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“Balta Sound and the figure of the
earth”

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Balta Sound and the figure of the earth

David L Walker

Introduction

In 1816, Francois Arago, on behalf of the French Academie des Sciences and Bureau des Longitudes, approached William Mudge, Superintendent of the Ordnance Survey, proposing a joint operation to improve the measurement of the shape or figure of the earth. Arago wished to extend into Britain the arc of meridian already measured by the French. This was welcomed by Mudge as an opportunity to compare their instruments, and by the Royal Society as an exercise in scientific collaboration. But in 1817 the disagreement that arose in the Shetlands between Arago's emissary, Jean-Baptiste Biot, and Mudge's chief assistant, Thomas Colby, frustrated the prospect of useful comparisons.¹ It was left to the local laird, Thomas Edmondston, to support observations at his house of Bunes, overlooking Balta Sound, by Biot in 1817 and by Henry Kater in 1818, both commemorated on this memorial stone at Bunes.



**TO THIS STONE
were attached the CLOCK and
PENDULUM employed by the
celebrated French Philosopher
BIOT**

**and on the one on which it rests
stood his repeating circle
The distinguished English
Philosopher
KATER
placed his
repeating circle
on this stone
also**

**The former was sent by the
Institute of France in the summer
of 1817 and the latter by the Royal
Society of London in the summer
of 1818 to determine by their
experiments & observations**

**The figure of the Earth
These memorials remain as pleasing
and lasting remembrance of the
splendid talents, great worth and
amiable manners of these eminent
men by
their friend
THOMAS EDMONDSTON
21 October 1818**

¹ JE Portlock, Lt-Col RE, *Memoir of the Life of Major-General Colby*, London, 1869, 69-85.

In the ‘official’ histories, Seymour et al² refer only briefly to the quarrel between Biot and Colby; Owen and Pilbeam³ focus on William Mudge’s mortification that their observations came to be made from different places; and Charles Close⁴ suggests that the operations ‘must not be looked upon as wasted, but as somewhat injured by the want of co-operation.’ However, Rachel Hewitt⁵ adds to Portlock’s memoir to provide a vivid and well-referenced account of the unfortunate affair, which this article supplements from sources including Admiralty records, Biot’s papers and very kind advice from Mr and Mrs David Edmondston of Bunes.

This article illustrates the very different talents and temperaments of Biot and Colby, while leaving the reader to judge the reasons for their disagreement, and it goes on to describe Kater’s pendulum observations at Bunes, those by Sabine, and their analysis by Professor George Airy. Although less conclusive than the geodetic evidence, this provided a stimulus for his determination of the figure of the earth in 1830 that endured as the basis for the Ordnance Survey’s principal triangulation, for its retriangulation and for the present-day National Grid.

Monsieur Biot’s welcome in Britain

At the time Jean-Baptiste Biot arrived in Dover in May 1817, the Ordnance Survey was interested in the figure of the earth in order to translate its trigonometrical survey into latitude and longitude; the French were also concerned with refining their definition of the metre (one ten millionth of a quadrant of the earth); and pure scientists wished to develop their knowledge of geodesy. Having agreed that the figure of the earth could be regarded as an oblate spheroid ie one having equatorial axes greater than the polar axis, they sought to refine these parameters by surface trigonometry and/or by measuring the increase in the length of a pendulum of constant period as gravitational force increased with latitude, the techniques being combined with the measurement of latitude by stellar observations.

Already well-respected as a scientist (and a Fellow of the Royal Society), Biot nevertheless felt flattered to be provided with an escort through the customs at Dover, and to be received in London by ‘ce vénérable compagnon de Cook’,⁶ Sir Joseph Banks, the President of the Royal Society.

From London, Biot with William Mudge travelled by coach to Edinburgh, where Mudge boldly published their objectives in *Blackwoods Magazine*.⁷ From measurements of the frequency of a pendulum, he reported, Monsieur Biot had

² WA Seymour (ed), *A history of the Ordnance Survey*, Folkestone: Dawson, 1980, 30.

³ Tim Owen and Elaine Pilbeam, *Ordnance Survey: mapmakers to Britain since 1791*, HMSO, 1992, 24-25.

⁴ Sir Charles Close, *The early years of the Ordnance Survey, 1926*, republished with an introduction by JB Harley, Newton Abbot: David & Charles, 1969, 68.

