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Scientific Instruments on the move in the North American Magnetic Survey, 1843-1844

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Article abstract

In 1843-4, John Henry Lefroy conducted a geomagnetic survey of Hudson's Bay Company territory in British North America. Lefroy and his instruments, guided by French Canadian voyageurs and Indigenous guides moved within the HBC network of forts and outposts. This paper complements and extends historical accounts of Lefroy's survey by examining how, and how well, Lefroy's instruments moved on this extensive survey. The recent material turn in the history and historical geography of science provides the framework for a closer reading of the spatial biographies of several of Lefroy's instruments. Focusing on their varying states of disrepair—and solutions to repair them—this paper not only recaptures the materiality of these instruments, but adds to our understanding of repair and maintenance in the history of survey science. Looking at instruments as objects to be carried and managed also helps illuminate the overlooked role of Indigenous and French Canadian voyageurs in scientific expeditions.

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Résumé : *En 1843-44, John Henry Lefroy a effectué une inspection du territoire de la Compagnie de la Baie d'Hudson (CBH) dans l'Amérique du Nord britannique. Lefroy et ses instruments se sont installés dans un réseau de forts et avant-postes de la CBH, guidé par de voyageurs canadiens français et de guides autochtones. Cet article complète et étend les récits historiques de l'exploration de Lefroy et examine en particulier comment les instruments de Lefroy ont été déplacés lors de cette enquête géomagnétique. Le tournant matériel récent dans l'histoire et la géographie historique des sciences fournit le cadre d'une lecture plus approfondie des biographies spatiales des plusieurs instruments de Lefroy. Mettant l'accent sur les instruments sur différents états de délabrement permet non seulement de ressaisir la matérialité de ces instruments, mais aussi de contribuer une meilleure compréhension de la réparation et de l'entretien dans l'histoire des sciences de l'exploration. Finalement, cet article contribue à éclairer le rôle souvent négligé des voyageurs autochtones et canadiens-français dans ces expéditions scientifiques.*

Keywords: John Henry Lefroy, magnetic crusade, scientific instruments, repair, geobiography

JOHN HENRY LEFROY IS WELL KNOWN to Canadian historians and historians of science alike (**Figure 1**). His role in helping to foster a scientific community in Canada during the time of his directorship of the Toronto Magnetic and Meteorological Observatory (1842-43, 1844-1853) has been remarked on in several different historical accounts, most notably those by Suzanne Zeller and Gregory Good. Zeller has also positioned Lefroy as one of a number of individuals of the early nineteenth century who can be described as "Humboldtian," or having

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***Figure 1**. Paul Kane, Canadian, 1810-1871. Scene in the Northwest - Portrait, c. 1845-1846. Oil on canvas. Overall: 55.5 x 76 cm (21 7/8 x 29 15/16 in.). The Thomson Collection © Art Gallery of Ontario, 2009/507. Image © Art Gallery of Ontario.*

operated within a Humboldtian network and paradigm, in their approach to doing science.[1] Zeller has positioned Lefroy in such a way largely because of his involvement in a magnetic survey of parts of what was British North America, Rupert's Land and the Northwest Territories, today collectively known as Canada, between May 1843 and November 1844. This survey was a constituent part of a wider geomagnetic project, known as the magnetic crusade—which was coordinated at and by Edward Sabine's magnetic department at Woolwich, England and Humphrey Lloyd's Dublin Observatory, Ireland. The magnetic crusade was in operation from 1839 to roughly 1854 and was made up by a combination of observation at fixed magnetic and meteorological observatories—both within and beyond the boundaries of the British Empire from Europe to South Africa to Australia—and by observation on a number of mobile surveys, of which Lefroy's was one.[2] The magnetic crusade was the most extensive and ambitious project of the early nineteenth century, a "combination such as the scientific world never before saw" according to Lloyd, who similarly expected that the results of such an enterprise would "correspond with the gigantic magnitude of the machinery."[3]

The most famous of the magnetic crusade's mobile surveys was arguably that of the expedition led by James Clark Ross to South Polar waters between

1839 and 1843. Lefroy's survey was in some respects an Arctic counterpoint to Ross's Antarctic voyage but it was also much more important than that statement suggests. Lefroy's survey was the only overland survey of the magnetic crusade sanctioned by the British government and the Board of Ordnance —two institutions critical to the organisation of the entire crusade—and it was motivated by the surprising discovery that "the highest isodynamic lines of the northern hemisphere were closed and irregularly elliptical curves, extending across the North American Continent nearly in a north-west and south-east direction, and having their central point, or the point of maximum of Force, approximately in 52° north latitude, and 270° east [90°W] longitude." Observations in the neighbourhood of this phenomena were, Sabine explained, "objects which presented themselves amongst the most important desiderata for our present knowledge, and as likely to have a peculiar value at a future period in respect to the Ætiology of the science [of terrestrial magnetism]" and research that "might serve to elucidate the laws of those secular changes, which, in our present ignorance of the causes of the earth's magnetism, seem even more mysterious than the apparently complex relations of contemporary phenomena."[4]

Much of this is already known, due largely to the scholarship of several Canadian historians. However, it is often the case that the story of Lefroy's survey is subsumed into wider historical narratives. For example, Zeller, who has probably provided the most robust accounts of Lefroy's survey, uses the survey in one instance to support a far-ranging history of the creation of a scientific community and legacy in Canada and in another Lefroy and his survey are positioned in relation to wider narratives of the Humboldtian traveller and Humboldtian networks.[5] In like manner, Ted Binnema utilises the story of the survey as one of a number of staging posts which help elucidate his history of the involvement of the HBC in a host of scientific knowledge-making enterprises from 1670 to 1870. For Binnema, "the geomagnetic survey also serves to illustrate as clearly as any aspect of the history of science in the HBC, that, although historians have often emphasised how scientists and companies acted as agents of empire, empires and companies were at least as likely to act as agents of science."[6] Trevor Levere's work on Lefroy is an exception here. While Levere has used Lefroy as part of a much wider and longer narrative of science in the Arctic, he has also provided one of the more detailed, if brief, studies of the materiality of Lefroy's survey.[7]

