MAPPING MONUMENTS:

THE LOUGH FOYLE BASELINE

Michael Cory

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Cover Picture: View from Binevenagh Cliffs across the plain by Lough Foyle where Colby's baseline runs. Photo by A Cory.

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"I made a cursory examination of the general idea of the country and to seek a proper place for the measurement of a new Baseline. The shores of Lough Foyle presented most advantageous for this purpose"

Thomas Colby[1]

Introduction

The view from the cliffs of Binevenagh Mountain is expansive. To the west across Lough Foyle lie the hills of Donegal, and to the north across the sea the western Isles of Scotland. The rocky escarpment rises 1,000 feet above a plain that stretches eight miles between Magilligan Point and Ballykelly, just 18 feet above sea level, intersected by hedges and walls surrounding green fields. Between the mountain and the sea, it is a landscape of great contrast and great beauty. The wide flat sandy expanses of Benone Beach to the north and Magilligan Strand to the west are edged by sand dunes that hide a prison, an army base and holiday caravan sites. A Martello Tower at Magilligan Point was built too late in 1817 to protect the wide natural harbour of the Foyle estuary from Napoleonic invasion. It mirrors a fort across the entrance of a Lough full of native oysters and the once abundant wild Atlantic salmon, swimming to their spawning grounds. Cut in half by the River Roe, the plain is now intersected by a railway considered the most scenic in Ireland.

Silently, below the cliffs of Binevenagh Mountain, and along the plain, stand three monuments aligned precisely to within millimetres of each other over eight miles. They form the Lough Foye Baseline, the heart of a monumental endeavour to map Ireland and Britain in the first half of the 19th Century. Witnessed by eminent scientists and surveyors, the techniques pioneered here would be replicated across the British Empire by Sir George Everest on his Survey of India, and by the Astronomer at Cape Town. The distance measured between the monuments was so precise that when remeasured by microwaves in 1960 it was found to be within one inch of Colby's carried out in 1827 and 1828. They have stood for nearly two hundred years, the foundation of all distances in Ireland and Britain until satellites changed our understanding of the world.

Before the age of lasers, microwaves and satellites the accurate measurement of position and distance relied on triangulation, a technique conceptualised by Gemma Frisius, a mathematician and teacher of Mercator, and developed by Tycho Brae, the Danish Astronomer, and Willebrod Snell the Dutch mathematician. It had been put to good effect by the Cassini family to map France during the Eighteenth Century. The basic idea of triangulation is well-known: if the distance between two points on the earth's surface is known and the angle from each of these points to a third is measured, then all the distances and all angles in the triangle formed by the three points can be calculated using trigonometry.

The job of the surveyor was to measure the distance along a baseline between the two initial points as accurately as possible and then to keep measuring angles using a theodolite so that all the distances could be calculated across a network of triangles on which maps could be based and accurate land surveys carried out. The points of the triangles had to be inter-visible and were therefore typically located on the tops of hills and mountains so that a whole country could be covered with the largest triangles possible. This 'primary' or 'principal' triangulation network could then be broken down into secondary and tertiary triangles, from which the maps could then be surveyed.

The distance and relative positions of the Paris and Greenwich observatories had been determined by triangulation in 1783, and this triangulation was extended across Great Britain by the Board of Ordnance, first to determine the size and location of Britain and its coasts, and then to help map the country at a scale of one inch to the mile. It had reached Scotland by 1820, from where the hills of Ireland could be observed across the Irish Sea. Lieutenant Colonel Thomas Colby, by then the Superintendent of the Trigonometrical Survey of the Board of Ordnance, had been tasked to carry out the Trigonometrical Survey of Ireland to be used to help apportion local taxes more equitably, requiring greater accuracy and "much greater dispatch to the work than has occurred in the Trigonometrical Survey of England".[2]

So, in 1824 Colby, accompanied by Lieutenant Thomas Drummond, had travelled Ireland from north to south, selecting the most suitable mountains for the Principal Triangulation stations and identifying a location for a new baseline on which the maps would be based. Visiting the plain along the shores of Lough Foyle he immediately saw its potential for a measurement that would require a "very delicate operation on which the credit of the whole survey would greatly depend".[3]

Baseline Measurements

Before the Survey of Ireland, baselines had been measured by a variety of methods using fixed length rods made of glass or wood or using a version of Gunter's 100-foot chain, made of 66 iron links. The first baseline in Britain was measured by William Roy in 1784 at Hounslow Heath, using a steel chain made by Jesse Ramsden, the celebrated instrument maker, for experimental purposes. It was then remeasured with three 20-foot deal rods, but it was found that their lengths varied depending on the temperature and humidity of the atmosphere, so it was remeasured using glass rods, but these were affected by flexing between the trestles supporting either end of each rod to such an extent that it created uncertainty in the length.

It was decided to remeasure the Hounslow Heath base at the start of the Principal Triangulation, using two new 100-foot steel chains made by Ramsden, the work carried out by Major Edward Williams and Lieutenant William Mudge in 1791. A second baseline was selected on Salisbury Plain to help verify the triangulation as it extended across the country west from Greenwich, also measured using Ramsden's steel chains, and the ends of both these bases were marked by iron cannons sunk into the earth.[4]

As the triangulation extended across the country, additional bases were measured using Ramsden's chains by Mudge at Misterton Carr (1801) and Rhuddlan Marsh (1806), and then by Colby at Belhevie Sands (1817).

Meanwhile, improvements to the method of measuring baselines using rods had been made in France by Jean Baptiste Delambre, Director of the Paris Observatory, and Pierre Mechain, a surveyor who had worked on the French side of the Paris – Greenwich triangulation.[5]

They had been tasked by the Paris Academy of Sciences to measure an arc of the meridian from Paris to Barcelona to determine the length of the metre, defined as one ten-millionth of the length of the meridian passing through Paris between the North Pole and the Equator. They measured their arc by triangulation from 1792 to 1799 with two baselines, one in the north of France, the other in the south, using four high-precision rods each twelve feet long and made of pure platinum, the newest and most expensive metal on earth, alongside a strip of copper so that the relative expansion of the two metals could be read with microscopic precision, and corrected to a standard length. Both bars were set in a wooden sleeve, and temperatures were measured along the length of the bars, so that their lengths could be corrected by a factor previously determined in laboratory tests.[6]

Their results, delayed by revolution in France, war with England, and affected by an error in the assumed size and shape of the Earth, led to the abandonment of chains for measuring baselines and a return to the idea that measuring baselines using rods was the best method.

Colby's Compensating Bars

At the start of the Irish Survey, Colby considered whether Ramsden's chains or French rods were best for his Irish baseline. The effect of temperature was of greatest concern: later experiments would show that a change of 1° Fahrenheit would alter the length of a 10-foot iron bar by 0.00783 inch,[7] a significant 1 foot over eight miles for every 4° change. The length of an Iron chain was also known to be affected by wear between the links. Although the French system clearly had merit, the rods were still expanding or contracting by differing amounts depending on the temperature, the material they were made of, their mass and the finish of their surface. Their lengths were even found to change by different amounts along their length. Colby consulted widely on the matter, including with his friend Charles Babbage, the mathematician, philosopher, and inventor of the first mechanical computer, and with "ardent zeal, and craving for improvement"[9] set his officers to the task of finding a solution. The winter of 1824-25 proved memorable for them as Thomas Drummond's quarters at Furnivall's Inn became a laboratory and workshop for developing a measuring apparatus that would address the problem. But it was Colby himself who came up with the solution.