⁵ Rachel Hewitt, *Map of a Nation*, Granta Books, 2010 (and Granta paperback 2011), 226-233.

⁶ MM Biot et Arago, *Recueil d’observations géodésiques, astronomiques et physiques*, Paris, 1821, 528.

⁷ ‘Communication from Col. Mudge’, *Blackwood’s Edinburgh Magazine*, vol 1, June 1817, 234-235.

estimated the force of gravity⁸ at points close to the measured meridian extending from Formentera in the Balearic Islands to Dunkirk. By extending this arc through Britain to triangulate 22 degrees of latitude, the grand design was to agree an international measure of length directly related to the circumference of the earth. Biot had by then established his pendulum at Leith Fort, and Mudge's intention at that time was that, after collecting the Ordnance Survey's zenith sector from Inverness, they would together make pendulum measurements and stellar observations at Kirkwall and then at Great Yarmouth (near to the Dunkirk meridian), at Blackdown in Dorset, and at the Royal Greenwich Observatory.

But while Biot was honoured in Edinburgh, and well supported by the Royal Engineers in making a series of pendulum observations at Leith Fort between 15 June and 2 July,⁹ Mudge to his chagrin fell ill, and had to entrust the expedition to Thomas Colby, who by then had extended the trigonometrical survey of Britain as far north as the Moray Firth,¹⁰ and had been measuring a new baseline at Belhelvie in Aberdeenshire. As Colby had set his sights on the Shetlands rather than the Orkneys, it was agreed that Colby, with Dr Olinthus Gregory from the Royal Military Academy and the Ordnance Survey surveyor James Gardner, should take the zenith sector to the Shetlands to observe for latitude; and that Biot supported by Mudge's son Richard should observe latitude with the French repeating instrument¹¹ from the same station, where he would also continue his pendulum observations for the measurement of gravity; and that the British triangulation would be extended to the Shetlands via the Orkneys and the convenient 'stepping stones' of Fair Isle and Foula.¹²

On their way north from Edinburgh, Biot was honoured further in Aberdeen where he discussed Professor Copland's collection of astronomical instruments and (with Colby) was made an honorary LL.D (in absentia on 4 September).¹³ Then from Aberdeen on 9 July Biot, with Colby, Richard Mudge and Gregory, boarded the survey brig *Investigator*, which had embarked Gardner, seventeen artillerymen and the 36-inch theodolite at Dundee.

⁸ Clairaut's theorem in 1743 had defined a relationship between the increase in gravitational force with latitude and the ellipticity or flattening of the earth. The relative increase in gravitational force could be measured in proportion to the increase in length of a pendulum beating seconds precisely. However variations in the length of the seconds pendulum were rarely measured directly, but derived in proportion to the square of the measured frequency of a calibrated pendulum.

⁹ *Recueil d'observations*, 528, 541, 543, 556 and 560.

¹⁰ David L Walker, 'The initial triangulation of Scotland', *Sheetlines* 98, 5-15.

¹¹ By cumulating repeated measurements of the same angle, the French repeating circle was intended to average out errors of observation. It was used in the horizontal plane for triangulation, like Ramsden's theodolite, and in the vertical plane for stellar observations, like Ramsden's zenith sector.

¹² Sir Charles Close, *The early years of the Ordnance Survey*, 67 and *Recueil d'observations*, 529.

¹³ JS Reid, 'Patrick Copland 1748-1822: connections outside the college courtyard', *Aberdeen Univ Review*, no 174, autumn 1985, 226-250.

The Shetlands voyage of HM brig Investigator

Investigator was a 16-gun survey brig launched in 1811, of external dimensions 76 feet length and 19 feet beam,¹⁴ and about half the tonnage of Darwin's better-known brig *Beagle*. Under her master and commander, George Thomas, *Investigator's* normal complement of six petty officers and 25 seamen and boys had already been augmented by a second master, a surveyor and a pilot.¹⁵ Now they also had to make room for the five gentlemen and 18 artillerymen. Whether the gentlemen displaced the commander from his cabin, or the petty officers from the gunroom, Captains Colby and Mudge, Dr Gregory, M Biot and Mr Gardner had to share, day and night, a cabin which was no more than 16 feet (5 metres) square – and twenty-five seamen had to make room for eighteen artillerymen as well as the displaced petty officers. To make matters worse, a voyage that might have been completed in a few days was extended to ten days by light airs and adverse winds. The circumstances were enough to test even travellers of an equable temperament – which these gentlemen definitely were not.

