

ROBERT F. ROTHSCILD

COLONIAL ASTRONOMERS
IN SEARCH OF THE LONGITUDE OF NEW ENGLAND

Navigation and surveying are essential to the mastery of new-found land, and knowledge of latitude and longitude is their chief ingredient. To measure these accurately was a matter of urgency for eighteenth-century scientists. Astronomy, the key to both, could readily be used to determine latitude. Without good clocks, the longitude was the great uncertainty since all east-west measurement depended on knowledge of the earth's rotation. Just as quickly as clocks were being developed in the eighteenth century, so too was the ability of astronomers to use them to measure longitude. The result was that by 1800 America not only knew how far Boston was from London but how far it was from Canada.

To measure longitude on land was far easier than at sea. On land, one could use a pendulum clock precisely regulated to local apparent solar time, and, by 1765, these had acquired temperature compensated pendulums so that they would automatically adjust to diurnal temperature variation and keep uniform time day and night.¹ Simplistically stated, the navigator going from London to Boston who knew only the latitudes had to get on the latitude of Boston and sail west until he reached the port. Once the latitude of Boston was accurately established, he could set a direct course to it from any other known point of departure, and as long as he kept track of any deviations from this course he was able to approach Boston directly from any angle. It was not until the invention of the marine watch, or chronometer, in 1831 that portable time became available and longitude at sea at last was within reach.

This paper shall deal with aspects of the progress made between 1755 and 1785 and shall attempt to demonstrate the true reasons for the failure of the Harvard-American Academy of Arts and Sciences expedition to Penobscot to see the totality of the solar eclipse of October 27, 1780. Significant new knowledge that resulted from that failure shall also be identified.

The first total solar eclipse to be visible to the American colonists occurred on October 27, 1780. On that sunny autumn day the path of totality is known to have traversed the coastline of present-day Hancock and Washington counties on its way out to sea. Unfortunately, the several thousand whites and Indians living in and around the settlements at Union River, Narragausus, Pleasant River, Gouldsboro, Jonesport, and Machias who must have witnessed this dramatic event with wonder and awe apparently left no record of what they saw.

The failure of the Penobscot expedition the previous year had brought the region to the brink of bankruptcy, starvation, and military disaster.² Yet for those who knew of the eclipse in advance, and even more for those who did not, those three or four minutes of darkness must have momentarily obliterated from their thoughts even the problems and terrors of war.

While the Commonwealth of Massachusetts was near bankruptcy, the eclipse was of sufficient importance that a plan to send observers was not abandoned even after the tide of war had turned so hopelessly against the colonial cause. Any why? Not merely because of the drama of this great celestial event, which, common though it is for our planet, is of such rarity in any particular geographic zone that few of us have more than one or two chances to experience it in a lifetime. The great significance of this particular event was the unique opportunity it gave American scientists to measure longitude.

By 1780 there had been countless successful transatlantic passages. Good navigators, from Samuel de Champlain onwards, could keep track of their latitude daily with an astrolabe³ or other means of measuring the elevation of celestial bodies above the horizon. The latitude north of the equator is equal to the elevation of Polaris, the Pole Star, above the horizon or can be calculated easily from the elevation of the noon sun and other bodies. Transatlantic navigators could sail due west on a fixed latitude to make a given landfall, if the latitude of the landfall were known. If they did not know their longitude they would not have known when they would arrive, but if they stuck to the fixed latitude, they would get there. But it was another matter to reach it on a northwesterly or southwesterly course, since, without longitude, they would not know in which direction to sail.

Well into the eighteenth century longitude was counted *eastward* from Ferro in the Canaries, which was then considered the westernmost point or the “beginning” of Europe. The coast of Maine would appear, for example, as longitude 320°,⁴ meaning 40° west of Ferro. By the mid-eighteenth century, British charts also showed degrees west of London,⁵ which is 17°14′ east of Ferro. Since St. Paul’s Cathedral, then considered the reference point, is 6′ of longitude west of the Royal Observatory at Greenwich, British maps of the second half of the eighteenth century must have 6′ added to the west longitude in order to be compared with maps based on Greenwich.

However charted, the measurement of longitude was seemingly an insurmountable problem. John Noble Wilford in *The Mapmakers* says that to know longitude almost became a colloquial synonym for “impossible.”⁶ Dead reckoning, the point-to-point method that is still the mainstay of the amateur sailor, was considered by

Champlain and others of the exploration period to be equivalent to placing one's faith in mere good luck, particularly on long voyages.⁷ The chief reliance for this method was on the chip log, of which Champlain gives the earliest known illustration. It consists of a wood chip cast on the water with a line attached. The rate at which knots in the line pass through one's fingers, compared with an hourglass, gives the means to compute speed, and, hence, the distance traversed.⁸ Champlain also believed in another method that relied on a theory that was utterly without scientific foundation: that the lines of constant magnetic variation ran north and south and were uniformly spaced. Since they do not run north and south and since they are not uniformly spaced, it is difficult to see how he navigated at all if he relied on this method.⁹ The inaccuracy of the best methods of measuring longitude even as late as 1755 can be judged from the excellent Thomas Jefferys map of that date,¹⁰ translated by LeRouge and entitled *Nouvelle Écosse ou Partie Orientale du Canada*, which contains a tabulation of the coordinates of various points according to leading cartographers. Taking Mount Desert Rock as an example, Jefferys gives its longitude as 50°08' west of Ferro but noted that other leading cartographers variously had given it as 50°28', 50°25', 50°09', and 49°25'. Jefferys's own longitude happens to be exactly correct, but this is just by chance since he believed Ferro to be only 17°35' west of London instead of 17°54'. But these longitudinal errors, amounting to as much as forty-five miles, are for points on land. Unfortunately, methods demanding stability, leisurely measurement, and repeatability of work by others were simply not available at sea. Navigation is difficult enough when both the position of the vessel and the longitude of the destination are known. If both are unknown, the problem becomes a nightmare.