One of his officers, J.E. Portlock describes how Colby grabbed his arm, saying *"Come my boy I have something to talk to you about"*[10] and practically ran him to his apartments at the Tower of London, where over dinner he outlined an idea for bars that self-compensated for changes in temperature. Colby's principle was based on the French bars and compensating mechanisms found in clocks and their pendulums. John Harrison, whose celebrated chronometer provided a reliable method for determining longitude at sea, had designed the gridiron pendulum for clocks which moved the centre of gravity of the pendulum as it expanded or contracted due to changes in temperature so that its length remained constant, and the clock kept regular time. Similarly, the Ellicott pendulum, made of two brass rods on either side of an iron rod which expanded or contracted at different rates, depressed or released levers that raised or lowered the pendulum bob, thus maintaining its length and its timekeeping.

Colby's approach also used two bars of different material – one of brass and the other one of iron - kept apart to avoid the effects of friction and fixed at the centre allowing the ends to expand and contract freely.

His innovation was at the ends of the bars, which were connected by a tongue or a lever that would move as the bars expanded or contracted by different amounts, rotating around a "compensation point", in such a way as to keep a constant distance from a similar compensating point on a lever at the other end of the bars.

Drummond, having spent so much time working on alternative solutions using Mica measuring rods, was somewhat put out by Colby's idea, and initially resisted it. But Colby and Portlock commissioned a model 3ft bar from Edward Troughton[11], the Cumberland born instrument maker, and tests on the model won Drummond over. There would later be some controversy, as to who in fact was the inventor of the bars, but this was ultimately addressed by attributing "to Colby the design, to Drummond the execution".[11]

Six pairs of bars were commissioned from Troughton, each one measuring 10 feet 1½ inch long, ½ inch broad, and 1½ inch deep. The iron and brass bars weighed 136 lbs and were placed 1¼ inches apart, on rollers inside a box constructed to protect them. Troughton was also asked to construct two standard bars, each made of iron 10 feet long, to be used to calibrate Colby's bars to a standard length at 62° Fahrenheit. These two standards were themselves extensively calibrated from ten other standard bars and used to determine the position of the compensation point – where the distance between the ends of the bars would remain constant.

Colby's theory could now be put to practical use on the Lough Foyle Base.

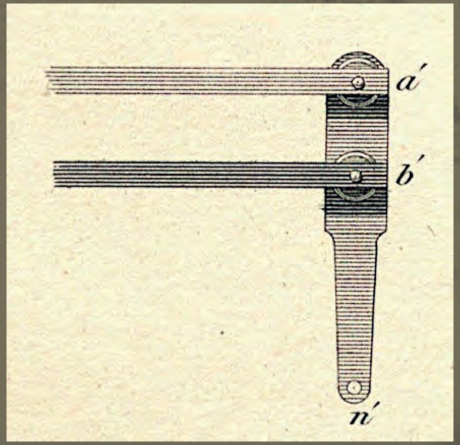

Fig 1. Compensation Tongue, attached to the ends of the brass bar (at a′) and iron bar (at b′) showing the compensation point n′.

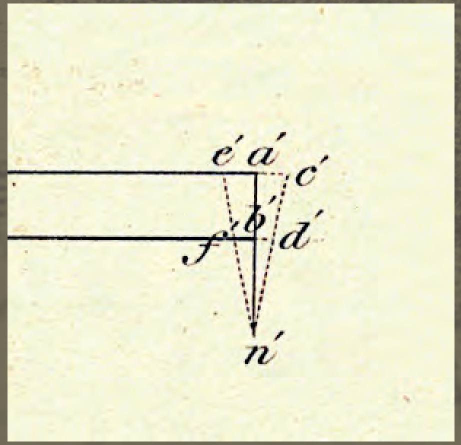

Fig 2. Depicting how compensation point n′ does not move when bar a′ and b′ expands or contracts.

Starting Work

The plain at Lough Foyle was ideal for the baseline, extending eight miles north to south and an average of 18 feet above sea level, surrounded by mountains on which the Principal Triangulation stations were located. But it was intersected by many hedges, walls and other obstacles, including the River Roe, all of which would have to be crossed, and the land was under cultivation too. The precise alignment of the line would depend on a detailed survey which the officers and sappers began in May 1825 and had finished by the end of January 1826.[12]

The original intention was to have measured the baseline in 1826, after the corn had been harvested, but "due to the present state of scientific information",[13] Colby wished to carry out experiments perfecting the means to do it and deferring the work until he had done so. The work was delayed further as Troughton perfected the manufacture of the compensating bars. But, by the summer of 1827, preliminary work could begin and on the 24th of June 1827 an encampment consisting of 27 Artillerymen, 25 Sappers, and three civilian labourers was established ".... by the side of Mr. Gage's park wall, near the Roe".[14]

Monumenting the Base

The first task was to establish where the line would run, and its start and end points. The northern end of the baseline was chosen first, with the southern and intermediate points established on an alignment, "..... almost rigorously directed on the trigonometrical station on Mullagh Clogher, or the Straw Mountain, one of the Sperrin Mountains, in the county of Tyrone, which is in sight from most parts of the line, at the distance of 27 miles from the North End of the base".[15]

Colby's desire for perfection extended to permanently marking the ends of the baseline, and unusual precautions were taken to ensure there was no risk to the points being lost or disturbed so that they would be available for reference in the future. Colby was taking no chances. The start and end points of the baseline, the North End and South End stations, were marked very precisely and permanently by a point marked with a needle in the end of a platina wire set in a lead filled hole 1 ½ inch in diameter and 6 inches deep bored into a large stone block cut from Dungiven sandstone, four foot square and 20 inches deep, laid on a cement bed over more stone blocks resting on a bed of masonry. During the measurement work the platina wire mark would have been exposed so that the instruments could be placed precisely over them. The stone block was encased in a masonry chamber which had a flagstone lid on which was marked a cross vertically above the dots in the platina wires. The design ensured stability, and much trouble was taken to ensure that each mark would be protected from accidental or malicious external disturbance, with an earth mound covering the chamber and surrounded by a circular two foot thick wall, 30 feet in diameter, topped with iron railings. The Board of Ordnance purchased the land to ensure it would remain protected.

A third mark, similarly monumented, was placed precisely along the alignment of the baseline approximately a third of the way along, just north of the River Roe, and called the Minearny Base. It was probably sited there simply because it provided a convenient point at which to pause the work during the coming winter months and it would form one end of a small 'comparative triangulation'

Fig 3. Ramsden's Board of Ordnance Great Theodolite used on the Principal Triangulation of Great Britain and Ireland, currently in the Science Museum, London.

scheme designed to verify the base once completed.