Colby was regarded as a demanding companion even by his friends,¹⁶ and he remembered Biot as a collaborator with Don Rodriguez, who had challenged the accuracy of the Ordnance Survey arc from the Isle of Wight to Yorkshire.¹⁷ Gregory wrote religious tracts as well as mathematical tracts, whereas Biot, an even more distinguished scientist, was regarded as a free-thinker. In later years, Gregory wrote¹⁸ of Biot that 'I do not hesitate to say that I never met so strange a compound of vanity, impetuosity, fickleness, and natural partiality, as is exhibited in his character.' Biot in his journal of the expedition chose not even to mention either Colby or Gregory, although he wrote kindly of William Mudge and his son Richard. But Richard Mudge was junior to Colby in service and experience, and proved incapable of keeping the peace as his father had intended.

After landing an advance party at the south end of the main island on 17 July, *Investigator* anchored at Lerwick on 18 July, when Colby and Biot took up the introduction to Dr Arthur Edmondston received in Edinburgh.¹⁹ Biot would have liked to base himself there at Fort Charlotte in Lerwick but found himself bound north in thick fog to Unst, where the party went ashore at Balta Sound on 22 July.

Here it was that Biot and Colby unfortunately established separate observing stations at the house of Bunes and on the island of Balta. According to Portlock's translation of Biot's account, the artillerymen found themselves unable to establish a station on the most northern hill (presumably Saxavord) and selected the island of Balta instead. Biot at first concurred, but then felt that his operations

¹⁴ James J Colledge, *Ships of the Royal Navy*, London, 1970.

¹⁵ *Ship's Muster, Investigator, 1815-1819*, The National Archives, ADM 37/5976.

¹⁶ JE Portlock, *Memoir of the Life of Major-General Colby*, 8.

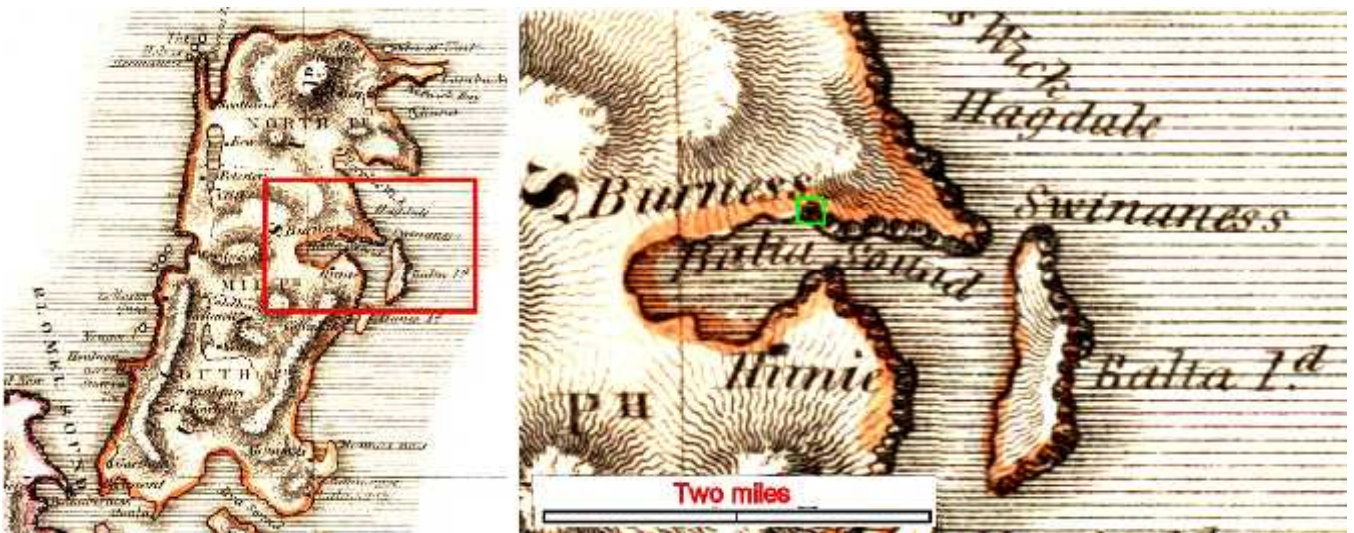
¹⁷ Don Joseph Rodriguez, 'Observations on the Measurement of an Arc of the Meridian etc in the Years 1800, 1801 and 1802', *Phil Trans R Soc. Lond*, 1812, vol 102. Philosophical Transactions of the Royal Society pre-1887 at <http://rstl.royalsocietypublishing.org/content/by/year>