In several respects, this paper is motivated by the work of Levere and by the need to sharpen the focus on the magnetic, meteorological, astronomical, and mathematical instruments which travelled with Lefroy to the Canadian Arctic and to the need to do so within the framework of the recent "material turn" in historical geographies of science literature.[8] First, a history of the problems involved in organising and staffing the survey will be offered, together with a condensed outline of the route and timings of the survey as it eventually turned out. From this, the focus switches to the instruments that travelled with

Lefroy. These instruments can tell us a lot about the process of doing scientific survey work at this time and in this country. In their "moments of disrepair" the instruments shed light on how instruments were managed, adjusted, and made credible on the move.[9] Importantly, such stories also offer much needed insights into the history of repair and maintenance in the survey sciences. The third section goes on to explore the scientific instruments as objects that were carried and the French Canadian and Indigenous labourers who bore them through the North American wilderness. In doing so it is argued that such invisible labour ought not to be ignored in our understanding of the ways in which scientific instruments were managed on the move. The role of such individuals in guiding the survey will also be remarked upon in this section. Finally, the paper will conclude with a tentative attempt at applying the concept of "geobiography" to an analysis of some of the instruments that travelled with Lefroy in order to destabilise their traditional temporal biographies or life-cycles.

Origin of the Survey

Edward Sabine had initially wanted to carry out a magnetic survey himself in British North America in 1839 (**Figure 2**). He had contacted the Hudson's Bay Company (HBC) about this expedition and later wrote to Humphrey Lloyd in the spring of 1839 telling him that the HBC had offered him a canoe and that he had already planned his route from Montreal to York Fort via Lake Superior and on the way back to Quebec to observe at Moose Rain.[10] However, at this time both he and Lloyd were frantically trying to complete their report on the British Magnetic Survey. It had already caused Sabine many anguished days and nights trying to incorporate the frequent revisions of Lloyd in time for it to be printed.[11] Its publication had been postponed once in October 1838 ("our poor report, alas! Must be suspended") and Sabine was unwilling to allow this to happen again.[12] Sabine was forced to choose between his "Canadian project" and "our British Report" and, he wrote to Lloyd, he "sacrificed the first!" The HBC's cooperation had been just what Sabine had wished for but he would have to have been in Montreal on 1 May 1839 and this, he explained, he "cannot do so, without abandoning the B. Report, so, the step is taken & regrets are useless."[13] However, as Sabine later wrote, "the project of a North American magnetic survey…was not suffered to drop."[14] Instead, a new candidate for Sabine's "Canadian project" was sought.

Charles J. B. Riddell—the first director of the Toronto Observatory—was next identified for the role by Sabine in 1840 but, perhaps because it would have been too much of a loss for the nascent Toronto Observatory, this idea was vetoed by Lloyd.[15] Lieutenant Charles Wright Younghusband, Riddell's assistant at the Toronto Observatory, was the obvious candidate to embark on the survey but, when Riddell was invalided home to England at the beginning of 1841, Younghusband was forced to take over management of the observatory. Lefroy was at this time still the director of the St. Helena Magnetic and Meteorological

Observatory—another of the colonial observatories of the magnetic crusade—but had expressed in a number of letters to Sabine and Lloyd his desire for survey work.[16] He had been rebuffed in his requests for a St. Helena or a South African survey but in August 1841 he was contacted by Sabine over the prospect of taking over Sabine's "Canadian project," to which Lefroy dutifully and enthusiastically committed himself. Lefroy had never been considered the best observer employed on the magnetic crusade. "Poor Lefroy," Lloyd remarked in a letter to Sabine in May 1841, "will never make an observer" as he had "no tact in overcoming practical difficulties, even of the simplest kind."[17] He was, however, an organised, industrious, and fit soldier and, as we will see later, not as impractical as Lloyd had thought. At any rate, extreme accuracy, on the part of the instruments and the observer, was both "impracticable and unnecessary" on a mobile magnetic survey, and of secondary importance to portability and fortitude.[18] Lefroy arrived in Montreal on 15 September 1842 and Toronto on 23 October. Officially, Lefroy was employed on a permanent basis as the director of the Toronto Observatory with only a "special view to his employment on the survey" but it seems certain that it was Sabine's desire for a magnetic survey in North America which was the primary reason Lefroy was brought over from St. Helena. As Sabine had originally intended, the survey was carried out with the enthusiastic support of the HBC, due largely to its London governor, J.H. Pelly, and North American governor, George Simpson. The HBC provided canoe conveyance and personnel as part of its "Brigade for the northern department."[19]

The Survey: Its Course and its Actors

Lefroy took over the running of the Toronto Observatory from Younghusband upon his arrival and for the next six months. The work of the observatory had "fallen terribly in arrears," as Lefroy himself noted in his *Autobiography*.[20] Younghusband had struggled to keep up with the unremitting observations and reductions that were required at the observatory and the physical condition of the observatory was similarly dire. The dismissal of both Bombardier Thomas Menzies (for drunkenness) and his replacement Acting Bombardier John McNaught (for being untrained and unskilled in observatory work) together with Riddell's departure had left the Toronto Observatory severely shorthanded.[21] "All in all," Julian Smith has noted, "it seemed as though Lefroy had assumed a hopeless task."[22] In March 1843 Lefroy travelled to Boston to take charge of a set of new transportable magnetometers devised by Riddell and constructed by the instrument maker Thomas Jones, which had finally arrived from England. After returning to Toronto for three weeks Lefroy left once again, this time to Montreal, where he arrived on 22 April 1843.

The survey had not yet begun, but already certain instruments had suffered from the exigencies of travel. Between Toronto and Montreal, Lefroy, together with Henry, had to travel in a "common open country waggon [sic.], filled with straw, in a sharp frost," as navigation on Lake Ontario was not yet open. The

effect of the jolting upon his instruments was "disastrous."[23] The Gambey and the Fox-type dip circles were "shaken to pieces," the Gambey "literally" so and the Fox "almost." The Gambey, Lefroy wrote to Younghusband from Montreal, consisted of little more than "loose parts lying about in a box" by the end of its transit. The theodolite was similarly shaken apart and, although Lefroy carried the barometers on his shoulders the entire way, "a little mercury" managed to escape one of them.[24] More problematically for Lefroy,

> Lloyd's static needles lost force from the effect of the jolting to such a degree as to entirely disconnect the subsequent observations from those intended to be the base series, taken at Toronto. The same remark applies to Fox's needle C, and a new base had to be taken for both, at Fort William (Station LXIX). The instruments were reinstated, as well as could be done, before starting.[25]

Lefroy was more sanguine in his assessment in his *Autobiography*, saying of the altered state of the instruments that "there was no help for it, and they were put in order again without much trouble."[26] However, Lefroy noted in his contemporary survey journal that, on the day the canoes launched from Lachine, he had "found such difficulty in turning Fox in azimuth as to fear a considerable injury to the axis" which he later discovered was due to the screws of the level coming through the copper plate and grating "upon the under."[27] Although the Fox had been "reinstated," it had not returned to its previous state; it now existed on the margins of a state of disrepair.