A fourth mark was similarly constructed at Mount Sandy, but has since been lost to coastal erosion. This point was established as an extension to the baseline, running almost along the same alignment to the north of the North End station. Its purpose was to form the other end of the small comparative triangulation scheme to help verify the baseline measurements and to improve the strength of the triangles connecting the baseline to the Principal Triangulation. The section between Mount Sandy and the North End station was not measured with Colby's bars as the ground between, situated on the edge of Benone Strand among the sand dunes, was too rugged and broken for the bars, and so the distance was calculated through the comparative triangulation.

Work on building and marking the stations at the North End, South End, Minearny and Mount Sandy stations was completed by the third week of August, allowing angle observations to be made to them by Portlock using Jesse Ramsden's Great Theodolite, an instrument with a three foot horizontal circle enabling very precise angles to be measured between the principal points of the triangulation, originally purchased by the Board of Ordnance for the Trigonometric Survey, and now in the Science Museum, London. These were observed from the top of Slieve Snaght in Donegal between August and September 1827 as part of the Principal Triangulation. Additional Trigonometric survey points were also established on Eskaheen Mountain, Cundtham and at Drung Point across Lough Foyle in Donegal, and at Artikelly and Gortmore to the east of the baseline. None of these points were permanently monumented.

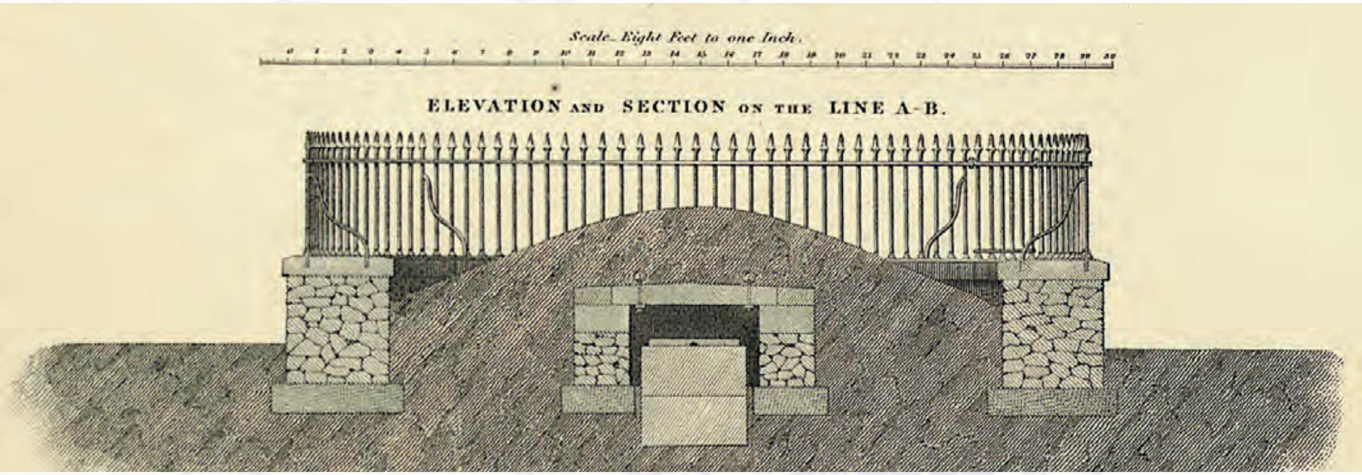

Fig 4. Section diagram showing construction of the base station.

Aligning Colby's Bars

A smaller 18-inch theodolite, also made by Ramsden, was placed over the North End Station and using either the South End station or the Minearny Station as a target (it is unclear which one, but the furthest point would have been the most accurate) the precise alignment of the baseline was set out by placing boards ¾ of a mile apart, alternating left and right, painted black and white, either side of the line, the inner edge of the boards providing the precise alignment. These were then used to place subsidiary boards 250 yards apart so that the telescopes on the compensation bars would keep the bars aligned between the stations when placed end to end along the line. The same theodolite was then used to set out pickets driven into the ground on which three legged wooden frames sat, one placed a quarter and another at three quarters of the length along each bar.

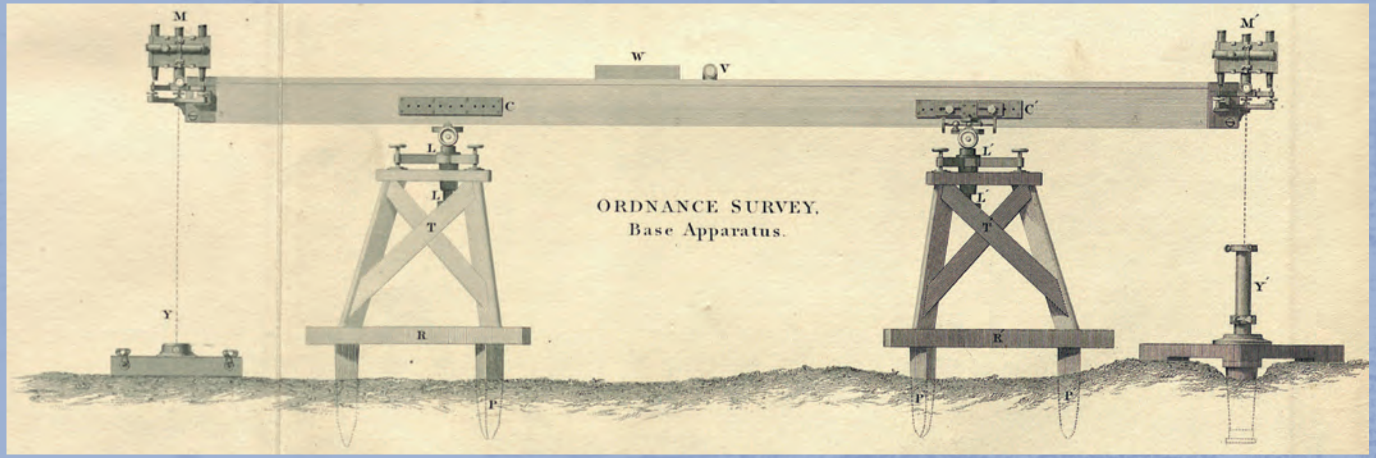

Fig 5. Colby's Base Apparatus. Diagram showing one of Colby's Bars, with pickets P; supporting three-legged wooden Trestle (T); Brass tripod (L); Point Carriers Y and Y'; and compensating microscopes, M and M'. V is a cross level, w a longitudinal level.

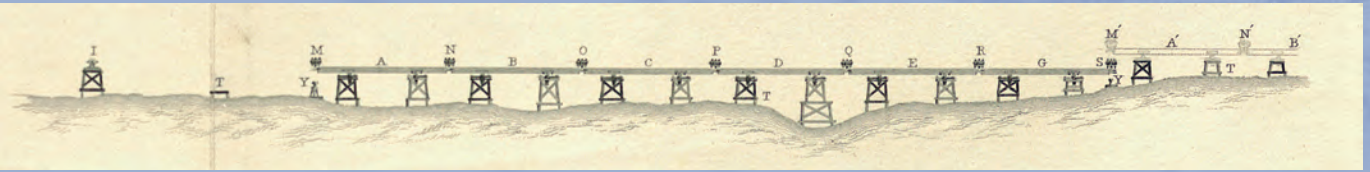

Fig 6. Showing the six bars (A B C D E G) laid end to end with trestles dealing with undulating terrain and stepped approach for slopes.