¹⁸ Biography of Jean Baptiste Biot, MacTutor History of Mathematics archive, www-history.mcs.st-andrews.ac.uk

¹⁹ *Recueil d'observations*, 531.

would be endangered by the exposure, the remoteness, and a lack of solid foundations. So, with Mudge, he took up the hospitality offered at Bunes by Thomas Edmondston (the brother of Dr Arthur Edmondston whom they had met in Lerwick).²⁰

So were the concerns recorded by Biot sufficient reason for the breakdown of relations between Colby and Biot, and could they not have found a reasonable compromise? The *Investigator's* logbook shows that the separation took place very hastily. After anchoring in a fresh gale on Tuesday 22 July, 'the surveyors' were landed for the first time – apparently to reconnoitre Unst. On the following day the wind dropped and 'the ship's company were employed disembarking surveyors' instruments and luggage' – presumably on Balta Island. Significantly, on Thursday afternoon, only 48 hours after their arrival in Balta Sound, they were employed 'landing M Biot's instruments etc from Balta Island to Unst.'²¹



*Unst, northern isle of Shetlands, with Balta Sound and Bunes (misspelled) inset
From John Tomson's map of 1827 by permission of National Library of Scotland*

Colby's achievements in the Shetlands

As the zenith sector had not (as intended) been collected from Fort George on the voyage north, Colby in *Investigator* sailed for the garrison on 1 August, taking only two artillerymen with him, and leaving the rest marooned on Balta with Gregory and Gardner. The voyage south took four days, landing to set up station staffs on the Outer Skerries and Fair Isle. After two days at Fort George, loading instruments and stores, the return north, unlike the previous voyage, was completed in two days. On the next day, *Investigator* 'at 10 received on board as a prisoner for Captain Colby Bartholomew Stonecliffe Bombardier'. For an unexplained offence, the RA corporal, who had been with Colby to Fort George, was imprisoned for seven nights. This hardly could have improved the morale of the artillerymen.²²

²⁰ *Memoir of the Life of Major-General Colby*, 77-79, translates *Recueil d'observations*, 531-532.

²¹ *Captain's Log, Investigator, 1811-1819*, The National Archives, ADM 51/2474, July 1817.

²² *Captain's Log, Investigator*, August 1817 and *Ship's Muster, Investigator, 1815-1819*.

Hindered by the excursion to Fort George, and perhaps the weather, it was not until 10 August that Colby and Gardner employed the 36-inch theodolite sited on Balta to commence observations of stations on Yell, Fetlar and Saxavord (the northernmost hill of Unst) and for one day only, on 28 August, Gardner made observations from Saxavord.²³ But it was not until 14 August that a party of men was sent in the cutter to erect a station staff on Fetlar and not until 27 August that *Investigator* journeyed to Yell Sound for her men to place a staff on Ronas, the highest hill in the Shetlands.²⁴ After this, Colby apparently achieved nothing further before choosing to depart from Balta on 9 September 1817, perhaps exasperated by unsuitable conditions for observing, and his observations on Balta remained unpublished for decades.

On 12 August William Mudge had written²⁵ to Colby expressing his dismay that a comparison could not be made between stellar observations made using the British zenith sector and the French repeating circle and tactfully enquiring as to progress with observations from Fair Isle and Foula. However this intended link with mainland Scotland was not achieved until 1822, when Colby returned on the survey brig *Protector*. Sailing from Leith on 28 April, the party landed at Fair Isle on 17 May, but *Protector* had to return to Leith to rectify some problem. Unfortunately, Fair Isle failed to live up to its name in June and Foula did live up to its name in July, and so it was not until August 1822 that Colby was able to complete sufficient observations in the Shetlands. In September he left Vetch and Drummond in the Orkneys to complete the link with the triangulation which had reached that far in 1819.²⁶