Before proceeding to the story of Lefroy's survey and an analysis of his instruments as they travelled it is necessary to pause and take stock of exactly what scientific instruments Lefroy took with him on his voyage. Trevor Levere has written a concise and highly informative account of the instruments Lefroy took with him on his survey, but the list he presents is limited to the main magnetic apparatus Lefroy carried and precludes a full appreciation of the extent of the meteorological, mathematical, and astronomical instruments also included in the survey inventory. The full list runs as follows:

1. One Declination Magnetometer and Bifilar, in one box, with canvas cover and straps complete with spare tube and suspension pins and spare therm[ometer].
2. Inclinometer, in box, with [*same as above*].
3. Declinometer (2, 4 inch & 1, 3 inch coll. needles), the box carrying also:
    - spare 3½ inch bars
    - 1 pair 2 inch bars
    - The brass table tops for the legs of inclinometer
    - A spare stirrup with revolving mirror made at Toronto, for vibrat[ing] all the smaller bars
4. Fox's dip circle complete, with two intensity needles A and C and one reversing needle B.
5. Gambey's dip circle, complete with a pair of Lloyd's needles and thermometer.
6. A theodolite.

7. A portable transit instr.

8. A repeating reflecting circle.

9. A small 4½ sextant, the property of Lieut. Younghusband.

10. An artificial horizon, with iron mercury bottle, also a box wood ditto.

11. Two Newman's iron cistern barometers nos. 33—119

12. One actinometer from observ[ator]y

13. One azimuth compass of the Committee's construction. 4 spare pivots.

14. One Kater's ditto.

15. Thermometer:

- 1 Newman's for boiling point of water.
- 1 ? registering in copper case, pierced and polished .
- 1 Newman's standard mercury.
- 3 Newman's merc[ury] max.
- 2 Newman's Spirit min[imum].
- 1 Newman's max with black bulb.
- 1 wet bulb Hygrometer, 2 therm[ometers].
- 1 Daniel's ditto, with ether
- 3 Therm[ometer]s merc[ury] purchased at Montreal, two of them max registering, one common mercury graduated to -35°.

15. Three cylinders capable of holding any of Newman's thermometers (standard excepted) polished copper, double in the lower part and pierced with holes so dispersed that those in the outer and inner case are not opposite.

16. A copper case to carry ditto.

17. Six year's meteorological forms from Professor Espy, for distribution.

18. One lanthorn [sic.] and fire lamps for illuminating the instr. at night. Also a few wax candles in canteen (cir. 400lbs).

19. Two of the Admiralty dip books (Capt. Ross's form), one half full.

20. Two Dip books for Fox.

21. 1 100 feet measuring tape.

22. A small Dollond common telescope.

23. One or two spare lots of legs, from the old transport[able] magnet[ometer].

24. A large box for stationery and miscall. stores.

25. Lind's wind gauge from the observ[ator]y.[28]

This is a much more considerable list than the one Lefroy later offered in his *Diary of a Magnetic Survey* (1883). The Diary list, which is Levere's source, does however offer up additional information on the makers of some of the instruments and Riddell's *Magnetical Instructions for the Use of Portable Instruments* (1844) gives some of their contemporary prices. Briefly: the Fox dip circle weighed 37lbs. in the box and cost £26 2s; the Gambey 27lbs.; the theodolite was made by Thomas Jones and weighed 10½lbs.; the declination magnetometer weighed 25lbs (the maker is not given but it was probably Jones) and cost £12; the

original transportable declinometer was by Weber but subsequently replaced by the "much superior instrument made by Jones" under Riddell's instruction and cost £14;[29] the transportable bifilar was also made by Jones, weighed 22lbs. and cost £19 10s; the inclinometer mentioned above was an induction inclinometer of Lloyd's design and Jones's construction that weighed 18lbs. and cost £15; the committee from which the azimuth compass came was the Admiralty Committee and was constructed by John Barrow; and the repeating-reflecting circle was made by George Dollond and weighed 25lbs.[30] Lefroy, prior to the survey, estimated in a letter to George Simpson that altogether the instrumentation necessary to "obtain any magnetic results of value may be brought well within the compass of 50lbs. weight."[31] In reality, as the above demonstrates, Lefroy's magnetic apparatus alone weighed well over 50lbs. and together with the meteorological, mathematical and astronomical instruments Lefroy packed which were also required to obtain "magnetic results of value," Lefroy carried around 180lbs. of scientific instrumentation on the survey.[32] As Levere rightly points out in a footnote, the weight of instrumentation is "not a trivial point when everything had to be packed into canoes and carried across portages."[33]

The most sensitive and arguably the most important magnetic instruments Lefroy carried were those made by Jones. Thomas Jones (1775-1852) was an English instrument maker who had learned his craft as an apprentice to the eminent Jesse Ramsden in London. Jones supplied geomagnetic instruments for several surveys during the 1830s, including the biggest of them all: the magnetic crusade. This despite the fact that he was accounted something of a "knave" and, as Sabine wrote to Lloyd in early 1839 as the magnetic crusade was beginning to take shape, Jones could not be depended on "in regard to time, nor correct execution."[34] Lefroy was not enamoured with his work either. He found the "partitions and fittings too slight; too coarse, heavy…screws work loose, portions chip off etc.."[35] Henri-Prudence Gambey (1787-1847), the maker of one of the dip circles Lefroy carried, was much more highly regarded. Gambey worked in Paris where he engineered precision instruments for the Paris Observatory as well other physicists and astronomers on the continent and in Britain.[36] Robert Were Fox (1789-1877), who produced Lefroy's other dip circle, was a Cornish geologist, physicist and designer of geomagnetic apparatus. Together with Thomas Brown Jordan (1807-1890), Fox's drawing master and engineer, the pair constructed some of the most well-respected and sought out scientific instruments, notably the Fox-type dip circle (**Figure 2**), which was used on many naval scientific expeditions.[37]