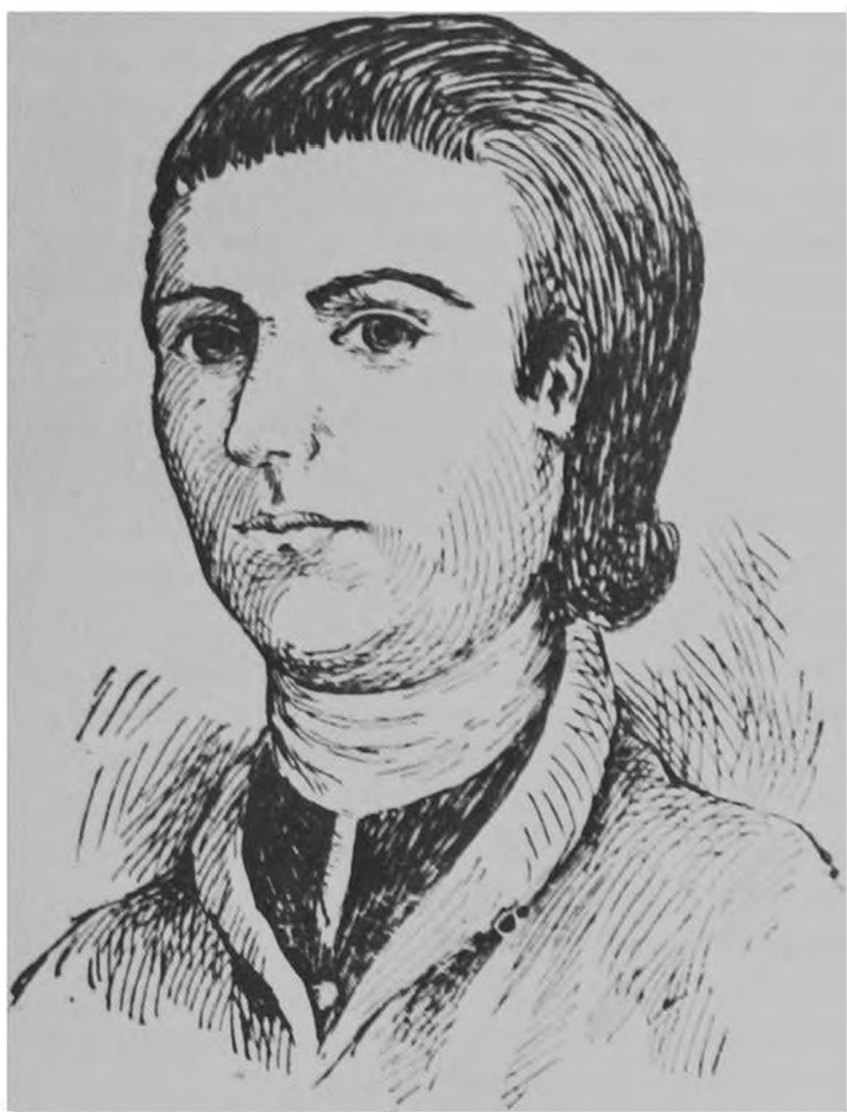
On land, the first great improvement in longitudinal measurement brought by the eighteenth century was the simultaneous observation of celestial events.¹¹ The pendulum clock, which could not be used at sea, could, of course, be adjusted on land to a high degree of accuracy. With a pendulum compensated for temperature changes, an invention of John Harrison in the 1730s,¹² a clock could be made that could be adjusted accurately to within a few seconds per day.¹³ Simultaneous observation of a transit of Venus across the sun, for example, or the eclipse of one of the Galilean moons on Jupiter, could be made in two places, the longitude of one of which is known, and thereby provide the means to compute the longitude of the other.¹⁴ A clock error of a second results in a longitudinal error of a quarter of a longitudinal minute, or less than a quarter of a nautical mile.

By the end of the 1750s, clocks with compensated pendulums were made in London and by David Rittenhouse in Philadelphia. Harvard College paid £35 14s to have an Ellicott clock made in London for the use of John Winthrop, then the Hollis Professor of Mathematics and Natural Philosophy.¹⁵ By 1780 Winthrop had died and had been succeeded by Rev. Samuel Williams. By then the measurement of longitude by simultaneous observation of celestial events was being tried whenever the opportunity presented itself. Williams had accompanied Winthrop to Newfoundland in 1761¹⁶ to observe a transit of Venus, although longitudinal determination was only a secondary purpose of the expedition. There were to have been observers at a total solar eclipse at Williamsburg in 1778, but that event was rained out, as we know from a letter of Thomas Jefferson to Rittenhouse.¹⁷ Thus, the solar eclipse of 1780 provided a great opportunity for American scientists, the first of its kind in the New World.

An important development in the quest for longitude had been made in 1755 by Johann Tobias Mayer of Göttinger, who published a set of tables of motion of the sun and moon, which, in 1770, became available in a new English edition by Nevil Maskelyne, the newly appointed astronomer royal.¹⁸ After Mayer died in 1762, Maskelyne saw to it that Parliament awarded his widow a portion of its famous prize for a method of longitudinal determination.¹⁹ The lunar data in the tables also provided an accurate method of making advance calculations of the exact time and path of any eclipse. It is no surprise, therefore, that it was from these tables that Samuel Williams computed the data enabling him to predict the time and the east coastal Maine path of the solar eclipse of October 27, 1780.²⁰

The American Academy of Arts and Sciences had been founded in 1780, and Williams communicated his predictions of the eclipse to his colleagues in the academy. James Bowdoin, the academy president, then petitioned the Massachusetts House of Representatives for "leave and accommodations" for Williams and a party of others to go to Penobscot to serve the "cause of Science" and to promote "the honor of the State" by viewing what he described as the first total solar eclipse to be visible to the colonies (and the last until 1806).²¹

Why did Williams wish to go to Penobscot of all places? The British had established an enclave there to serve as a source of timber, a military beachhead, and a refuge for all Tories on the Maine coast, and their control had been made secure by the ignominious failure of the American naval expedition of 1779.²² While Williams's calculations from Mayer's tables have not been preserved, a record of his predictions was published by him in an article appearing in the *Continental Journal* of September 28, 1780, stating that the center of the eclipse would pass over



Rev. Samuel Williams
(1743-1817)

Fort Halifax, the St. George River, and thence out to sea over Penobscot Bay in a southwesterly direction, a prediction that proved to be fifty miles too far to the southwest.

The instruments Williams required were costly and virtually unique; in wartime they were irreplaceable. The largest and heaviest instrument, the pendulum clock, was the most important. Unfortunately, water transportation provided the only conceivable means of bringing the instruments within the path of the eclipse. Neither the Kennebec nor the St. George River was navigable as far as would have been necessary to travel. Furthermore, Williams wanted to find a site as close to the center of the eclipse as possible in order to give himself the longest possible duration of totality and to insure himself against any slight inaccuracy in Mayer's tables. He also had reason to doubt the accuracy of the maps onto which he plotted the coordinates computed from the tables.

The choice of Penobscot, therefore, must have been the result of all of these considerations, combined with a reasonable confidence that the British would provide safe passage. If he had been willing to risk the western edge of the path as he calculated it, he would have gone to safe American territory between Bath and Thomaston. The eastern edge of his calculated path would have sent him to Union River or Mount Desert, and he would have had to skirt around the British-held bay. However, had he but correctly predicted the center of the eclipse, Machias would have been an excellent choice. It was the largest and most strongly American-held post east of Penobscot Bay. After the opening naval battle of 1775, " . . . Machias was not visited afterwards by the enemy during the war of the Revolution."²³

But Williams chose what he expected to be the center of the path of totality, and the Massachusetts House sent a

letter of Lt. Col. John Campbell, the British commander at Penobscot. Written by John Hancock, the letter requested permission for what may have been the first scientific expedition ever to pass into enemy territory. The letter is of sufficient moment to warrant quotation in full:

Boston Sept. 12, 1780

Sr

It is expected there will be a very remarkable Eclipse of ye Sun on ye 27th of Octo next, and that it will be central & total at or near the british Post at Penobscot where you command: the centre of ye Moon's Shadow if the longitude & latitude of that place by ye Maps can be depended on, being by calculation to pass over Penobscot Bay. As accurate observations of this Eclipse at a place so situated, may be greatly beneficial especially in Geography & Astronomy, the Genl Assembly of this State have made provision for Suitable persons to observe it at any place most proper for that purpose, and to which they can have access. The Gentleman who will be employed is ye Revd Mr Saml Williams Hollisson Professor of Mathematics & Natl Philo at our University at Cambridge with such assistants as he shall take with him. If he shd judge your Post or any other place within your command most suitable for making his observations it is not doubted that as a Friend of Science you will not only give him yr permission for that purpose, but every assistance in your power to render the observations as perfect as possible. Though we are politically enemies, yet with regard to Science it is presumable we shall not dissent from the practice of all civilized people in promoting it either in conjunction or seperately as occasions for it shall happen to offer.