Biot and the Edmondstons

Reverting to 1817, while Colby was off to Fort George, Biot had settled at Bunes, had started his astronomical observations on 2 August, and on 10 August commenced his pendulum observations within the massive walls of an empty sheep-house.²⁷ By 17 August, assisted by Richard Mudge, he had completed eight days of pendulum observations and 270 astronomical sights. But Mudge's health was suffering, which Biot sympathetically attributed to the climate – particularly the cold wind from Spitzbergen. However, on 14 August 'arrived a Greenland ship from Greenland bound for Aberdeen' and when on 17 August *Investigator* 'observed the Greenland ship making signal for sea' the decision was made and 'embarked on board the Greenland ship for Aberdeen Dr Gregory and Capt Mudge.'²⁸

²³ *Account of the Observations and Calculations of the Principal Triangulation etc, Drawn up by Captain Alexander Ross Clarke under direction of Lt Col H James etc*, London: HMSO, 1858, 75 & 148.

²⁴ *Captain's Log, Investigator, 1811-1819*, The National Archives, ADM 51/2474, August 1817.

²⁵ *Memoir of the Life of Major-General Colby*, 79-83.

²⁶ *Master's Log, Protector, 17 Nov 1820-31 Dec 1826*, The National Archives, ADM 52/3953 and *Account of the Observations and Calculations of the Principal Triangulation etc*, 89-166.

²⁷ *Recueil d'observations*, 531, 561 and 563.

²⁸ Verbatim extracts from *Captain's Log, Investigator, 1811-1819*, The National Archives, ADM 51/2474.



*Jean-Baptiste Biot by kind permission
of David Edmondston of Buness*

Biot was at first alarmed at the loss of his assistant, but, after Thomas Edmondston found a young carpenter to take Mudge's place, Biot was much impressed by the youth's Scottish education in reading, writing and arithmetic, and appreciative of his timely and trustworthy assistance. So it was that they were able to complete 31 days of pendulum observations and 400 observations of latitude on 9 September – which was marked by the surprising turn of events described below.

Biot's dislike of Thomas Colby was at least matched by his respect for Thomas Edmondston and his way of life. In his wide-ranging report on his journeys, Biot contrasts the savage scenery and climate of Unst with their admirable way of life, sustained by

the land and the sea. He goes out of his way to express his delight with the Edmondstons' hospitality, support and advice, which was marked by the gift of the miniature which remains in the family's keeping, and by a letter of thanks from the Academie des Sciences.

Probably Biot would have found similar hospitality anywhere in Unst, but he was fortunate at Buness in finding himself in a culture which in many respects matched his own. Dr Arthur Edmondston of Lerwick had written a monograph on ophthalmia in 1806 and *A View of the Zetland Islands* in 1809. Thomas's other brother, later Dr Lawrence Edmondston, was a keen observer of natural history and Lawrence's wife wrote on local history.

Biot's return from Balta Sound

Whereas the behaviour of Colby and Biot on 24 July seems unreasonable, the events of 9 September appear outrageous. At Buness, Biot was apparently engaged from morning until evening on his last of 31 days of pendulum observations.²⁹ Within sight, in Balta Sound, Colby, Gardner and fifteen artillerymen came on board *Investigator* by 11am and at noon sailed for Lerwick, picking up stores there on 10-11 September, and in due course discharging Captain Colby, Mr Gardner and 14 of the artillerymen at Leith late in the day on Friday 19 September.³⁰ So had Colby failed to warn Biot of his departure or had Biot refused to board *Investigator*?

²⁹ 'Jours et époques des observations comparées', *Recueil d'observations*, 562.

³⁰ *Captain's Log, Investigator, 1811-1819*, The National Archives, ADM 51/2474, September 1817.

Portlock implies that Biot left Balta before Colby, having ‘returned southward before the *Investigator* could be despatched to remove him’³¹ but he fails to explain that it was not until 29 September that *Investigator* was despatched from Leith. After Colby’s departure from Balta Sound, Biot had spent another two weeks in the Shetlands, finding a passage to Edinburgh about 24 September. His voyage south was dramatically quicker than his journey north: he recorded that ‘an equinoctial gale took me to Edinburgh in fifteen hours’.³²