Measuring the Base

Each end of the compensation bar box was placed on a brass levelling tripod on top of the three-legged wooden frame of varying heights, to cope with the undulating terrain. The brass tripod had screws that allowed the bars to be raised or lowered vertically and for fine alignment of the box horizontally (longitudinally and transversely) and vertically (in elevation) so that they could be aligned and levelled. The start of the first bar was placed over the North End station mark, and carefully adjusted by viewing the platina wire mark through a telescope that pointed down, and its position adjusted using the brass tripod screws so that it was vertically over the mark. The far end of the bar would then be adjusted to align with the baseline, using the boards placed every 250 yards. A second bar was then placed in line precisely six inches from the first by careful observation and adjustment with a pair of compensating telescopes, designed and manufactured by Troughton specifically for this purpose.

Up to six sets of bars were laid and levelled end to end in this manner, along the line of the base. The end point of such a series of bars was transferred to the next series of bars via a "point carrier", laid on the ground beneath the end of the last bar in the series. The point carrier was a massive triangular cast iron plate, 15 ½ inches long on each side, with a short flat hollow tube of brass placed in the centre, enclosing a moveable disc with a fine point engraved on it, whose position could be adjusted by three screws set around the brass tube. The point carrier was viewed through the telescopic microscope at the end of the bar, pointing down, and the mark could then be adjusted to sit precisely under the end of the bar. This mark was then used as the starting point for the next series of compensation bars.

Work began on measuring from the North End station and moved steadily southwards. But the weather was already closing in, and in the early hours of 9th September a "very violent hurricane" blew away a tent and knocked one of Colby's bars to the ground. Fortunately, no damage to the bar occurred and as this was only two days into the measurement it was easily repeated and checked. However, steps were taken to protect and guard against this happening again. Captain Pringle writes to Colby,[16] who was based at the "Trig Survey Camp, Magilligan", on 13th September 1827, about the severe gales frequently expected in the area during autumn, and a requirement for extra guards at night to protect the equipment. From then on, the bars were removed each night and placed on "skidding" under two tents with a guard overnight. The first 400 feet had been remeasured as a check and found to agree within 'a small segment of a dot', confirming that Colby's bars and the methods employed were operating with the precision required. By the time the work stopped at the Minearny Station on the 25th October 1827, 13,250 feet (a third) of the baseline had been measured, taking 35 days including testing and remeasurements.

Fig 7. Mode of proceeding: Engraving of a sketch made by Sir John Herschel when visiting the baseline, showing the tents covering the compensating bars laid out for measurement.

Crossing the River Roe

Work resumed the following year, and on the 3rd July 1828, Pringle writes again from Magilligan Camp, "We have been examining the Roe and considering the easiest mode to measure across it. Driving piles appears on the whole the best, so I shall order piles, etc., from Derry. We are experimenting with a frame filled with sandbags, or stones …". Actual measurement of the baseline began again on the 7th July 1828 and progress was good. By the 16th July 1828 Pringle writes "We now hope to pass the Roe the end of this week. We have been pushing very hard to do so, commencing at 3 a.m., as the tides will answer best – being high water at mid-day…". This suggests that measurement was dependent on the tides, not surprising given that men would have to wade into the water during the crossing. But it is unclear whether it took place at high tide or low tide, and although low tide seems more sensible there is a note with the observations that the tongues of the bar were "eight inches above the water at high tide, not being spring tides". On the 18th July Lieutenant

Hastings Murphy R.E. writes to Colby at Magilligan Camp, "We are getting on famously, having last night reached the Roe; if this day were not so windy we should be across this evening. We have been at work 16 hours a day". The crossing of the Roe turned out to be more straightforward than expected. The bars were rested on trestles set on the piles driven into the bed of the river. Measurement was carried out twice; once on the 19th and 20th July, and verified by a repeat measurement on 21st and 22nd July, each a distance of 462 feet, the two measurements agreeing to within 1/37th of an inch.

Consideration had been given to buying up the crops so that measurement could continue while the weather was good, but this had been rejected as it would cause unnecessary damage, and so work was paused on 25th July until the crops had been harvested. The soldiers were then to be marched to Charlemont Fort barracks once the piles in the River had been removed,[17] but instead they were retained on half pay for six weeks until the work recommenced on 13th September. At one place along this final section of the line, on 13th October, the line passed close to the gable end of a mud cottage and a cut had to be made into the wall of the cottage so that it could continue. The measurement of the baseline was completed at the South End station by the 20th November 1828, a total of 60 days measuring the 30,533 feet of the second part of the line, an average of 509 feet a day.

Somehow, in between his responsibilities on the Trigonometric Survey, climbing mountains, securing and training men, and supervising the baseline, Colby had met his future wife. Five days after the work on measuring the baseline was completed, Colby married Elizabeth Hester Boyd, daughter of the late Archibald Boyd, Treasurer of the City of Londonderry, at the Cathedral Church Londonderry.[18]

Verification and Extension

The pursuit of accuracy and the avoidance of error was paramount and so the measurement of the base was verified in several ways. The first 400 feet were remeasured by the bars to confirm they were performing as expected and as a check of the point carrier system. Double measurements were made by different officers, such as that across the River Roe, providing an effective way to check that there was nothing immediately amiss. In one instance a remeasurement was made in the presence of Sir John Herschel, President of the Royal Astronomical Society and Charles Babbage, who "expressed themselves much pleased with the near coincidence of the two measurements."[19] Furthermore, certain sections were repeated if there was any doubt that a bar had been affected by some