Please to favour me with an answer, and with Passes for the safe going & return of Mr Williams & his associates, and of the Vessel and Mariners.

I am respectfully Sr yr most obt hble Servt^{2d}

The letter confirms what was later published in the September 28 issue of the *Continental Journal*, erroneously stating that the center of the eclipse was expected to pass over Penobscot Bay. It emphasized the uncertainty regarding the latitude and longitude given by maps. When this uncertainty was later grossly exaggerated it masked Williams's far greater error in determining the path. But most importantly, Hancock gives insight into the attitudes of the warring parties toward each other. The benefits to

“Geography and Astronomy” were presumed to be results in which both sides would share.²⁵

The Massachusetts House also approved a resolution providing for the use of the state galley *Lincoln* and made an appropriation for supplies, an act which Williams himself later recognized as an expression of the extraordinary importance of scientific research to the new nation. “Though involved to all the calamities and distresses of a severe war,” he wrote, “the government discovered all the attention and readiness to promote the cause of science which could have been expected in the most peaceable and prosperous times; and passed a resolve directing the Board of War to fit out the *Lincoln* galley to convey me to Penobscot or any other port at the eastward, and with such assistants, as I should judge necessary.”²⁶

In writing his article for the *Continental Journal* Williams had sought to enlist the general public in the task of accumulating as much eclipse data as possible. He gave the anticipated times of beginning, ending, and maximum in Cambridge and urged amateur observers everywhere to record the times of those events in their own locality. He even provided simple directions for obtaining the desirable data. In concluding his plea, Williams wrote as follows:

Observations of Eclipses are so useful that the curious are requested to pay all the attention they can to this phenomenon. An account of all the observations any gentleman may make will be of service to the cause of science, and may be esteemed a particular favor.²⁷

Since his own observations proved a vast disappointment, amateur observations would have been more valuable than he anticipated. They would have shed light on the surprising discrepancies between what he observed and what twentieth-century astronomers calculate he should have observed. Evidence is lacking to

indicate that he received any reports from the area of present-day Hancock and Washington counties; no record of any such observations has been found.²⁸

Whether the *Journal* of September 28 ever reached the Washington County area in time for the eclipse is unknown, but there is at least the probability that it did. On September 23, 1780, John Avery, acting as agent for Col. John Allen, the commander at Machias, petitioned the Council of Massachusetts for small arms and ammunition for the protection of the vessel in which he was about to leave for Machias carrying "the Priest and a quantity of stores . . . now ready for sail." The petition was granted on September 25, followed by an appropriation of £400 on October 4 for the pay of Allen's men.²⁹ Since the vessel remained in Boston until the fourth and was ready to sail, it seems reasonable to conjecture that she may have carried copies of the *Continental Journal* and arrived with them at Machias before October 27.

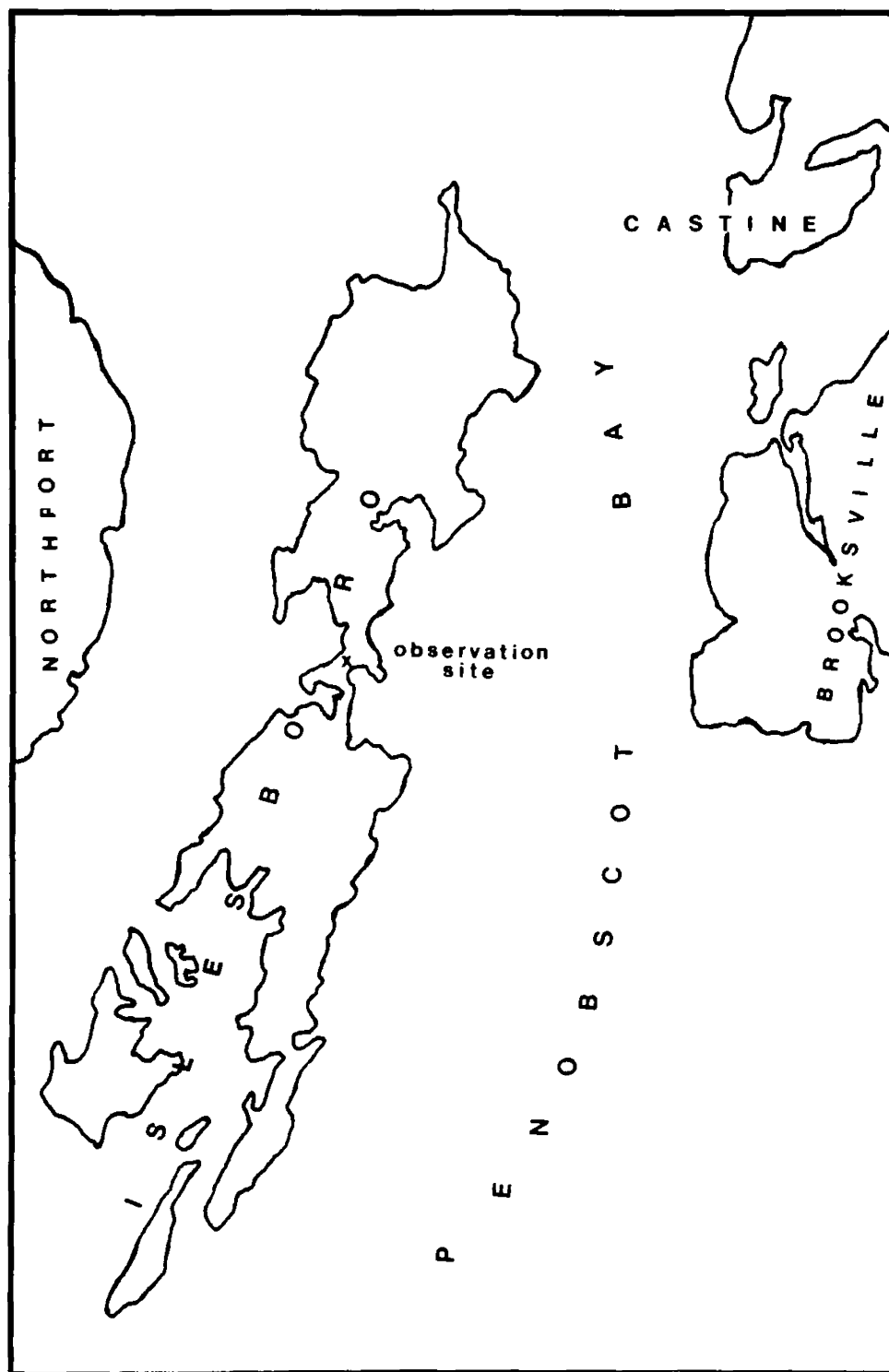
The *Lincoln*, an old row galley of about 250 tons, was scrapped shortly after this voyage, perhaps because of the difficulty of obtaining seamen willing to serve on a ship that might have to be rowed. She carried her crew, the Rev. Mr. Williams and three colleagues, six students, one or more passengers, the scientific instruments, and the supplies.³⁰ Setting out from Boston on October 9, the *Lincoln* arrived in the Bagaduce River below St. George on October 17.