Be that as it may, the Caledonian Mercury reported on Monday 6 October that Monsieur Biot had arrived in Leith ‘on Friday last’ after a very speedy voyage from the Shetland Islands, and ‘It is with no small degree of surprise that we have learnt that this eminent philosopher was entirely abandoned by the gentlemen who were sent to accompany him on his expedition’ although ‘From the inhabitants of Unst he received every kindness and hospitality they could bestow on him.’ The best response Gregory and Colby could muster (from Woolwich) was that ‘We have read, with considerable surprise, [this] paragraph A newspaper is not the place to enter into a refutation, point by point, of so strange a paragraph, resting upon anonymous authority, as that to which we refer’.³³ Thus it was that the expedition which had been so celebrated beforehand was put at risk of public ignominy (at least in the eyes of the Edinburgh literati, who, interestingly, were subsequently provided in Edinburgh journals³⁴ with reports of Biot’s observations in Unst).

Having enjoyed the hospitality of the Royal Engineers in Edinburgh, and paid visits to the Universities of Oxford and Cambridge, Biot, now joined by Arago, was received by the Astronomer-Royal at Greenwich, where they completed further pendulum experiments.³⁵ These proved valuable later in providing the basis on which Biot’s observations could be brought together with those by Kater and Sabine which soon followed.

Captain (RE) Henry Kater FRS at Balta Sound in 1818

The House of Commons, under pressure to standardise weights and measures, in 1816 had passed a resolution directed at ‘ascertaining the length of the pendulum vibrating in seconds of time in the latitude of London, as compared with the standard measure in possession of [that] house, and for determining the variations in length of the said pendulum, at the principal stations of the Trigonometrical

³¹ JE Portlock, *Memoir of the Life of Major-General Colby*, 83.

³² ‘Un coup de vent de l’équinoxe me ramena à Edinbourg en cinquante heures’, *Recueil d’observations*, 538. But this would have required a speed of 15 knots, even from Lerwick, whereas the reputed top speed of a brig is about 11 knots.

³³ Nineteenth-century newspapers, *Caledonian Mercury*, 9 and 16 October 1817. *The Times* on 16 October reported the kindness and hospitality of the inhabitants of Unst, but not the abandonment of Monsieur Biot.

³⁴ M Biot, On the length of the seconds pendulum observed at Unst, *Edinburgh Philosophical Journal*, 1819, vol 1, 77-79 and ‘Proceedings of Public Societies, Royal Institute of France’, *Edinburgh Annual Register*, 1819, 197-199.

³⁵ Sir Charles Close, *The early years of the Ordnance Survey*, 68 and *Recueil d’observations*, 538-540.



top: watercolour of Bunness in 1818 with observatory on left and Balta Sound to the right, reproduced by kind permission of David Edmondston of Bunness
lower: Bunness and Balta Sound in 2013

Survey extended through Great Britain; and also for comparing the said standard measures, with the ten millionth part of the quadrant of the meridian, now used as the basis of linear measure on (a part of) the continent of Europe' – and the Royal Society had accepted this objective.³⁶

Perhaps unimpressed by the results of the 1817 expedition, the Royal Society in 1818 entrusted the Commons' task to Henry Kater, supported by a small party from the Royal Artillery and an Admiralty sloop. Kater arrived in Lerwick with a letter of introduction to Dr Edmondston, who made his brother Thomas ready to welcome Kater in Unst. After examining the outbuildings of Edmondston's house, Kater chose to locate his 'invariable pendulum' (of his own invention) on a wall, three feet thick, next the building in which Biot had conducted his experiments in 1817. Frustrated by two weeks of fog and rain, he eventually was able over a few days to observe the stellar transits required to calibrate his pendulum and the solar observations he used to determine his latitude. On 29 July 1818 he took his leave, echoing Biot's appreciation of Mr Edmondston's kind hospitality and 'every anxious exertion that could tend to forward the enquiry in which I was engaged.'

³⁶ Capt Henry Kater FRS, 'An account of experiments for determining the variation in the length of the pendulum vibrating seconds, at the principal stations of the Trigonometrical Survey of Great Britain', *Phil Trans R Soc. Lond*, 1819, vol 109, 337-538 – which is the source for most of this section.

Probably the watercolour opposite, attributed to one of Thomas Edmondston's sisters, dates from Kater's observations in 1818 rather than Biot's in 1817.³⁷ The photograph, taken in 2013, shows that little has changed, except that the memorial stone originally placed near the house has been moved to a site near to the road.