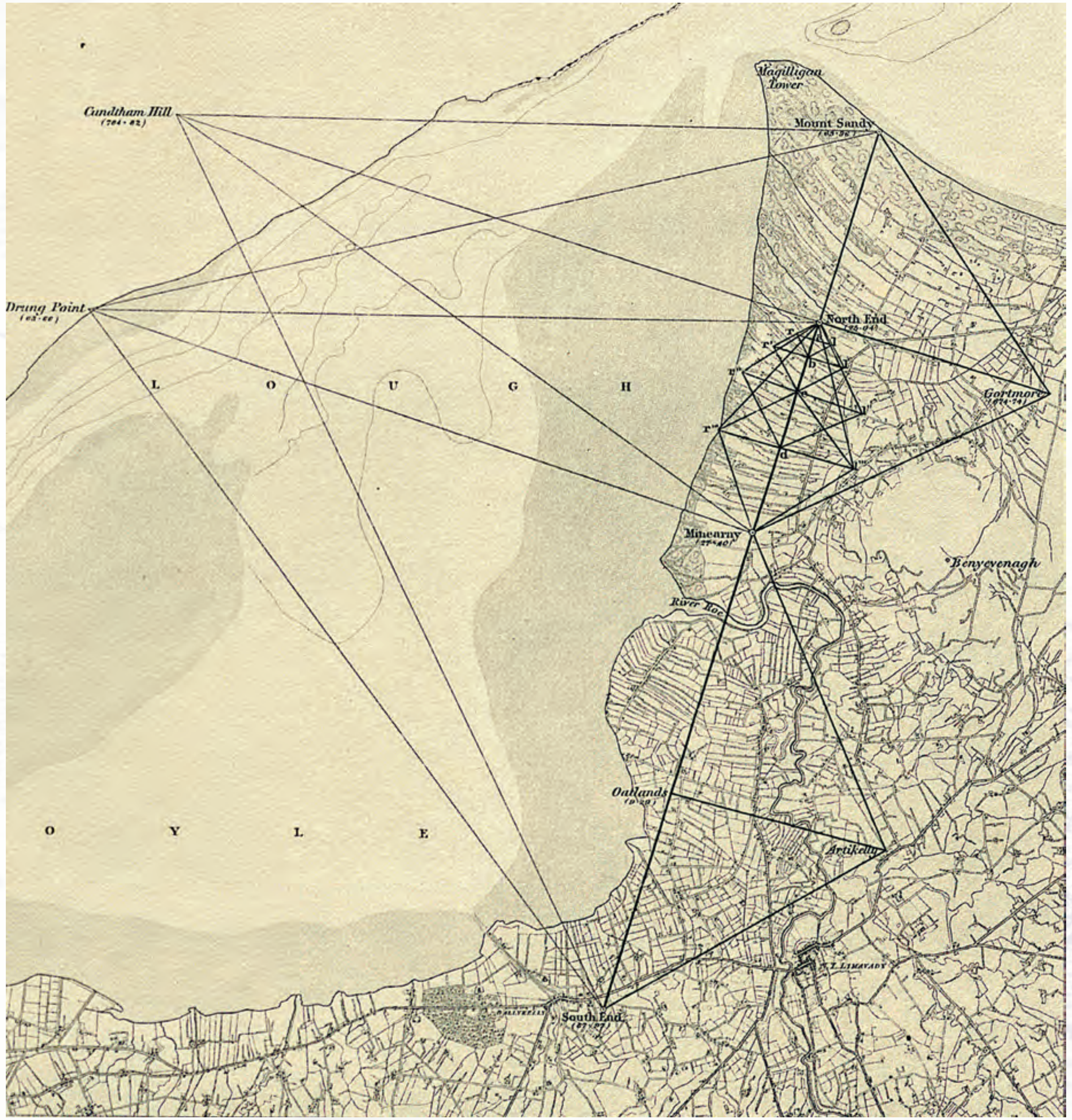

Fig 8. Plan of the Baseline near Lough Foyle showing the comparative triangulation scheme used to help verify the baseline, with intermediate points along the baseline at a-d and at Oatlands, and temporary stations either side of the line on the left at l′, l″, l‴ and right at r′, r″, and r‴.

problem, or that an actual or suspected error had occurred. For example, there were continuing problems with wind disturbing the bars, and on one occasion it was noted that strong sunshine had warmed one brass bar more than its iron bar, and so a remeasurement was required.

The measurement of the base was also verified by a small comparative triangulation scheme established in its immediate vicinity and observed by Drummond. During the first season (1827), a series of four intermediate points between the North End and Minearny Station were used for this purpose, along with a number of temporary points either side of the line. In the second season (1828), an intermediate point was placed at Oatlands, which along with temporary stations at Artikelly, and at Cundtham and Dung Point across the Lough, formed a verification triangulation on the southern part of the line. The scheme established allowed the baseline to be split into several sections so that one part of the base could be calculated through the triangulation from another part, and then compared to its distance as measured with the bars. This provided a crude check that a single bar had not been omitted from the measurement of any section, but also helped confirm the accuracy of the method used. For example, by this means the measured line from Oatlands to the South End station agreed by about an inch with that calculated from other parts of the line, and from Minearny to the South End station agreement was better than 0.005 inch.

In addition, the baseline was extended to Mount Sandy station, and a point at Gortmore was established for this purpose. The distance from the North End to Mount Sandy was then calculated through eight different triangles agreeing within a probable error of plus or minus 0.031 foot (less than 0.4 of an inch) over its accepted distance of 11,559.8270 feet.

Connection to the Triangulation

As the purpose of the baseline was to provide scale and distance for the whole triangulation scheme it was necessary to accurately connect the ends of it by angular observations to the Principal Triangulation stations at the distant mountain tops. The North End and South End of the baseline was connected to the stations on the Scottish mountains at Jura and Ben Tatrtevil (Islay), and the Irish mountains at Slieve Snaght, Sawel and Knocklayd. The additional point at Mount Sandy improved the conditioning of the triangles and was also included in these connections.

Another point had been established on Eskaheen Mountain in County Donegal to help in the connection to the Principal Triangulation, but the target pole erected for the purposes of observations from the baseline stations had been found to have been disturbed by a strong wind,

