20, 1909, pp. 535-36. Dedication Address, Swift Hall of Engineering, Northwestern University.

1909

Notes on the 1909 Conference of the International Geodetic Association. *Engineering News,* Vol. 62, No. 2, November 11, 1909, pp. 532-33.

1910

The Relation of Pure and Applied Science to the Progress of Knowledge and to Practical Affairs. Presented before the Illinois State Academy of Science, Urbana, Ill., February, 1910.

1910

Is It Advisable to Make Large Expenditures for the Improvement of Our Waterways? Paper presented March 10, 1910, to Engineering Club, Northwestern University.

1910

Precise Leveling. Paper presented before engineering students, University of Iowa, April 25, 1910, and before engineering students, Iowa State University, April 28, 1910. Published, *Iowa Engineer,* June 1910, pp. 144-51.

1910

Theory and Practice of Surveying by Johnson-Smith. John Wiley & Sons, 1910. (Assisted in preparation of chapters on "Triangulation" and "Precise Spirit Leveling.")

1910

Supplementary Investigations in 1909 of the Figure of the Earth and Isostasy. Separate publications, Coast and Geodetic Survey, 1910, 80 pp.

1910

Recent American Precise Leveling. Abstract *Engineering Record,* June 25, 1910, p. 823. Vol. 61, No. 26. Full paper, *Iowa Engineer* for June.

1911

The Relation of Isostasy to Geodesy, Geophysics, and Geology. *Science,* N. S., Vol. XXXIII, 1911, pp. 198-208. Address of Retiring Vice President, Section D, American Association for the Advancement of Science, Minneapolis, 1910.

1912

The Effect of Topography and Isostatic Compensation Upon the Intensity of Gravity. Coast and Geodetic Survey Special Publication No. 10, 1912. (Joint author with Wm. Bowie.)

1912

Geodetic Surveying by Ingram. Review published in *Engineering News,* March 30, 1912.

1912

Isostasy, a Rejoinder to the Article by Harmon Lewis. *Journal of Geology,* Vol. XX, No. 6, September-October, 1912, pp. 562-78.

1912

Panama-Costa Rica Boundary. Paper presented before the Men's Club of LaGrange, Illinois.

1913

The Best Preparation for Engineering. Northwestern University Bulletin, Vol. XIII, No. 21, February 7, 1913, 7 pp.

1913

Report, Commission of Engineers and Panama-Costa Rica Boundary. (Part of Report by John F. Hayford.)

1913

Measuring the Earth. Paper presented before University of Chicago Chapter of Sigma Xi, May 22, 1913. Also before Geographic Society of Chicago, May 23, 1913, the Western Society of Engineers, November 3, 1913, the Mathematics Club, Northwestern University, January 11, 1922, the University of Wisconsin, March 10, 1911, and the Chaos Club of Chicago, March 18, 1911.

1915

Reflections of a Director. Society for Promotion of Engineering Education. Paper presented at the Ames, Iowa, meeting, June 1915.

1915

The Earth From the Geophysical Standpoint. Proceedings, American Philosophical Society, Vol. LIV, No. 219, September 1915, 11 pp. Also Smithsonian Institution, Annual Report, 1916, pp. 239-48 (1917).

1916

Discussion, Col. Townsend's paper on Currents of Lake Michigan. Journal, Western Society of Engineering, Vol. XXI, No. 4, April 1916.

1916

The Great Land Slides at Panama. Paper presented at Class Day Exercises, Michigan School of Mines, Houghton, Michigan, April 14, 1916.

1916

The Importance of Gravity Observations at Sea on the Pacific. Paper presented before National Academy of Sciences, April 17, 1916. Proceedings, National Academy of Sciences, Vol. 2, pp. 394-98, July 1916. Abstract, *Science,* Vol. 20A, No. 715, 1917.

1917

Examples of Accuracy. Compilation of instances of very accurate work done in the Coast and Geodetic Survey. Furnished to Prof. George F. Swain, Massachusetts Institute of Technology, June 11, 1917, for use in book upon the Engineers, being prepared by Prof. Swain. Typed ms. 4 pp.

1917

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