Together with the instruments listed above, Lefroy outlined the other necessities for his journey, such as a gun and a rifle, canteens, cassettes, other luggage, portable inkstands, bedding, blanket, one-and-a-half gallons of wine, tobacco, tea, powder, shot and balls. Extra clothing for his assistant, Bombardier William Henry, was purchased at a total cost of £6 16s 0½d and included a pea coat, a red flannel shirt, a pair of shoes, a lowland Scotch cap, a grey cloth

Figure 2. *Example of a Robert Were Fox dip circle made by W George of Falmouth, Cornwall, England, c.1840. Image courtesy of The Science Museum.*

jacket, two chamois leather shirts and two chamois leather drawers.[38] Lefroy also gave red shirts to Baptiste and Roubillard, two of the voyageurs on the survey, "by way of uniform."[39]

Thus equipped, Lefroy and Henry were ready for their overland voyage of exploration. Lefroy was initially bullish about the prospect, writing to Sabine as Lefroy crossed the Atlantic aboard the Prince Regent that "no exertion of mine shall be wanting and so I confidently hope to be able to give you in 1844…as large a body of results as will in some degree answer the questions that must grow out of those Ross is obtaining at the opposite Pole."[40] Lefroy obviously saw this survey as a mirror of the triumphant Antarctic survey James Clark Ross had, by the time of this letter, almost completed. In reality, it was of secondary importance to Ross's attempt to map the mostly uncharted

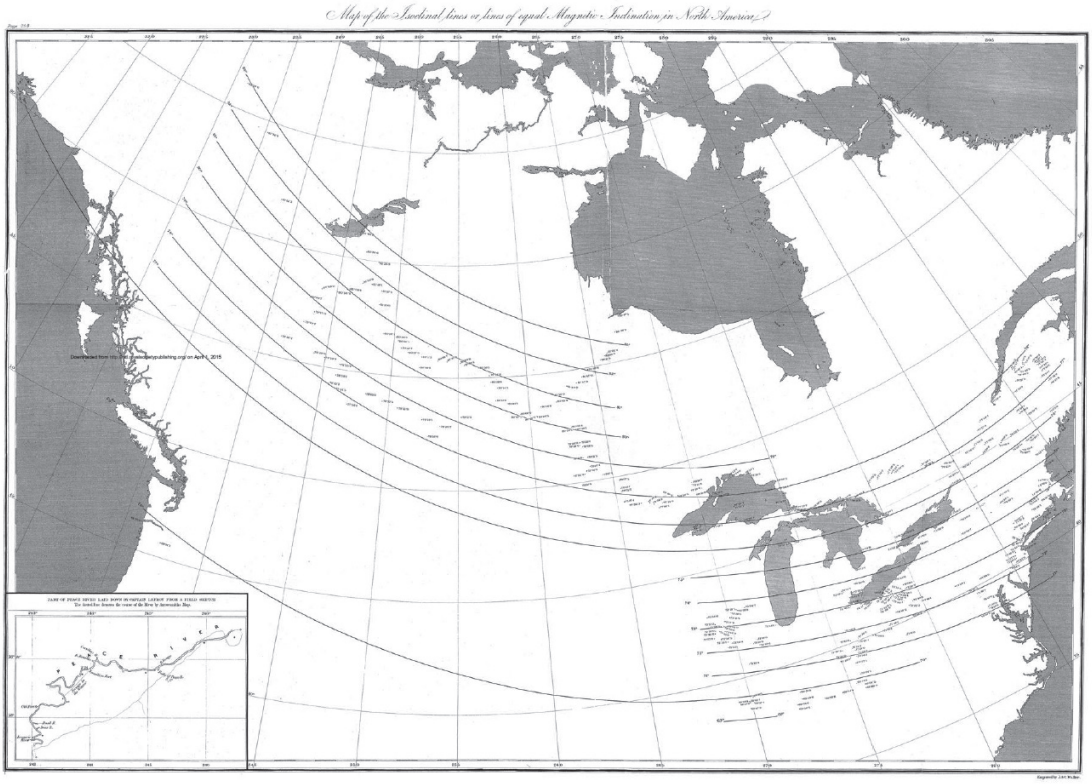

Figure 3. *Map of the Isoclinal lines or lines of equal Magnetic Inclination in North America, in Edward Sabine, "Contributions to Terrestrial Magnetism, No. VII,"* Philosophical Transactions of the Royal Society *136 (1846): 258.*

magnetism of the Antarctic region, but the Canadian survey was still expected to be highly significant in exploring and confirming the "previously unsuspected characteristic of the magnetic system of the globe," namely that it was in these parts that the intensity of the earth"s magnetic force in the northern hemisphere had its focus.[41]

The first observations of the survey were made in the vicinity of Hudson's Bay House at Lachine on 30 April 1843.[42] The next day the canoes—"canots de maitre," able to accommodate 13 or 14 voyageurs and up to four passengers—departed from Isle d'Urval and headed up the Ottawa River. The course of Lefroy's route is traced in several accounts of his survey and so it is appropriate here to simply give a brief overall outline. Lefroy and company headed northwest. They navigated both Lake Superior and Lake Winnipeg, stopped at several important HBC outposts—e.g. York Factory, Norway House, Cumberland House—and traversed many difficult portages, the "Rat Portage" being probably the most infamous, on their way to Fort Chipewyan, which the party reached on 23 September 1843 and where they wintered until 5 March 1844. Along the way Lefroy and his assistant Henry had made magnetic and meteorological observations almost daily, as the weather allowed. At Fort Chipewyan, Lefroy and Henry established a temporary observatory in which, working 12-hour shifts each, they almost ceaselessly recorded magnetic and

meteorological observations at hourly intervals during daylight hours and every 2 minutes during magnetic disturbances, from 16 October 1843 to 29 February 1844.[43] Leaving Fort Chipewyan on 3 March on snowshoes, three "trainaux" (sledges) and a cariole, Lefroy and his party trekked to Fort Simpson, where a second temporary observatory was also established from March to May 1844. When the ice broke on 25 May 1844, Lefroy headed instantly for Fort Good Hope, reaching there on 29 May. This was the farthest north they would reach, and the occasion on which they "touched the confines" of the Arctic Circle.[44] This was the apotheosis of Lefroy's survey. After this point, the party turned south and made their way to Montreal via several of the same HBC posts as they had visited on their way north. Lefroy and his party made their way (noisily) into Toronto on 18 November, before the survey ended on 25 November 1844 in Montreal. At the culmination of the survey, the party had covered close to 6,000 miles and observed at over 300 stations (**Figure 3**).