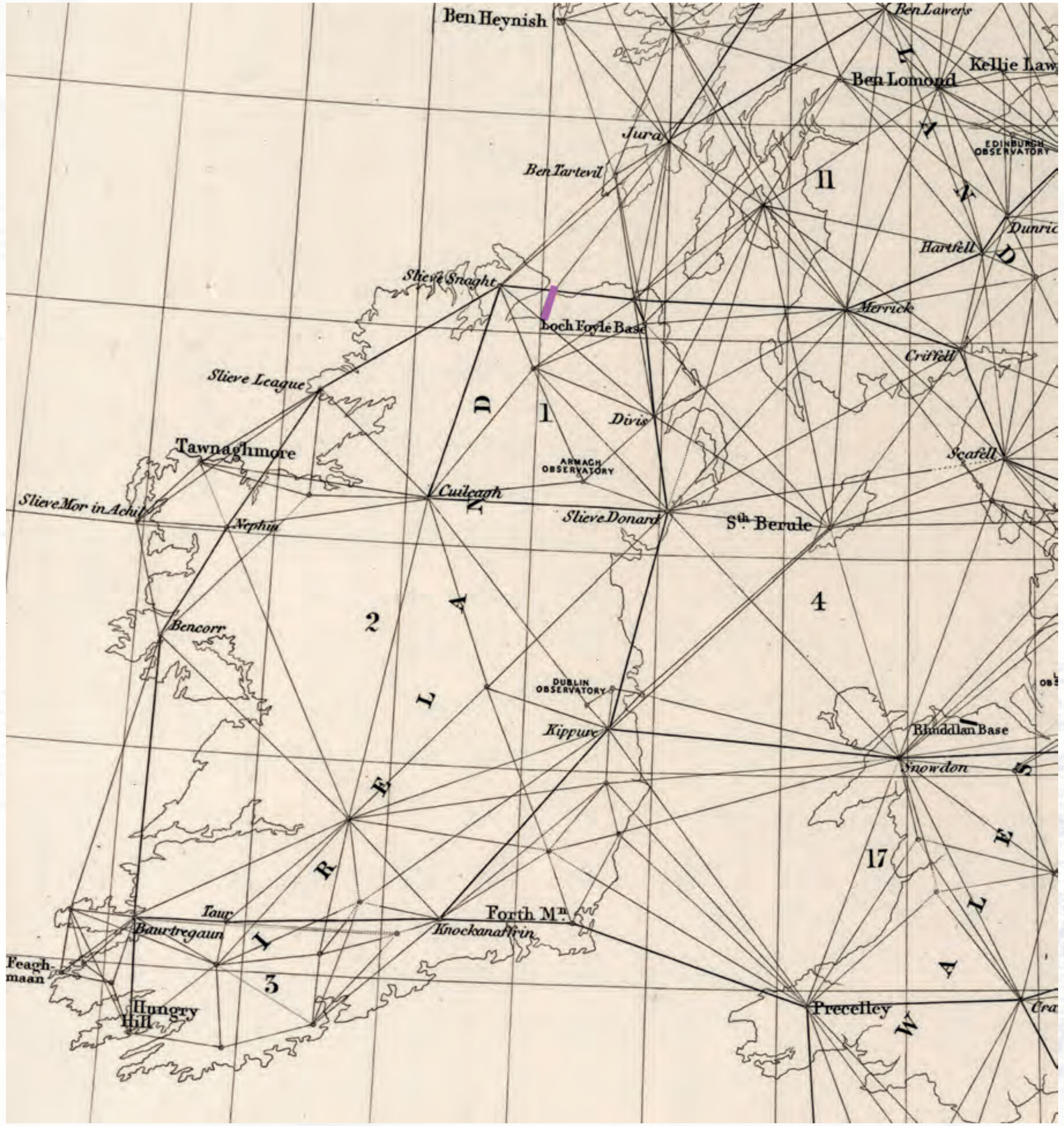

Figure 9. The Principal Triangulation of Ireland, showing the location of the baseline and its connections to Great Britain.

and while certain corrections were applied for the purposes of verifying the baseline, the observations were not suitable to use for a principal point in the final Account of the Principal Triangulation published in 1858.

The work in Ireland took time to organise and get underway, and Colby was under significant pressure to make progress, with criticisms and complaints about his methods even reaching the ears of Lord Wellington, who was by now Prime Minister.[20] Colby himself moved to Dublin in 1828 to take personal charge of the Survey of Ireland, and there was an urgency about the speed of the work. Whilst the baseline was complete, the angles of the triangulation were required so that all the observations were available to calculate the trigonometric distances for the interior survey to begin. Officers and men of the Survey camped out on the mountains, even during the winter months of 1827 and 1828, to get this work done.

Angles to the North and South End of the baseline, and the one established at Mount Sandy, had already been observed by Portlock between 24th August and 25th October 1827, using Ramsden's three-foot Great Theodolite. Once the distance measurements using the bars had been completed for the 1827 season, a two-foot theodolite was placed on the North End station in November 1827 and angles to the South End station, Sawel Mountain, Slieve Snaght, Cundtham, Drung Point, Mount Sandy and Magilligan Tower were observed by Lieutenants Henderson, Murphy and Mould, their observations completed by January 1828. The two-foot theodolite was again used to observe the angles from the South End station on completion of the measurement work there, between November 1828 and January 1829, observing the North End station and the stations on Slieve Snaght, Drung Point, Cundtham, Mount Sandy and Ballykelly church tower. Captain Pringle and Lieutenants Henderson, Murphy and Mould completed these observations. Observations were then made from Mount Sandy using the two-foot theodolite in June and July 1829 to the North and South Ends of the base, Drung Point and Cundtham, as well as Magilligan Fort and to Sawel Mountain, Slieve Snaght and Knocklayd in Ireland, and stations on the Western Isles of Jura and Islay (Ben Tartevil). The final observations involving the baseline were not made until 20 years later, in 1849, when Mount Sandy was observed from Jura using the three-foot Great Theodolite.

Results

The Lough Foyle baseline was measured as being 41,640.9228 feet long, after correction for expansion to the standard length of the Ordnance Bar O2 at a temperature 62° Fahrenheit. This distance had to be reduced to sea level for calculating the trigonometric distances through the triangulation for use in the Interior Survey. At that time the earth was assumed to be nearly a sphere coincident with sea level,[21] and so the measured length was reduced to sea level from the heights measured to the baseline stations. These had been obtained by observing vertical angles from the surrounding triangulation stations, including to a picket driven into the ground at low water mark near Drung Point in County Donegal.[22] It is important to realise that knowledge of the shape of the Earth and of sea level as a suitable reference surface for heights was limited at this stage, and the measurement of vertical angles to determine heights, were thought to be adequate for mapping purposes. However, the large variations in measurements caused by refraction and the approximate nature of sea level, whilst acceptable for mapping purposes, was found to create uncertain results. Elsewhere it was found that the height determined for one point using vertical angles from different triangulation stations, and from different reference sea levels around the coast did not agree. So, in the 1830s sea level was measured at 32 different locations around the coastline of Ireland to determine the best reference surface for height,[23] following which a single reference point was established at Poolbeg Lighthouse in Dublin. The points around the coast were then connected by spirit levelling across the island and a series of benchmarks cut into walls, bridges, and rock, leaving permanent reference points for future use. The Lough Foyle baseline was connected into this network, and heights levelled to the top of the sandstone blocks in which the platina wire mark had been embedded.[24] These new spirit levelled heights were used in Captain Yolland's 1847 Account to reduce the measured baseline to sea level, by 0.03555 feet to 41,640.8873 feet.

No astronomical observations were made at any station connected with the baseline at the time of the measurements in 1827 – 1828. Instead, meridional bearings were calculated from astronomical observations made at Dublin Observatory and used with the baseline distance to establish the positions of the triangulation stations used to control the interior survey. By 1843 observations for the determination of astronomical latitude of the station at the South End were made using the Airy Zenith Sector, but these were thought to be affected by significant local gravitational attraction from the nearby mountains, and its observed position differed significantly from its position calculated through the triangulation.

Salisbury Plain Remeasurement

Following the completion of the Irish Survey, work resumed in England and Scotland and Colby's Compensation bars were used in 1849 to remeasure the Salisbury Plain baseline in England. The original measurement had been found to be inaccurate when compared to the distance calculated through the Principal Triangulation from Lough Foyle. The remeasurement was carried out under the direction of Captain Yolland, and the work carried out by Sergeant Steel and a party of Sappers and Miners. The only change from the techniques used in Ireland was to increase the number of comparisons undertaken to calibrate the six-inch gap between the bars. The guns marking the ends of the baseline were found to be intact, but the North End, three miles west of Aylesbury on Beacon Hill, and the South End, 1 ½ miles from Salisbury near Old Sarum Castle, were not intervisible, therefore a theodolite at the South End had to be elevated on a tower above the mark to keep the bars aligned. The 11-degree slope at the North End also proved a challenge, but nevertheless the baseline was remeasured satisfactorily and found to be 36,577.8581 feet when reduced to mean sea level (a reduction of -0.6294 feet). The length of the remeasured Salisbury Plain baseline was then recalculated from Lough Foyle and found to differ by 0.3193 feet (3.83 inches). It is reported that the stations marking the ends of the Salisbury Plain baseline are still there, although the one at the south end of the line is buried in undergrowth and the northern one had a triangulation pillar built over it in 1936.[27] The other four baselines measured with Ramsden's 100-foot steel chain were used to verify the distances calculated from Lough Foyle, and with the greatest difference between computed lengths and measured lengths of just three inches, these provided the verification required. Their end points were marked by wooden blocks, long since gone.