The British commander proved to be no great "Friend of Science" as Hancock had flatteringly called him. Indeed, Campbell cut short the time the party could remain after the eclipse, and he delayed the commencement of their measurements. The British hero of the siege of Penobscot, Henry Mowat, captain of the *Albany*, gave the party "every kind of assistance which it was in his power to give."³¹ The party was directed to land on the east shore of Islesboro (then Winslow's or Long

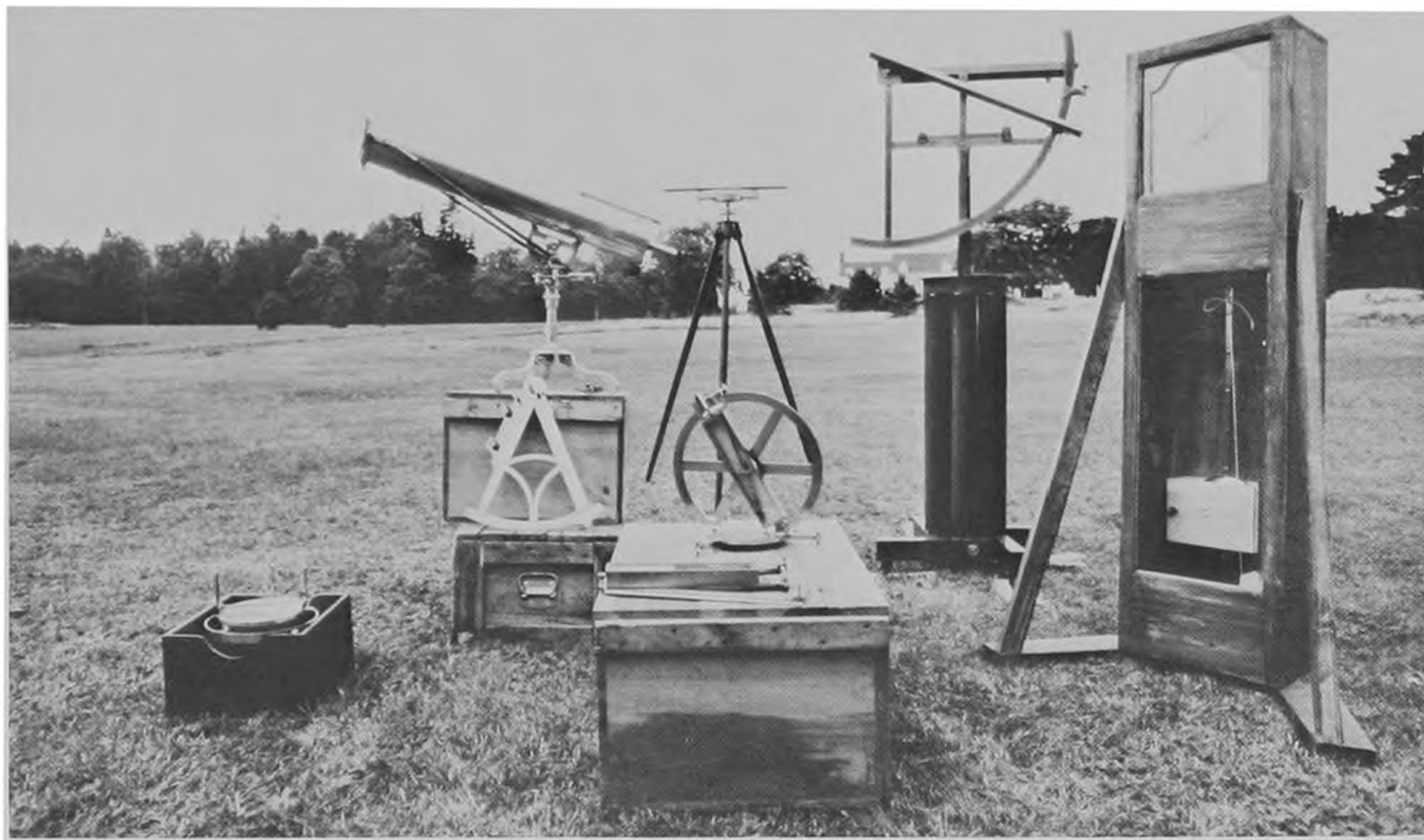
Island) at Bounty Cove on the property of Shubael Williams who was not related to Rev. Samuel Williams. Shubael Williams, said to have been the island's first settler, had cleared land from the east to west shore at the Narrows in 1764 and had built a log house and barn, which are shown on detailed versions of Joseph F. W. Des Barres famous maps of 1777.³² The location of the buildings corresponds closely to an irregularity still found in a field. Since the Des Barres map is extraordinarily precise and agrees with Williams's own description of the site, we can be quite certain of the latitude and longitude of the observation site, a matter of considerable importance.³³

After being rowed ashore and carried from the beach to the barn, the brass instruments must have required considerable attention after their long journey.³⁴ The time between October 9 and 26 was, therefore, undoubtedly spent caring for them and taking the many sun and star sights necessary to ascertain the precise latitude. Though the mean was computed to be $44^{\circ}17.7'N$, about one-and-one-half nautical miles south of the correct latitude, it agrees with most of the maps of the period.³⁵

Undoubtedly the most important activity of the week involved the regulation of the clock to local apparent noon, which is determined by averaging the morning and afternoon times the sun is at the same altitude above the horizon. The pendulum is then adjusted the next day when it is seen that the clock has run either fast or slow. After several such adjustments it can be determined that the clock gains or loses so many second per day. The variation in this final figure from day to day is a measure of the clock's accuracy, as distinct from the correctness of its adjustment. One week sufficed for the expedition to adjust the clock to an accuracy of within two seconds per day,³⁶ a variation that would introduce a longitudinal error of only one-half minute east or west, or three-tenths of a mile.



Islesboro



These instruments, now part of the Harvard Collection of Historic Instruments, were used by Williams in 1780. They are shown here on the approximate site used by Islesboro expedition.

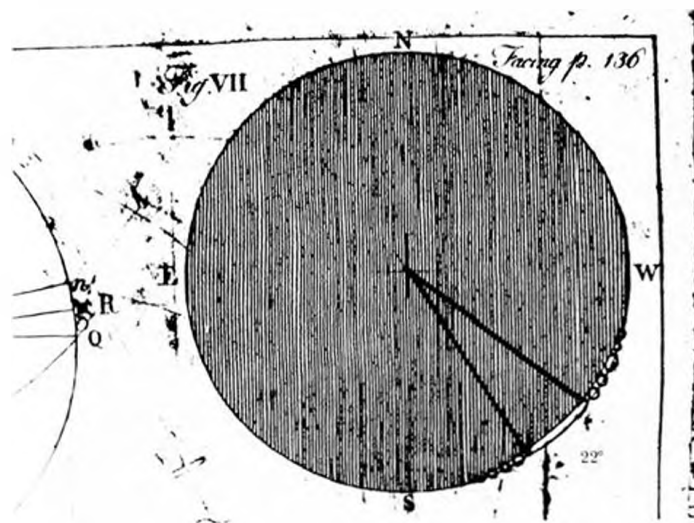
When the long-anticipated day finally dawned on Friday, October 27, the sky was hazy at first but soon cleared. At 11:11:08, Williams observed the beginning of the eclipse and began to measure its progress with a micrometer attached to his telescope. At intervals of a minute or two he recorded the visible part of the sun, which, when uneclipsed, is one-half a degree or about 3,600 arc-seconds. At 12:28:48, the sun was down to a crescent of only 24.7 arc-seconds in thickness. At this point 99.4 percent of the sun's diameter was in shadow and only .6 percent remained. It was then that Williams made his first important discovery, which he reported in 1784 to the American Academy of Arts and Sciences.