Kater then proceeded to repeat the same exercise at Portsoy on the Moray Firth; at Leith Fort on the Firth of Forth; at Clifton in Yorkshire; and at Arbury Hill in Northants. From Arbury Hill he hastened to the Isle of Wight at the end of October. Frustrated by the weather, he returned there to complete his observations the following May and yet completed his comprehensive paper to the Royal Society for delivery on 24 June 1819.

Kater was gratified to report that Biot's estimate of 'the acceleration of the pendulum between London and Unst' differed only very slightly from his own estimate (which Biot confirmed when he published his detailed results in 1821)³⁸. Kater had hoped from his pendulum observations to improve previous estimates (of around 1/300) for the ellipticity³⁹ of the oblate spheroid representing the figure of the earth. But, having tabulated his observations of the length of a seconds pendulum compared with latitude, he was disappointed to find that stepwise comparisons of adjacent stations gave irregular results. These he attributed to differences in the density of the underlying strata causing variations in the force of gravity, and he concluded that to overcome this disturbing factor a more extended arc of stations was required, preferably of similar geological character.⁴⁰

Expeditions in the 1820s of Captain (RA) Edward Sabine FRS

In the spirit of the age, another army officer, Captain Sabine, was already prepared for this forbidding task. Having measured clock vibrations in London and the Shetlands in 1818 and on Melville Island at nearly 75 degrees north in 1820,⁴¹ he was able to secure support from the Royal Society and the Board of Longitude as well as the Admiralty for an ambitious expedition in the sloop *Pheasant*.

Sabine conducted measurements in Sierra Leone in March 1822, St Thomas in May/June, Ascension in June/July, Bahia in July, Maranham (similar in latitude to St Thomas but on alluvial strata) in Aug/September, Trinidad in September and

³⁷ Kater wrote: 'The bell tent before mentioned was suspended over the transit from three spars lashed together at the top.' The watercolour shows two similar vessels at anchor (with the Island of Balta behind), consistent with Kater writing that 'On the 9th July [1818] we arrived at Unst, having been joined on the voyage by the Cherokee, bearing an order from the Admiral commanding at Leith to relieve the Nimrod.' Capt Henry Kater, 'An account of experiments etc', *Phil Trans R Soc. Lond*, 1819, vol 109, 346 and 340.

³⁸ *Recueil d'observations*, 576-583.

³⁹ Given a = equatorial radius, and b = polar semi-diameter, ellipticity = $(a-b)/a$.

⁴⁰ Capt Henry Kater, 'An account of experiments etc', *Phil Trans R Soc. Lond*, 1819, vol 109, 425-426.

⁴¹ Edward Sabine, 'An account of experiments to determine the acceleration of the pendulum in different latitudes', *Phil Trans R Soc. Lond*, 1821, vol 111, 163-190.

Jamaica in October. The way in which Sabine adapted to circumstances and secured local support during the turmoil in the Spanish colonies is as impressive as the prompt and thorough documentation of his results. With even greater audacity, he extended his terms of reference to divert *Pheasant* to New York on the way home, where he secured free passage through the US customs, the support of the President of the University of Columbia in accommodating his instruments in the Cupola of the College Chapel, and the collaboration of the Professor of Natural Philosophy, to which he courteously and promptly responded by presenting a paper to the Philosophical Society of New York.

Having prepared the ground in letters from the tropics, Sabine on his return to London soon secured the support of the Royal Society and the Admiralty for a voyage to the Arctic, which commenced in June 1823 in the sloop *Griper* under the same Captain Clavering. As painstaking as he was bold, he recalibrated Kater's pendulum at the Royal Society in Portland Place and adapted his equipment in the light of his previous experience. Sabine's diplomacy and determination in finding sites for the pendulum proved as effective in the Arctic as in the Tropics, and over the short summer he made observations at Hammerfest in Norway, at nearly 80 degrees north in Spitzbergen, at nearly 75 degrees north in Greenland and at Trondheim back in Norway.⁴²

Thorough as usual, Sabine recalibrated his pendulum at Portland Place on his return, and prepared the impressive account of his journeys which incorporated his earlier observations at Melville Island. This includes his comparison (by regression analysis) of the length of a seconds pendulum with latitude from the equator to the 80th parallel. Modest in his interpretation of his results, Sabine concluded that 'The individual who has conducted the experiments is peculiarly disqualified for anticipating the general opinion as to their conclusiveness and the decision must remain with those, in whom maturity of judgment gives authority to opinion.'⁴³