Colby was too busy progressing the maps of Ireland to write up the results of his work at the time, and Drummond was called away from Ordnance Survey work early after falling out with Colby in the 1830s, to undertake political duties – he later became Chief Secretary of Ireland, and his statue stands in Dublin City Hall. Murphy, also active in the base measurement, was called to lead the scientific operation of the Euphrates Expedition, and so it was not for another 20 years, in 1847, that an account of the measurement of the base was written by Captain Yolland. Although he was not present at the time of the original measurement he relied on Colby and Drummond's recollections for his account and had overseen the use of the bars at Salisbury Plain. Colby was not a man to boast of his achievements, but the work had been witnessed and recorded by many eminent scientists and surveyors, and word of its achievements spread widely and quickly. Sir George Everest had heard of it whilst recovering from illness in England and ordered the same bars from Troughton and Sims for use on the Great Trigonometrical Survey of India, measuring a baseline near Calcutta. Colby's bars were also sent to South Africa in 1839 where they were used by the Astronomer at Cape Town, Thomas Maclear, for the first baseline measured in Africa, and Captain Henderson, who had been employed on the Lough Foyle Base under Colby, observed the actual measurement there. The bars themselves made their way back to Southampton, where the Ordnance Survey had moved in 1841, and ultimately one was returned to Phoenix Park following a request by the Free State Government in November 1923,[25] where it still resides. Another bar, on loan from the Greenwich Museum, London, is on display at the Tower Museum in Derry.

1858 Calculations

Observations of the Principal Triangulation covering Ireland was completed by August 1832, and by 1858 the rest of the Principal Triangulation had been completed and a detailed account of the observations and calculations used in the whole network published.[26] The two baselines at Lough Foyle (7.89 miles) and Salisbury Plain (6.93 miles) were used to calculate all trigonometrical distances. The difference between the measured lengths and their lengths computed through the triangulation is given as +/- 0.4178 feet, or about five inches. This difference was divided in proportion to the square root of the lengths of the measured bases, from which was obtained the mean base used in the triangulation; with a probable error of +/- 0.2 feet, or 2 ½ inches.

1960 Remeasurement

In 1952 a new triangulation was observed in Northern Ireland and connected to the recently completed retriangulation in Great Britain with connections across the border to a planned new scheme in the Republic of Ireland. It was not thought necessary to remeasure Colby's Lough Foyle baseline, and instead, the positions of four of the original Principal Triangulation stations (at Knocklayd, Trostan, Divis and Slieve Donard) were kept at those calculated in 1858, thus the maps, distances and scale continued to be based on the original measurement of the Lough Foyle baseline. The development of microwave electronic distance measurement equipment after the Second World War allowed Colby's Lough Foyle baseline to be remeasured in 1960 and it was found to be 0.024 metres (less than 1 inch) longer than Colby's measurement, confirming the original measurement as a truly outstanding achievement.[28]

Conclusion

Today the three monuments protecting the South End, North End and Minearny Base stations on the plain by Lough Foyle stand testament to a remarkable achievement. Not many who come across these monuments fully realise their purpose, their significance to the maps of Ireland, or appreciate the history behind their development. Nor is it obvious how they have contributed to the development of the work of the Ordnance Survey in Ireland and beyond, particularly in this age of satellite GPS and phone-based mapping technology, recent innovations that have profoundly affected the way in which maps are surveyed, presented and used.

The baseline marked out by the three monuments achieved a level of accuracy that was truly remarkable for its day, contributing to science and to an understanding of the world around us. It is an achievement that is even more noteworthy when considering the ingenuity of the concept behind the compensation mechanism, turning that idea into a design that worked, and the manufacture of the bars and their associated instrumentation. Along with the method of execution on the ground, designed to overcome man's inherent biases and follies,[29] the logistics and organisation of the whole operation and the sheer persistence and perseverance of the men involved to achieve the results they did was truly exceptional.

The Lough Foyle baseline was the basis for calculation of all trigonometrical distances across the islands of Ireland and Britain, and beyond. Its distance was used by Sir George Airy, the Astronomer Royal, to help determine the size and shape of the Earth, a Figure of the Earth that was refined by Alexander Ross Clarke, and is still in use in many countries. The baseline has stood the test of time, and although it is no longer necessary for the maps of Ireland, it was only replaced in 1995 by satellite derived measurements.[30]

There are few surviving baselines around the world. Similar monuments in India are crumbling, the material remains of an Imperial past, a sort of archaeology of Colonial Cartography.[32] In Ireland, sharing a similar imperial history, they are listed as "Special buildings of local significance", thus protected, seen to have community and tourism value, recognising their uniqueness in the heritage landscape. In so many ways the whole exercise that produced them epitomises the Imperial era of scientific discovery and innovation, and like all great achievements have stood the test of time.

The three monuments still stand silently there in a line under the cliffs of Binevenagh Mountain: but today they are monuments to a different era, silent witnesses to times past.

Minearny Base station today under Binevenagh Cliffs.
Photo by M.J. Cory

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This paper is based on several sources:

- *"Memoir of the Life of Major-General Colby"* by Lt. Col. J.E. Portlock, Seeley, Jackson & Halliday 1869;
- *"An Account of the Measurement of Lough Foyle Base with its verification and extension by Triangulation"*, by Captain William Yolland, Board of Ordnance, 1847;
- *"Account of the Observations and Calculation of the Principal Triangulation"* (and of the Figure, Dimensions and mean specific gravity of the Earth as derived therefrom)", drawn up by Captain Alexander Ross Clarke RE FRAS under the direction of Lt Colonel H James, RE FRS MRIA &c., Superintendent of the Ordnance Survey. Published by George Edward Syre and William Spottiswoode, 1858;
- *"Early Years of the Ordnance Survey"* Colonel Sir Charles Close, Institution of Royal Engineers, 1926;
- Some additional sources which are mentioned in the text.

Note: NAI means National Archives Ireland, and PRONI, means Public Record Office Northern Ireland.

Footnotes

[1] Lt. Col. Colby's report to Sir Henry Hardinge KCB, Clerk to the Ordnance, 2nd February 1826, "Report to Sir Henry Hardinge KCB on the Present State and Progress of the Irish Survey" NAI, OS/1/1.

[2] Report of the Select Committee of the House of Commons into a Survey and Valuation of Ireland, Chaired by Mr. Spring-Rice, 1824.

[3] Colby's first report to Sir Henry Hardinge, January 1826; NAI/OS/1/1.

[4] General Roy's Hounslow Heath Base was marked by partially buried 32 pound cannons, one at each end when it was remeasured in 1791. Work on the runways of the future Heathrow Airport required that one to be moved to outside the temporary headquarters of Ordnance Survey in Chessington in 1944. When Ordnance Survey Great Britain moved to its new headquarters at Southampton in 1968, the cannon was returned to its original location where it remains on permanent dispalay. [Source: "Ordnance Survey Map Makers to Britain since 1791" Tim Owen and elaine Pilbeam, HMSO 1992.