Immediately after the last observation, the Sun's limb became so small as to appear like a circular thread, or rather like a very fine horn. Both the ends lost their acuteness, and seemed to break off in the form of small drops or stars, some of which, were round, and others of an oblong figure. They would separate to a small distance: Some would appear to run together again, and others diminish until they wholly disappeared.³⁷

These then were Baily's Beads, "discovered" at 12:29 P.M. on October 27, 1780, at Bounty Cove, Islesboro. They would no doubt be called "Williams's Beads" today had the British been sufficiently attentive to the American Academy of Arts and Sciences *Memoirs* and not waited eighty years for their own astronomer, Francis Baily, to rediscover them.³⁸ In further describing his unusual discovery, Williams continued:

Finding it very difficult to measure the lucid part any longer, I observed again the larger telescope, looking out for the total immersion. After viewing the Sun's limb about a minute, I found almost the whole of it thus broken or separated in drops, a small part only in the middle remaining connected.³⁹

Williams shows that he understood the novelty of his observation by his verbal description and by his drawing, which, we may conclude, represented the appearance of the sun from about 12:29½ to about 12:30½.⁴⁰ He may



Williams's drawing showing the remaining visible arc of the sun at approximately 22° as the eclipse reached its maximum. (Angle and measurement added. —Ed.) The United States Naval Observatory calculates that the remaining arc should have been 89°

not, however, have understood the explanation. Just before the sun is completely obscured, the mountain peaks on the moon's profile reach the far side of the sun, but the valleys between them do not. Thus, minute chinks allow the passage of bright spots of light to reach the earth. It happens that the highest mountains (about five miles) occur on the south-southwest portions of the moon's disc.⁴¹ It is fortuitous that the expedition was so located that the opportunity for observing the beads was optimized. Had any other part of the moon's circumference been the last to reach the far side of the sun, the opportunity to observe the beads would have been far less, and had the arc of sun remaining been thicker, its brilliance would have been so dazzling that the beads

would not have been seen at all. This latter point is demonstrated by the fact that the beads were seen only at the moment the eclipse approached a maximum, a fact of very considerable significance.

In his report to the academy, Williams went on to say:

This appearance remained about a minute, when one of my assistants, who was looking at the Sun with his naked eye, observed that the light was increasing. At this time I could not see any appearance of an increase of the lucid part. At 12°31'18'', it was evident that the broken parts of the Sun's limb began to increase and unite. I immediately applied to the micrometer and measured the chord of the lucid part, and found it amounted to 42° or 43°: This was from the extremity of each limb taken from the most distant parts that were visible. I then measured the connected part of the limb, and found it to be 24° or 25°. As the light and limb were by this time very sensibly increasing, I again began to measure the quality of the lucid part, and made the following observations with the micrometer.⁴²

After measuring the arc-thickness at intervals until the end of the eclipse at 1:50:25, he was able to add:

From these observations it may be inferred, that the greatest obscuration was at 12:30:12: at which time the Sun's broken limb was reduced to so fine a thread, and so much broken as to be incapable of mensuration.⁴³

One can imagine the shock, the tragic disappointment, and, perhaps even worse, the embarrassment this must have been for Williams after so much planning and effort on his part and so much sacrifice by others to have missed the climax of what he had come all this distance to see! But why did he fail to see it? And by how much? The reasons given by Williams himself do not seem to fit the facts. What is more, modern theory indicates that he should have missed the eclipse by far more than he did. These discrepancies will be explored since they led to information that was useful at the time and, surprisingly, useful to us today.

Only three reports of the expedition have been found: a newspaper report dated November 10, 1780;⁴⁴ a letter of 1781 written by Joseph Willard, later president of

Harvard College, to Rev. Dr. Nevil Maskelyne, the astronomer royal;⁴⁵ and Williams's own report to the American Academy, written in 1784.⁴⁶ Not only do these reports not agree, they contradict each other on almost every significant point.

The newspaper account stated that Mayer's tables led the members of the expedition to expect to be at the center of the path, but, instead, they found themselves "just at the southern extremity," and that the remaining visible arc of the sun was one-fifteenth of the circumference (24°) and not more than nine arc-seconds in thickness. This report also notes that the expedition "had the happiness to succeed fully" in its objectives.

President Willard did not disclose to Maskelyne that he did not agree that the center of the path was at Penobscot Bay. He apparently made his own calculation from Mayer's tables, and the accuracy of that calculation is confirmed by a recent recalculation showing the path to have been thirty-four miles northwest of the expedition site.⁴⁷ In his letter, Willard used the minimum remaining arc of the sun, which he said was eight arc-seconds, to compute the error produced by Mayer's tables. When a couple of modern adjustments are made to this calculation, the error comes out to twenty-one additional miles. Interestingly, a modern calculation made by the United States Naval Observatory places the path fifty-five miles from Williams's observation site, or almost exactly where Willard thought it should be.⁴⁸ Thus, without explicitly so stating, President Willard's letter to Maskelyne tells us that Williams's calculation contained an error of thirty-four miles, which, when added to the twenty-one mile error in the table themselves, puts the site substantially outside the edge of the path of the eclipse, which was total only thirty-five miles on each side of the center of the path.

In the third account, presented by Williams to the American Academy in 1784, no reference was made to any error in the tables nor to the fact that his computation from them differed from Willard's by thirty-four miles. This thorough and detailed report merely concludes with the following bland statement of explanation:

The longitude of the place of our observation agrees very well with what we had supposed in our calculations. But the latitude is near half a degree less than what the maps of that part of the coutry had led us to expect. On this account our situation, instead of falling within the limits of the total darkness, proved to be very near the southern extremity.⁴⁹

But did such erroneous maps actually exist? We have no record of which maps Williams took with him nor which maps John Hancock had in mind when he warned that the calculation would be only as reliable as the latitude and longitude of the available maps. After surveying the prominently used maps of the period and comparing the latitude of the expedition site on them with the true latitude of 44°19.1', it is clear to this author that none had an error of "near half a degree," or 30'.