Initially, Lefroy travelled as part of the HBC "Brigade for the northern department," led by John Maclean. Lefroy was to be afforded two hours a day for observations (should the weather be conducive for such), four hours at each post they stopped at and twenty-four hours on days which coincided with the magnetic Term Days which the colonial and foreign observatories were all following simultaneously on Göttingen mean time.[45] After only a few days Lefroy's arrangement with the HBC Brigade was changed. Two voyageurs were placed at Lefroy's disposal—Edouard Genereux and Pierre Roubillon—"to carry the instruments over Portages, pitch [his] tent, and be otherwise useful" and Lefroy's canoe was "detached" from the Brigade in order to give him more time for observations. This new organisation was "an improvement on the previous arrangement" but only lasted until Fort William at the head of Lake Superior—reached at the beginning of June 1843.[46] Here, Lefroy's

> connection with the Hudson's Bay Company canoes was entirely dissevered. The large canoes, called Canots de maître, then went on no further than this point; the number and length of the portages precluding their further employment, a lighter canoe, called the Canot du Nord, came into use, one of which was appropriated to myself by the directions of Sir George Simpson, with a guide and a supply of provisions, and henceforward I commanded the disposition of my own time, subject only to the necessity of getting on.[47]

Lefroy had always felt that his and Henry's survey work made them a "constant source of anxiety" for the HBC as any "accident" on their part would have entailed lengthy delays for the time-conscious Brigade. After parting ways at Fort William, this anxiety was lifted but outside of the embrace of the Brigade, Lefroy and Henry were required to care for themselves, having to cook and carry more on the portages, which created their own time pressures.

Time was always a factor on the survey, whether with the Brigade or without. Lefroy described his initial routine in a letter to Younghusband shortly after the canoes had first departed Lachine:

> We start about ½ p 3 every morning, stop for breakfast about ½ p 7 when I observe for time and Var[iatio]n, and for dinner about ½ p 1. The other canoes proceed

> immediately after dinner, mine remains behind while I observe Gambey and Fox. This takes about 2 hours, we then follow, and overtake them after they have encamped, usually about 8 oclock—take supper and lie down until the cry of lève! lève! turns us out before three in the morning. The discomfort of this mode of travelling is chiefly a want of time for washing, dressing and so on.[48]

It is not clear from the above whether Lefroy and Henry observed Gambey and Fox for the full two hours or whether this included the time needed to set up and take down the instruments. As a point of interest, Lefroy noted once that he (along with, probably, Henry or others) "packed up the instr., struck the tent" and was afloat in the canoe "in less than 40m from the last observ."[49] Lefroy was also required to observe on Term Days, which lengthened the time of instrument adjustment. Term Days were prescribed by Lloyd and occurred one day each month. On such days, all observatories or magnetic surveyors participating on the British magnetic scheme were to simultaneously observe their magnetometers and inclinometers on six-minute cycles for an entire 24-hour period, all set to Göttingen mean time. For Lefroy and company to set up and adjust the transportable magnetometers and induction inclinometer instruments on these days required approximately two hours.[50]

Lefroy's comments to Younghusband seem to have described an average day of observation. At other times, observations could take up almost the entire morning. For instance, on 19 September 1843, Lefroy reported having spent from 0715 to 1125 making observations.[51] It was also not uncommon for observations to be taken at dinner time for one to three hours.[52] When daylight shortened, evening observations had to be made by candlelight, something not easily achieved. Wind and rain were two of the most frequent barriers to observation outdoors by candlelight. For instance, Lefroy "decided not to keep" the Term Day of 20 September 1843 because by then the nights were "so long, so much candle light in the open air would have been necessary and so much chance of wind etc. as to make it unadvisable."[53] On a separate occasion Lefroy did not observe in the evening because he had "strained [his] eyes considerably in examining the axles of Fox's needles" during the day.[54] Early in the survey it seems that Lefroy also used the evenings for observational practice as, on 14 May 1843, he described feeling "uncommonly savage at the cry of Leve! Leve! about ¼ to 4, [as he] had been practising lunars until past 12 o"clock."[55]

Despite the fact that Lefroy and Henry had parted company with the Brigade at Fort William in June, they were still subject to time pressures and the need to complete their navigation north to Fort Chipewyan before winter. On 10 July 1843, Lefroy reported that he could not complete all the observations he had wanted to on stopping in the afternoon because they needed to keep moving while the wind allowed it. Lefroy complained that "were it not for an occasional detention I could not easily keep my head above water."[56] Lefroy was the more aggrieved as well because, he wrote, "we had a tolerably pretty spot also. A level floor of smooth granite running out from a sandy beach which was covered with a beautiful wild pea, while a thicket of aspen spruce and willow screened us on one side from the wind." Such an excellent example of the temporary

and fleeting sites used for observation were to be cherished because often (as, for instance, Lefroy encountered later the same day) the spots they halted at were "very bad." A "wet and sandy beach where the surf dashed within a few feet of the tent" for example, or a beach of shingles, or on the "swampy soil" of the Long Portage.[57] These individual and continually changing sites had to be negotiated by Lefroy and Henry in the context of changing weather conditions and, importantly, the changed and ever-changing condition of the magnetic and meteorological instruments they carried.