[5] "The cadastral mapping system of Bukovina: from emergence to GIS integration" Alexandru Ionuț Cristea Stefan cel Mare University of Suceava.

[6] "The Measure of All Things: The Seven-Year Odyssey and Hidden Error That Transformed the World", Ken Alder, Free Press, 2003.

[7] As reported in Yolland's Account.

[8] Portlock, page 267.

[9] Portlock, page 269.

[10] Edward Troughton was based at 13b Fleet Street London and was known for manufacturing a range of astronomical surveying and navigation instruments. This included the Troughton Equatorial Telescope in 1795, a 2-inch aperture refractor telescope mounted equatorially, and still to be found at Armagh Observatory. He went on to establish Troughton & Simms Ltd, the famous manufacturer of survey, navigation, and scientific instruments, which remained in business until it finally closed in 1966.

[11] Noted by John Andrews in his book "A Paper Landscape", Oxford University Press, 1975.

[12] Ordnance Survey Progress Reports and Returns, return by Captain M.A.Waters RE, January 1826; NAI, OS/1/1.

[13] Colby's first report to Sir Henry Hardinge.

[14] Letter from Drummond's papers quoted by Close, page 115.

[15] Yolland's Account, page 29.

[16] Close, page 116.

[17] Letter 26th July 1828 from Captain Pringle, quoted in Close p117.

[18] The Belfast Newsletter, 2 December 1828.

[19] Yolland, page 28.

[20] Wellington wrote to Lord Anglesey on 30th March 1828, instigating an inquiry into progress of the Survey, and this ultimately led to Colby being sent to Ireland to personally oversee the work there. PRONI record.

[21] Although evidence was available that it was an oblate spheroid – that is a sphere flattened at the poles – the amount of 'flattening' had not been determined and was not thought to be material enough to affect the accuracy of mapping.

[22] Appendix XI of Yolland's Account includes these measurements taken between 1827 and 1829.

[23] "On the Laws of the Tides on the Coast of Ireland…." G.B. Airy, Astronomer Royal "Philosophical Transactions" 1844.

[24] Later levelling would leave a benchmark on the exterior circular wall of the baseline stations.

[25] NAI, TAOIS/S 5043A.

[26] "Account of the observations and calculations of the principal triangulation, and of the figure, dimensions and mean specific gravity of the earth derived therefrom." Clarke, A.R., Officer in Charge of the Trigonometrical and Levelling Department of Ordnance Survey. Eyre and Spottiswoode, London, 1858.

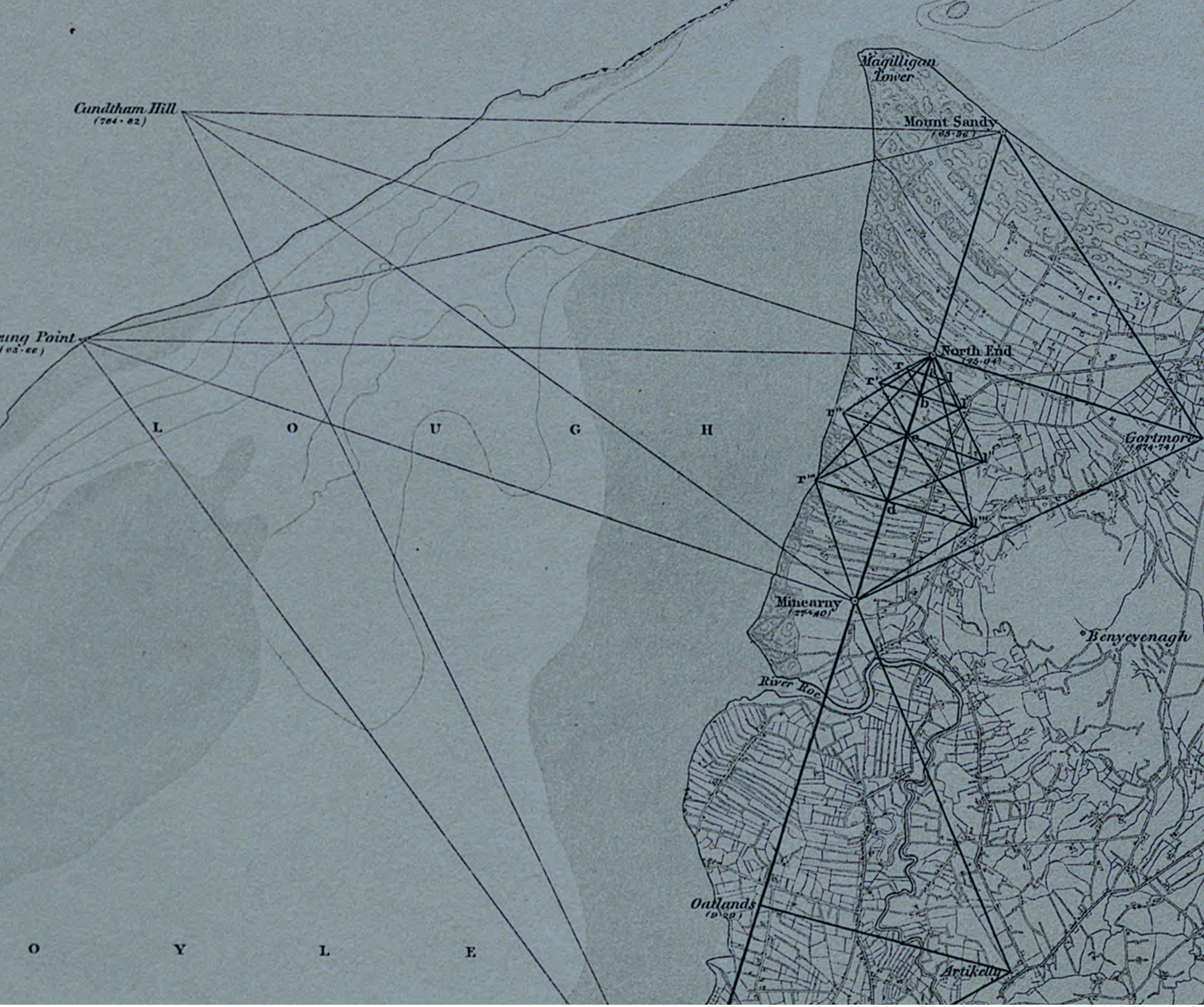
[27] See www.trigpointing.uk website: accessed December 2022.

[28] Chapter III The re-measurement of the Loch Foyle Base Line" in "An outline of the re-triangulation of Northern Ireland" Lt. Col. W.R. Taylor, HM Stationery Office, 1967.

[29] "Beyond Measure: The Hidden History of Measurement from Cubits to Quantum Constants", by James Vincent; Faber, 2022.

[30] "Remeasuring the Size of Ireland" M J Cory, Irish Scientist Yearbook, 1997; and "GPS Compatible Positioning in Ireland" M J Cory, I C Greenway and C J Hill, Survey Review, Pt 1 October 2003 and Pt 2 January 2004.

[31] "Surveying Empires: Archaeology of Colonial Cartography and the Great Trigonometrical Survey of India." Keith D. Lilley, 2020.



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