From the more prominent pre-1780 maps it is easily seen how much more accurately the latitude of the Islesboro site was known than was its longitude. The latitudes on the maps examined varied from 4' less than the correct value to 14.6' more, and all but two of them were within 6'. On the other hand, the longitudes ranged from a minute or two too far west to 45' too far east, except John Smith's *Map of New England* of 1716 and Rev. John Senex's *New Map of English Empire in America* of 1719, the two earliest maps examined, which place the longitude of the site still farther east. Thus, when Hancock made reference to the unreliability of the maps, he was reflecting an awareness of their possible inaccuracies, particularly with regard to longitude. Williams's statement that latitude was in error by almost 30' is not confirmed by any map found. While the mere existence of accurate maps does

not suffice to gainsay his statement that he had the misfortune to have relied on inaccurate ones, it does seem improbable that he could have relied on one that was off by “near half a degree,” or thirty miles. Indeed, it does not seem as though the *Lincoln* would have even found the mouth of the Bagaduce River with such a map!⁵⁰

One of the most beautiful and the most famous maps of American history is surely John Mitchell's *Map of the British and French Dominions* of 1755. Mitchell, an extraordinarily talented man who was a physician, botanist, and an author of tracts on anthropology, chemistry, physics, current history, and international affairs, made only this one map. It was started in 1750 after he returned to Britain to live, and it was drawn entirely from British sources, some of which were then out-of-date. Many revisions, translations, and plagiarisms appeared in succeeding decades, some of which reduced or corrected the errors of the original, but some of which perpetuated or even increased them.

It would be natural to assume that in a matter as important as the planning and execution of this expedition Williams would have used the best known map, which may have been the Mitchell map. Unfortunately, the only clue as to the map's identity is provided in Williams's prediction in the *Continental Journal*, which stated that the center would pass over “Fort Hallifax (*sic*), St. George's (*sic*) River, and out over Penobscot Bay.” A line through Fort Halifax and the St. George River on the fourth edition of Mitchell's map, the one used by John Jay in negotiating the Treaty of Paris of 1783, does indeed go out into Penobscot Bay near Islesboro. Probably published in 1774, this edition could have reached Cambridge before the outbreak of the war, but no copy of it survives at Harvard. The Mitchell's map now on file there is from the first edition on which the Fort Halifax-St. George line goes out to sea in Muscongus Bay and not in Penobscot. We are constrained, therefore, to reject Mitchell's map as the basis

for the prediction. Furthermore, the latitude on these maps is only twelve minutes more than Williams measured at the site. On the basis of this evidence one is forced to conclude that Mitchell's maps were not used. Since *no* map can be found containing anything approaching an error of latitude of "near half a degree," an error so gross as to be incomprehensible, one is tempted to discredit Williams's explanation as to why he missed totality.

In 1780 the *Continental Journal* reported the minimum thickness of the remaining arc of the sun to be nine arc-seconds. In 1781 President Willard stated that it was eight seconds, and then calculated a twenty-one-mile error in Mayer's tables, which has been shown to be about correct. Yet, in his 1784 report, Professor Williams not only failed to give any such figure, but stopped measuring the thickness at twenty-five arc-seconds, saying it was so thin and broken as to be "incapable of mensuration." Why? Why did he pass up the opportunity to make and report a calculation of the error in Mayer's tables, which, after all, still provided the best means of calculating longitude at sea and of predicting eclipses? If, however reluctantly, one hypothesizes that Williams made a deliberate misstatement about the gross error in the maps in order to avoid acknowledging the error in his prediction, one must see that Willard's computation would have also entailed a similar error. While Willard has surely hinted at Williams's error in his letter to Maskelyne, it would have been quite another matter for Williams to acknowledge it in so important a publication as the *Memoirs*, which was published four years later.

Williams personally took no measure of the thickness of the solar arc at the maximum of the eclipse; he quit the telescope with the micrometer when he realized that totality was approaching and went to the more powerful telescope then being used by an undergraduate assistant

by the name of David Atkins. Thus free to use the instrument with the micrometer, Atkins could have then made the measurement, which Williams later declared impossible, and reported it to President Willard, even though Williams did not believe it.

Fortunately, astronomy and geography have benefited at least as much as Professor Williams's near miss as they would have from a complete success. As has been noted, the discovery of Baily's Beads could have occurred only at the very edge of totality, thus making possible some inferences about the physiography of the lunar surface. From the measurement of the minimum arc of the sun at the time of maximum eclipse, Williams's colleagues could calculate, perhaps for the first time, the true accuracy of Mayer's tables.

It was Williams's measurement of the chord of the luminous remaining solar arc, made when he realized the maximum had passed, that led to the drawing submitted to the American Academy and to the report in the *Continental Journal* that the arc was reduced to one-fifteenth of the sun's circumference, or 24° . It is difficult not to believe that this is exactly what Williams and his fellow observers saw, yet it is in conflict with what modern calculations indicate should have been visible at Islesboro during an eclipse of that magnitude. Modern calculations lead us to expect that Williams would have seen visible not less than a quarter (89°) of the sun's circumference. This is nothing like the drawing he presented to the academy and is far more than he reported to the *Continental Journal*. Furthermore, with an arc as long as indicated by modern calculation, there would have been so much brilliance that it does not seem possible he could have seen Baily's Beads, much less been their discoverer as seems likely from his vivid description of them.

This discrepancy as well as others between the times of observation of the eclipse by Williams and by people in other locations between Halifax and Newport have been discussed by this author in greater detail in a recent article in *Sky & Telescope*.⁵¹ In a commentary on that article, contained in the same issue, Dr. Alan Fiala of the United States Naval Observatory suggests that a better fit to the circumstances of the 1780 eclipse might be made if a new solar system ephemeris is employed for its calculation. Fiala's only other explanation is totally unacceptable: that Williams either was not where he said or did not accurately describe what he saw. We know the location of Shubael Williams's farm, and Professor Williams's presence there is confirmed, among other things, by the latitude and longitude he reported. Since no previous total eclipse had been observed carefully in America, his description of events must have been drawn from onsite observation and could not have been fabricated. Thus, we are left with significant and unresolved problems, which the editors of *Sky and Telescope* call "an historical curiosity with, perhaps, the potential for being astronomically important."⁵²

It would be helpful in resolving this dilemma to find other observers in the path of totality who recorded the duration of the eclipse. In the light of Williams's own plea for observers, this hardly seems too much to hope for, but none has yet been found. In Yarmouth, Nova Scotia, a Mr. Pool did report to one Joseph Peters of Halifax that "the eclipse there was total for a momentary space."⁵³ Fragmentary and indirect though this is, it tends to support modern calculations of the path, but, as evidence, it obviously weights as nothing compared with all that provided by the expedition.

President Willard's letter referred to above, listed his astronomical observations from 1769 to 1780 and the longitudes he calculated from them. The errors ranged

from five miles down to three for Cambridge and about six miles for Islesboro. But Williams summed up his 1784 report to the American Academy by averaging his eleven eclipse calculations of Cambridge longitude at $71^{\circ}09'$, exactly the correct value.⁵⁴ The age old uncertainty of the width of the ocean and the longitude of America was ended. He had measured the latitude of his Islesboro site as $44^{\circ}17.7'N$ instead of $44^{\circ}19.1'N$, an error of only 1.4 miles. His 1784 average of his eclipse calculations enabled him to calculate the longitude of his Islesboro site at $68^{\circ}49'W$ instead of $68^{\circ}54'W$, an error of only three miles. By 1784, therefore, Williams had published the longitude of Cambridge correct to the nearest minute (or one-half mile) and for his Islesboro site correct to five minutes, compared with the fourth edition of Mitchell's map which had Cambridge almost twenty minutes too far east and Islesboro thirty minutes.