Instruments: Moving, Changing, Changed

Lefroy's instruments changed dramatically over the course of the survey. This was of course to be expected "under the circumstances of a long land journey."[58] Even so, the catalogue of injuries Lefroy's instruments suffered and the repairs that had to be undertaken along the way were extensive. Changes in the state of the instruments Lefroy carried occurred for a number of reasons. First, there were many seemingly mundane accidents. The thermometer which worked in tandem with the inclinometer, which Lefroy was carrying with the intention of trying to "unite the broken column, fell from pocket on stooping for something, and broke."[59] Lloyd's needles were almost lost twice in the space of a couple of days. On one occasion a "Mr Ross" "let them fall into the stream just before encamping" after which they "floated down, but the canoe recovered them about 3 miles down."[60] Two days later, Lefroy dropped the same needles out of his Macintosh pocket at a portage.[61] That the readings made by Lloyd's needles later seemed anomalous would suggest that these needles had suffered a loss of magnetic strength as a result of their falls and brief river excursion, although Lefroy in his journal believed that "no cause can be given for such an occurrence."[62] At another time part of the Fox-type dip apparatus was dropped by Henry in his rush to shoot at a moose which had suddenly appeared. Although no injury seems to have occurred by this, it does remind us that making observations was not always the main priority on the survey.[63]

Some of the most significant accidents and breakages occurred with the meteorological instruments Lefroy carried, which is perhaps unsurprising given that these were some of the most fragile. A spirit thermometer "fell from the place on which it had been supported all night, and got broken."[64] Both of the barometers were similarly put out of use: no. 11 was simply "broken in the canoe," and no. 119 broken because it "had been so placed in the canoe that the cistern end projected a little, unobserved, beyond the gunwale, and on approaching the shore it came violently in contact with the overhanging stem of a tree."[65] The loss of both barometers was a "sad disappointment" to Lefroy.[66] Previous to their final demise, one of the barometers had also been used by a French Canadian child as rock-throwing target practice: "well he was not an Indian," Lefroy drily observed in his journal, "or it had been a 'gone' barometer."[67] Newman's maximum registering thermometer no. 10 was broken at the first "carrying place," i.e. a portage, only a few days after the survey had

first embarked.[68] A second "New. Max therm." was broken not long after, "in the water, apparently by the force of the current."[69] Before the canoes had even launched from Lachine, Lefroy's servant, had "let the box of thermometers fall from the hand cart on which it was going down, on to the stones, breaking two thirds of the contents." Only one hygrometer and "one or two" thermometers managed to escape this "most unfortunate piece of clumsiness."[70] It is not entirely clear if Lefroy had a chance to replace all of the broken thermometers before the survey properly launched.

In addition to the above accidents, several of the mathematical and astronomical instruments were also damaged or changed. For instance, the circle of the theodolite was "much bent" by a fall at the François River.[71] The brass plummet was also "abstracted…from the Theodolite box" by a group of Chipewyan children which Lefroy "endeavoured in vain" to recover.[72] One of the glasses of the artificial horizon was smashed when Henry dropped it at a portage.[73]

Finally, there were also the many and varied ways in which Lefroy's magnetic instrumentation was damaged and changed as it moved through the different sites and settings of the North American survey. A couple of these incidents have been related above but there were several more instances along the way. After stopping and setting up instruments on 20 June 1843, Lefroy was surprised by the occurrence of a stray calf blundering into his instruments. Lefroy was attempting at the time to observe the meridian altitude of the sun but instead observed the calf knock over his Gambey dip circle and smash the cover "to pieces."[74] By this unfortunate accident the Gambey was "rendered for the time unserviceable," Lloyd's needle A "which was on it at the moment, was ruined," and a deviation of the survey's route to take in the Red River settlement, and lower Fort Garry specifically, was required in order to affect repairs.[75]

There were four particularly precious instruments which travelled with Lefroy: the three transportable magnetometers and the induction inclinometer. These were precious because they measured the earth's magnetic force in absolute, rather than relative terms, and were the instruments employed on magnetic Term Days to observe simultaneously with all observatories on the British magnetic scheme. They were to be set up only at particularly long stoppages along the way at forts, and within the temporary observatories at Fort Chipewyan and Fort Simpson. Precious as they might be and as infrequently used as they were in comparison to the other instruments, they also suffered. On two separate occasions when the transportable magnetometers were set up, they were blown down. The declinometer, used to measure the variation of the magnetic force, escaped largely unharmed from its fall, although the theodolite in use alongside it had its vertical and its horizontal limbs bent and "bruised."[76] On the occasion when the transportable bifilar magnetometer was blown over, both its suspension tube and thermometer were broken.[77]

Damage to the limbs, or the body of the apparatus, were not the only problems to afflict the magnetic instruments. The needles by which they operated also

continually suffered. The most frequently recorded trouble was that of the needles contracting rust because of extended "exposure" to the environment. Axles were also frequently put out of shape. On 24 July 1843, Lefroy reported on the state of his eight needles at this early point in the survey. Rust had not yet set in but already Lloyd no. 2 had a "sensible bend at the shoulder of the front axle"; Fox C's back axle shape was not good; Gambey 1's sides were "not quite straight lines"; and the polish on half of them had already begun to wear away.[78] Fox A seems generally to have "worked with very tolerable freedom, not as a positively good one, but not as a positively bad one" although some irregularity was noticed with the weight at 4.0 grams seemingly "due to a bruise on the axle." Fox B "did not work freely" and "ceased to vibrate almost instantly"; and Fox C was so often found to be irregular in its force that Lefroy "condemned the axle and substituted a spare axle for it" in August 1843.[79] Two new Lloyd's needles were forwarded to Lefroy in 1844 at Norway House but "they proved to be about 0.2 inch too long for the [Fox] dip circle, and were never used."[80] This marginal but significant error speaks to Jutta Schickore's studies of imperfection in microscopes and how in the early nineteenth century, i.e. the period the magnetic crusade covered, "the individual differences between instruments" or in this case, needles, "produced by the very same maker came into the fore."[81] Repair and maintenance by the user was now the assumed method of ensuring that a particular device was in perfect-working order. Lefroy could not achieve this with these replacement needles. However, thanks largely to a network of HBC outposts and his own occasional labour, Lefroy managed to repair his instruments following breakages en route.

Fixes

Histories of maintenance and repair are still largely to be written.[82] It is a topic of "growing interest for geographers," but these efforts have tended to fall outside the realm of the history of science.[83] According to Fraser MacDonald and Charlie Withers "we have paid too little attention to fallibility and to how truth claims about science and exploration were made despite, not because of, the instruments used."[84] As Schaffer rightly pointed out in 2011, "some histories of broken instruments and their fixes might help."[85] The previous section was an answer to the first part of Schaffer's request, and the following speaks to the latter.