Figure of the earth published in 1830 by Professor George Airy FRS

Sabine's invitation was soon taken up by George Airy, who in August 1830 for the Encyclopaedia Metropolitana compiled a confident and (appropriately) encyclopaedic article on the figure of the earth. This from his desk at the Cambridge Observatory brought together scientific theory relating to the shape of the earth, a history of the expeditions devoted to its measurement, and his own conclusions derived from his collection of worldwide observations. Airy's article explains the three quite different approaches: by triangulation – the geodetic approach; by measuring the gravitational force through the frequency of a standard pendulum; and from lunar observations.⁴⁴

⁴² Edward Sabine, *An account of experiments to determine the figure of the earth by means of pendulum vibrating seconds in different latitudes*, John Murray, bookseller to the Board of Longitude, London, 1825.

⁴³ *An account of experiments to determine the figure of the earth*, 354.

⁴⁴ 'Figure of the Earth', *Encyclopaedia Metropolitana*, vol V, 1848, 165-239.

For pendulum observations, Airy felt able to separate those observations which he deemed reliable from those which he did not, and compiled a table of ‘first-rate observations’, of which 31 out of 49 were attributed to Biot, Kater or Sabine, comparing the length of a seconds pendulum with latitude between 80 degrees north and 52 degrees south. The laborious observations made at Balta Sound are summarised in a single line of data assigned to Biot and Kater at Unst. However, due to the irregularities of gravity which he attributed to the underlying strata, Airy found that this approach could provide only approximate support to his more precise geodetic conclusions.⁴⁵

By selecting from fourteen arcs of meridian measured and documented over the previous century, Airy boldly concluded on 17 August 1830 that the earth’s surface at sea level might be represented ‘on the whole’ by an ellipsoid of revolution with polar semi-axis of 20,853,810 (English) feet, equatorial radius of 20,923,713 feet, and ellipticity of 1/298.33.⁴⁶ In this country, Airy’s figure of the earth has endured well. These dimensions were put into use at the Ordnance Survey by the 1840s, used for the calculation of the principal triangulation in 1858, used again for the retriangulation of 1936 to 1962, and still continue to provide the basis for Ordnance Survey mapping at all scales and for the National Grid.⁴⁷

Postscript

Airy’s autobiography,⁴⁸ an interesting demonstration of his scientific versatility and lifetime enthusiasms, mentions that he with his wife visited the Shetlands in the summer of 1849. Later, in a letter to Biot,⁴⁹ Airy reported that he had enjoyed the hospitality of Thomas Edmondston at Bunes, that Thomas’s nephew⁵⁰ had been named Biot Edmondston and that he had inspected the memorial stone – the very one which stimulated this article.



The author is a retired civil engineer whose family history research has been nourished by the resources of the map library of the National Library of Scotland.

Photographs by the author

⁴⁵ ‘Figure of the Earth’, *Encyclopaedia Metropolitana*, vol V, 1848, 228-231.

⁴⁶ ‘Figure of the Earth’, *Encyclopaedia Metropolitana*, vol V, 1848, 217-220.

⁴⁷ www.ordnancesurvey.co.uk/docs/ebooks/re-triangulation/index.html and www.ordnancesurvey.co.uk/business-and-government/help-and-support/navigation-technology/os-net/surveying.html

⁴⁸ Wilfred Airy (ed), *Autobiography of Sir George Biddell Airy*, Cambridge University Press, 1896, 202. www.ordnancesurvey.co.uk/docs/ebooks/re-triangulation/index.html

⁴⁹ RGO 6/362, Airy to Biot, 12 Feb 1850, Cambridge University Library Archives.

⁵⁰ Born 1827, son of Lawrence Edmondston, later Revd Biot Edmondston and author in 1888 of *Home of a Naturalist*. Unfortunately Lawrence’s eldest son Thomas, perhaps the most talented naturalist of this talented family, had died in 1847. Having by the age of 12 identified an unexpected species of plant to the satisfaction of William Dawson Hooker, Thomas wrote a Flora of the Shetlands, and in 1846 was elected Professor of Botany in Glasgow, but instead became naturalist on HMS Herald. He died in an accident in Ecuador before reaching the age of 21 and yet achieved a place in the Oxford Dictionary of National Biography.