Even if Mitchell were slow in employing the latest data, it is evident how rapidly the accuracy of navigational data was improved by the work of the astronomers of the educational establishment. And when one considers this advance from the viewpoint of the navigator who no longer had to choose between a succession of short coastal passages or a long shot at coming within a few dozen miles of reaching port on a direct course, it made an immense difference that by war's end, he could sail a compass course direct from Boston to Islesboro.

Because the first scientific expedition of our new republic went to a site in Maine from which it could not have seen totality, it must have seemed a failure in its time. Despite this egregious error, however, the observations made there substantially closed the broad gap in the navigator's knowledge of the longitude of the New England coast. But what is more striking and unexpected is that the error in computing the path of totality has

brought into question our own sophisticated twentieth-century astronomical calculations. It is not too much to hope that some day a letter will come to light that was written on October 27, 1780, from some known location in Washington or Hancock counties noting how many seconds the sun was in darkness. If we had such a document and it was mathematically consistent with Williams's drawing and description of the eclipse, we would have more perfect proof of the imperfection of the best solar system calculation we are able to make today.

NOTES

¹Harvard ordered its Ellicott clock from London in 1765 (see David P. Wheatland and Barbara Carson, *The Apparatus of Science at Harvard, 1765-1800* [Cambridge: Harvard University Press, 1968], pp. 71-72) and Thomas Jefferson ordered such a clock from David Rittenhouse a few years later (see Jefferson to Rittenhouse, July 19, 1778, in Thomas Jefferson, *The Writings of Thomas Jefferson: Being His Autobiography, Correspondence, Reports, Messages, Addresses, and Other Writings, Official and Private*, ed. H. A. Washington, 9 vols. (Washington, D.C.: Taylor & Maury, 1853), 1:210 (hereafter cited as Jefferson, *Writings*).

²James S. Leamon, "The Search for Security: Maine after Penobscot," *Maine Historical Society Quarterly* 21 (Winter 1982): 119-20. An illustration of how dire the economic stringency had become can be found in a letter of February 26, 1781, by Charles Miller to James Richardson, printed in James Phinney Baxter, ed., *Documentary History of the State of Maine*, 24 vols. (Portland, Me.: Maine Historical Society, 1857-1916), 19: 156-57 (hereafter cited as *Doc. Hist. Me.*). In that letter, Miller denied a request for two hundred barrels of flour and one hundred barrels of pork for the 473 men defending the three eastern counties, explaining that he could not obtain the supplies without cash, of which he had had none for three months.

³Samuel de Champlain, "Treatise on Steamship: How to Be a Good Seaman," trans. in Samuel Eliot Morison, *Samuel de Champlain, Father of New France* (Boston: Little, Brown, 1972), Appendix II, pp. 239-67 (hereafter cited as Champlain, "Treatise"). See especially p. 247.

⁴See, for example, Captain John Smith's *Map of New England*, 1616.

⁵For example, the 1776 LeRouge translation of Thomas Jefferys's 1755 map of New England and Nova Scotia, entitled *Nouvelle Écosse ou Partie Orientale du Canada* (hereafter cited as *Nouvelle Écosse*), shows longitude both west of Ferro and west of London, with meridians marked at the bottom edge of the map: 30°, 35°, 40°, etc.; the same meridians at the top are marked: 47°35', 52°35', 57°35', etc. The difference of 17°35' is what the mapmaker believed to be the difference in longitude between London and Ferro. The actual difference is exactly 17°54'

⁶John Noble Wilford, *The Mapmakers* (New York: Alfred A. Knopf, 1981).

⁷Champlain wrote, "It is certain that the observations of latitude taken, whether by the sun, or by the pole star or others, gave accurate information from the point of departure up to that destination, and one's latitude, which puts the seaman right. But they do not give the length of the course, which can only be done by guesswork; quite apart from one's position north-south . . ." Champlain, "Treatise," pp. 255-56

⁸If the knots are seven feet three inches apart and the hourglass is good for twenty-eight seconds, the number of knots passing in one period of the glass is the number of nautical miles (or knots) per hours the ship is making through the water. Champlain, "Treatise," p. 266.

⁹*Ibid.*, p. 249.

¹⁰*Nouvelle Écosse*.

¹¹"Almost all methods of determining the difference of longitude between any two places depends on the general principle of finding the difference between the times of taking any observation estimated under the meridian of both of those places. Nathaniel Bowditch, *The New American Practical Navigator*, 3rd ed. (New York: E. M. Blunt, 1811), p. 148 (hereafter cited as Bowditch, *Practical Navigator*).

¹²Wilford, *The Mapmakers*, p. 131.

¹³Bowditch, *Practical Navigator*, p. 31.

¹⁴" . . . and eclipse . . . observed at both places at the same moment of absolute time . . . the difference of times will be the difference of the longitude. An observation of the Sun . . . is the most accurate method known." *Ibid.*, p. 149.

¹⁵The Ellicott Regular Clock that was used to time the eclipse in Penobscot Bay was regulated over a period of a week until it was gaining between no less than forty-nine and no more than fifty-one seconds per day. Thus, the time could be calculated with a maximum

error of no more than two seconds. Samuel Williams, "Observations of a Solar Eclipse, Oct. 27, 1780, Made on the East Side of Long Island, in Penobscot Bay," *Memoirs of the American Academy of Arts and Sciences* 1 (1785): 90-92 (hereafter cited as Williams, "Observations").

¹⁶Wheatland and Carson, *Apparatus*, p. 70.

¹⁷Jefferson to Rittenhouse, July 19, 1778, Jefferson, *Writings*, 1: 210.

¹⁸Tobias Mayer, *Tabulae motuum solis et lunae, novae et correctae; auctore Tobia Mayer: quibus accedit methodus longitudinum promota, eodem auctore. Editae jussu praefectorum re longitudinariae*. (Londini: Guilielmi et Johannis Richardson, 1770). This work is a translation of Mayer's 1755 method of computing longitude, with corrections and "Use and Explanation Tables" by Nevil Maskelyne.

¹⁹This £20,000 prize was for the development of means to measure longitude correctly to within a half degree (thirty nautical miles) on a transatlantic voyage; the balance of the prize went to John Harrison for his "Watch No. 4" in 1773. See Wilford, *The Mapmakers*, 135-36.

²⁰(Boston) *Continental Journal*, Sept. 28, 1780.

²¹Petition of James Bowdoin and others, *Doc. Hist. Me.*, 18: 394-95. In part, the petition states, "... observations of Eclipses have been attended with so many advantages to mankind that they are universally esteemed objects of great Attention in every civilized nation: That They have been of great use in chronology, serving in several cases to ascertain the date of ancient transactions, and have been applied with Great advantage by Divines in determining ye important point of the christian era. That in Geography they have been of Singular Service in determining the longitude of places; and in astronomy they are of the greatest use to perfect the lunar Theory and Tables. With these two last Objects navigation, and the consequence, Commerce must always be very nearly connected."