In writing his post-factum Diary, Lefroy hoped to demonstrate in part "the perplexities of a magnetic observer out of reach of skilled mechanical assistance."[86] To some extent, this is true. There were no (human) Foxes, Gambeys, Lloyds or Newmans at large and on hand to help in the places to which Lefroy and his instruments travelled in British North America and the Northwest Territories. Lefroy could and did rely on his own reasonable personal knowledge of the mechanics of his instruments. He filed, straightened, remounted, and sometimes recycled instruments in order to restore their ability to observe, measure, and record. For instance, when the Fox-type dip circle

"became partially broken from the shank" when in use, Lefroy "endeavoured, apparently with success to fix [the problem] with Blowpipe" after which he was able to continue observing the Fox.[87] Later, in September, when Henry broke one of the glasses of the artificial horizon, Lefroy "was obliged to take the back glass of the actinometer and cut it for a new glass."[88] The actinometer became, in the mobile, isolated, context of the Northwest Territories, not only an instrument but a resource, a recyclable object. This incident perhaps also speaks to the hierarchy of instrumentation in Lefroy's survey: what could be bastardized and what could not be spared. If we think back too to the incident in which the calf damaged the Gambey dip circle, an incident which diverted the course of the survey, it is clear that certain instruments were too important to be left in a state of disrepair. Some instruments, however, could be entirely foregone. For instance, several of the barometers and thermometers were also smashed and broken—some quite early in the course of the survey—but Lefroy only mentions procuring one replacement Dollond spirit thermometer from a Mr Swanston at Fort William at the end of May 1843.[89]

Although Lefroy did indeed manage the state of several of his instruments by his own hand and resources, he also relied in great part on the network of HBC forts through which the survey passed and, specifically on the armourers or blacksmiths that worked in these places. The most notable of these occurrences was at Fort Garry, a.k.a Stone Fort, within the Red River settlement, which Lefroy and company reached on 28 June 1843. The party remained at Fort Garry until 4 July in order to have repairs to the dip circle and other articles effected.[90] The "tangent screw of azim[uth] limb of inclinometer" which was "crooked and occasioned irregularity in the motion" was repaired; the "footscrew of vibration box [was] straightened from bend caused by fall at L. Huron"; the "vertical limb of theodolite which was bent by [the same] fall as above [was] flattened; and Lefroy "allowed the armourer to try to straighten the bent axle of Lloyd no.1, it being quite useless in that condition." For this the armourer "first took out the temper [and] afterwards rehardened it." For this last fix Lefroy wrote that the armourer "appears to have succeeded."[91] Lefroy also stated that the armourer's repairs to the dip circle were "very neatly executed." Once again however the humble wagon proved to be a dip circle's nemesis as, when it was moved from lower Fort to upper Fort Garry (where Lefroy was residing) "it was shaken to pieces by 21 miles transport in a cart without springs" even though it was packed in appropriately. Lefroy "had to take it all to pieces and tighten all the screws," an operation which did not seem to require much time as Lefroy was observing the dip later the same day.[92]

This stop was a deviation from the original intended route of travelling from Fort Alexander to Norway House, a fact which demonstrates the importance of certain HBC outposts and the knowledge that skilled mechanical assistance was sometimes, though not always, within reach during the survey.[93] In certain respects, comparison can be made with Lefroy's time in St. Helena, where Lefroy also felt as if he had been "thrown only on one's own resources." This despite the fact that there were workmen in the colony who were not only capable

of repairing instruments but who were willing and able to "pick holes in the coat of a London artist" and make alterations to instruments to improve their functionality, such as occurred with Lefroy's anemometer.[94] Prior to departing for St. Helena, Lefroy had expected that the blacksmiths on the island were capable only of "rough work, but not fine or nice work."[95] In this supposition Lefroy seems to have been proved wrong. Such blacksmiths and armourers were the invisible maintainers of the material parts of the magnetic crusade, given that they were responsible for the upkeep and continual evolution of the physical space of colonial observatory complexes around the world.

A Multiplicity of Hands: Indigenous and Other

The labour of Fort armourers is not the only example of the invisible work behind maintaining Lefroy's survey. Both the French-Canadian voyageurs and Indigenous guides who accompanied Lefroy are also often overlooked in accounts of Lefroy's survey. Thinking about the materiality of the survey—of the non-human actors—is, perhaps ironically, one of the means by which these individuals can be brought into focus because this perspective illuminates the multiplicity of different hands through which these instruments passed on the survey and pays due attention to the fact that although this survey is remembered as Lefroy's survey, it was dependent and contingent upon the capacity of a number of other individuals, from Lefroy's servant, to his assistant Henry, to the various French Canadian voyageurs and local Indigenous guides who carried the fragile instruments and kept them as safe as possible given the arduous travel circumstances. As Lefroy rather rudely put it in a letter to his mother prior to the survey,

> You cannot think what an anxious business has been the conveyance of so many Instruments safely from Toronto by land, and with every care several of them have suffered a good deal—nor will my uneasiness upon this score be soon relieved for the canoes are unloaded every night, and every night will put it in the power of a clumsy voyageur to ruin my hopes.[96]

These "clumsy" voyageurs were men such as Edouard Genereux, one-eyed Pierre Roubillon, Pierre Blondin, Narcisse Arel, and Baptiste Ayot—the "Sancho Panza of the party"—among others.[97] There were also a number of Indigenous men who participated in the safe passage of the survey and its instruments, such as Laurent Tewakewassin and "Louis," both Iroquois, Baptiste Sateka, and two Chipewyans, Gougro—who went "by the agreable [sic.] name of the "Man-Eater""—and Assagai.[98] It was the role of these individuals in particular to carry the entire material inventory of the survey over portages—which ranged from one or two miles to twelve miles in length and could take up to two days to traverse. Lefroy explained the process in a letter to his sister Isabella in October 1844:

> When we arrive at such a place, the canoe is unloaded, taken out of the water, carried across by land, by two of the men, and then the loading carried over to it…The canoe weighs about 400lbs, and two men have to carry it on their shoulders. I have a box

> weighing 100lbs. Someone has the pleasure of carrying that, and so of everything. 180lbs is considered a full load, if compact. They have to go and return as often as necessary until every thing is carried… I always carry something, more indeed than most gentlemen in this country, for the sake of example, and because I have many small separate packages requiring constant care and watchfulness.[99]