²²John Calef, *The Seige of Penobscot by the Rebels* (London: Printed for G. Kearsley, 1781), pp. 15-43.

²³Stephen Jones, "Historical Account of Machias," *Maine Historical Society Quarterly* 15 (Fall 1975): 56.

²⁴*Doc. Hist. Me.*, 18: 402-3.

²⁵Hancock assumes the British commander will expect the benefits of the expedition to be shared, as they were. President Willard of Harvard communicated them to the Royal Society before the war was over in a letter to Nevil Maskelyne that concluded: "I hope, Sir, no umbrage will be taken at my writing you on account of the political light in which America is now viewed by Great Britain. I think political disputes

should not prevent communications in matters of mere science, nor can I see how anyone can be injured by such intercourse." Royal Society of London, *Philosophical Transactions*, vol. 71, pt. 2, p. 507 (hereafter cited as *Philosophical Transactions*).

²⁶Williams, "Observations," pp. 87-88. The Board of War, on October 4, 1780, gave orders to Captain Joseph Ingraham, master of the *Lincoln*, to convey Williams to Penobscot "or elsewhere as you may be directed by Williams." *Doc. Hist. Me.*, 18: 456.

²⁷(Boston) *Continental Journal*, Sept. 28, 1780. It is interesting to compare Williams's appeal to "the curious" with that of Edmund Halley in England before the 1715 eclipse, especially in light of Halley's successful result. As quoted by F. Richard Stephenson in "Historical Eclipses," *Scientific American* 247 (October 1982): 170-71, Halley made a "Request to the Curious to observe what they could about it, but more especially to note the time of total Darkness, as requiring no other instrument than a *Pendulum Clock* with which most Persons are furnish'd, and as being determinable with the utmost Exactness, by reason of the momentaneous [*sic*] Occultation and Emersion of the luminous Edge of the Sun, whose least part makes Day." Stephenson goes on to say that "Halley's motive in promoting the timing experiment was to improve the accuracy of future eclipse predictions. He harvested nine ostensibly accurate measurements from various parts of Britain."

²⁸In hope of finding some reference to the 1780 eclipse in a manuscript of an observer, the author has searched the manuscript files of Maine Historical Society, New England Historical Genealogical Society, and the Boston Athenaeum. He has also written to the American Antiquarian Society, the John Carter Brown Library, the Massachusetts Historical Society, and to the historical societies of Machiasport, Bar Harbor, East Machias, and St. Andrews, N.B. Inquiries were also directed to the Public Archives of Nova Scotia, the New Brunswick Museum, the Provincial Archives of New Brunswick, and to Professor Roy Bishop of Acadia University, Wolfville, N.B. Several reference lists of manuscripts have also been consulted, notably that of Elizabeth Ring, *A Reference List of Manuscripts Relating to the History of Maine* (Orono, Me.: University Press, 1938).

²⁹*Doc. Hist. Me.*, 18: 434-35.

³⁰For a list of provisions see *Doc. Hist. Me.*, 18: 247-48.

³¹Williams, "Observations," p. 87.

³²Joseph F. W. Des Barres, *Atlantic Neptune. Published for the Use of the Royal Navy of Great Britain, by Joseph F. W. Des Barres, Esq., under the*

Directions of the Right Honble the Lords Commissioners of the Admiralty. 2 vols. (London: 1777).

³³The extraordinary accuracy of the Des Barres *Atlantic Neptune* maps is not necessarily consistent with their dates. It has been reported to the author that these maps were frequently revised and republished without a record of the republication dates. Having been made by the British Admiralty as coastal charts, an effort may well have been made to keep them from falling into American hands. There is an interesting aspect to this however. Captain Henry Mowat, hero of the British defense of Penobscot and captain of the *Albany*, whose help Professor Williams fulsomely acknowledged, was said to be the skipper with whom Des Barres sailed in his voyages to make the maps. If so, he would have been in a position to tell Williams the correct latitude when he met him on October 17, if Williams had based everything on preposterously erroneous maps. Of course, Williams's own accurate latitude measurements, beginning October 20, would have told him the same thing.

³⁴In September 1980, in commemoration of the bicentennial year of the expedition, students of the history of science at Harvard visited Islesboro with the original instruments, which are still preserved in working order in the magnificent Harvard Collection of Historical Scientific Instruments. During the reenactment, all observers could see the extreme sensitivity of the clock to the least movement or imbalance and understand the time and skill required to adjust it. Robert F. Rothschild, "What Went Wrong in 1780?," *Harvard Magazine* 83 (Jan./Feb. 1981): 20-27.

³⁵Williams, "Observations," pp. 99-101. The Des Barres map has the barn at 44°17.1'N, 0.6 miles south of Williams's measurement. The true position is 44°19.1'N.

³⁶Williams, "Observations," pp. 87-92.

³⁷*Ibid.*, p. 93.

³⁸Though "beads" such as these must have been seen many times in human history, no earlier description or drawing of them is known. We feel we have a right to credit Williams and his party with a discovery because of the seemingly unique historic event: the party stood at an identified location at a time in history known to the nearest few seconds and perhaps said, "Behold! We are seeing for the first time an event of great beauty whose cause is unknown and whose precise nature is imperfectly understood."

³⁹Williams, "Observations," p. 93.

⁴⁰*Ibid.*, Fig. VII, facing p. 136.

⁴¹Private communication of Dr. Alan Fiala, United States Naval Observatory, Washington, D.C., to the author.

⁴²Williams, "Observations," pp. 93-94.

⁴³*Ibid.*, p. 95.

⁴⁴(Boston) *Continental Journal*, Nov. 16, 1780.

⁴⁵*Philosophical Transactions*, pp. 503-7.

⁴⁶Williams, "Observation", pp. 81-109.

⁴⁷The prodigious task of computing this eclipse from Mayer's tables was accomplished at the author's request by Charles Kluepfel of New York, using a program he constructed for his computer. This may be the first time in a century that Mayer's tables have actually been used to calculate an eclipse.

⁴⁸This calculation, made at the request of Owen Gingerich of Harvard's Smithsonian Observatory of Astrophysics by Dr. Alan Fiala of the United States Naval Research Laboratory, Nautical Almanac Office, in April 1981, was communicated directly to the author by Professor Gingerich. The result was confirmed by Charles Kleupfel and reported by him in "The Eclipse of 1780," *Harvard Magazine* 83 (May/June 1981): 20-21.

⁴⁹Williams, "Observations," p. 102.

⁵⁰The *Lincoln* was used as an express to transport personnel and papers from place to place along the coast. During the Penobscot seige, for example, Solomon Lovell's journal refers to her being sent back to Penobscot Bay from Boston with orders and of being sent back a day or so later with a messenger. It seems quite likely that she was the means of sending back the first bad news of the failure of the Penobscot expedition of 1779. Her captain, Joseph Ingraham, may not have had the latest British maps on board, but he surely knew the latitude of Penobscot well enough to have told Professor Williams that he was thirty miles off before they even left Boston.

⁵¹Robert F. Rothschild, "Where did the 1780 Eclipse Go.?", *Sky & Telescope* 63 (June 1982): 558-60.

⁵²*Ibid.*, p. 559.

⁵³Williams, "Observations," p. 114.

⁵⁴*Ibid.*, p. 102.