Lefroy was always keen, in his memoirs and in his letters, to point out that he carried a "tolerable burden, even for a bourgeois," which included "gun, barometer, dish, haversack with books and axe" at these crossing places.[100] By this admission, however, it would seem that Lefroy did not carry the bulk of his instruments. The instrument he did carry, a barometer, was for the majority of the survey broken. I think it is important to note that the vast majority of the time in which the instruments were carried on the survey it was by the hands of someone other than Lefroy for a couple of reasons. It is true, as MacDonald and Withers and Dunn and Naylor have all pointed out, that using instruments is, as much as anything, a story of training and disciplining the user to manipulate technology. Instrument use was an embodied practice which bred dexterity and regularity in both the user and the object.[101] It is also true, I would argue, that we ought not to dismiss the dexterity, sensitivity, and skill with which voyageurs and Indigenous guides unloaded, carried—sometimes for many miles across steep and swampy ground—and reloaded the hundreds of pounds' weight of instrumentation which made up Lefroy's survey on hundreds of occasions, sometimes incessantly on the days they encountered many small portages. As we have seen on several other occasions, the scientific equipment which travelled on this survey was often extremely fragile and liable to break at even the slightest of rough treatment. Lefroy made it clear in the letter to his mother above how easy it would have been for a "clumsy" voyageur to ruin the hopes of his survey. But, in the hands of a competent voyageur or Indigenous guide, instruments were safely moved and thus their state of existence—whether broken or usable—stabilized. They did not "use" the instruments, but they managed them in arguably as important a way as Lefroy did.

Alongside their management of the state of the instruments, the survey crew also managed the state of the canoes in which Lefroy and the instruments mostly travelled. There are numerous references in Lefroy's field journal to the fact that frequent stops were required for "gumming" of the canoe. The canoe was an important space for the survey. It was both carrier and carried. It provided a space for Lefroy and Henry to sleep following the exhausting ritual of Term Day observations and, occasionally, it was made into a space from which to observe while moving, as Lefroy did with the actinometer on 25 August 1843, although he did not consider the observations "so good as a shore one."[102]

In his recent book on the history of the relationship between the HBC and science, Ted Binnema has explained how, "aboriginal people routinely served not only as trappers, but also as guides, couriers, and hunters for traders throughout the HBC territories."[103] The aboriginal people of Lefroy's survey fulfilled all three of these roles, but Lefroy largely noted their prowess as

guides. Even when Laurent—Lefroy's first guide—"got completely bewildered" for a time "among the archipelago of small low-wooded islands, all singularly alike, which fills the centre of the Lake of the Woods"—the wonder, Lefroy wrote, was

> not that the Iroquois lost his way, but that they should know it at all: that over a line of some three thousand miles these Indians know every stone and stump, and are able to guide a canoe without compass through intricate channels in which a European eye is lost at once.[104]

For navigation, Lefroy had only John Franklin's route maps—which had been made during Franklin's journey of 1819 and which while "very creditable" to the officers that made them, "were at the best imperfect"—as well as astronomical and mathematical instruments such as sextant and azimuth compass, and Indigenous and HBC guides, upon whom Lefroy greatly relied. "Native expertise" had similarly been the context in which several attempts to find the Northwest Passage were made as the local knowledge of Indigenous peoples was "impeccable" because they had "travelled widely" and had a "pretty fair idea of neighbouring topography for many days" travel" as Levere has argued.[105]

Conclusion

The point of illustrating the amount and frequency of the breakages that occurred to Lefroy's instruments during the survey is not to try to demonstrate that the survey was a failure or that Lefroy was an incompetent surveyor. Both are false. Lefroy's survey was an extraordinary feat of scientific endeavour that collected magnetic observations from more than 300 stations across British North America and beyond. His survey remained the "main standard and reference for magnetic observations in western North America for the next three decades" and Lefroy himself was labelled a "highly trustworthy traveller, and one accustomed to rigorous and exact observations" by the Austrian author and magnetic researcher Carl Weyprecht in 1874.[106] Considering the fragility of most of the instruments, the extreme environment and climate through which Lefroy and company bore them, and the several different modes of transport by which they travelled—wagon, canoe, cariole, horse, sledge, on backs and in hands—the instruments survived remarkably well and, as has been said, remained sufficiently workable to make a voluminous amount of credible observations.

Davis Baird has argued that "many instruments hide the very materiality they are made from."[107] Without the breakages that occurred along the way, this would have been true of Lefroy's instruments. The only other references to the instruments in Lefroy's journals except for those made in moments of disrepair are simple statements such as "Obsd with Fox" or "Observed dip with both of Gambey's needles." To use an oft-cited remark of Bruno Latour's, "scientific and technical work is made invisible by its own success. When a machine runs efficiently, when a matter of fact is settled, one need focus only on its inputs

and outputs and not on its internal complexity. Thus, paradoxically, the more science and technology succeed, the more opaque and obscure they become."[108] Or, as Stephen Graham and Nigel Thrift have observed, "things only come into visible focus as things when they become inoperable."[109] This is when the materiality of Fox, Gambey, the magnetometers, and the meteorological instruments becomes tangible and graspable. The point of looking for and exploring instruments in varying states of disrepair is then to recapture a semblance of their materiality and, following Schaffer, to understand how instruments were managed in altered states and to increase an awareness of the importance of repair and maintenance in mobile scientific practice and how this was "dependent on relations between makers, users, and travellers."[110] To this last point I would also add, in the specific context of Lefroy's survey, that focusing on instrument failure and repair also illuminates the particular network of HBC outposts through which Lefroy and his party travelled and in which instruments and magnetic needles were mended and reanimated.

"Each needle has its personal history" wrote Lefroy in his post factum Diary.[111] Arguably, this could be taken further to say that each needle—even each instrument—has also a personal geography. We might call this an instrument's "object biography," "spatio-temporal life," or "social-spatial biography."[112] Just as Pike distinguishes the "geographical notion of entanglements" to demonstrate that brands and branding are inescapably intertwined with spatial associations and connotations and, crucially, that "such attachments shape and are shaped by the agents involved," so we ought similarly to pay attention to the geographical entanglements involved in the biographies of Lefroy's instruments.[113] Caitlin DeSilvey's favourite term for this, and perhaps my own too, is an object's "geobiography."[114]

A geobiography, as Pauli Tapani Karjalainen describes it, is "the expression of the course of a life as it relates to the places lived."[115] It is part of understanding objects, artefacts, scientific instruments, as more of a "process rather than a stable entity," and that the "provisional identity" of a thing can depend in large part on "where they are in their geobiography."[116] For one example of this, we might profitably turn to the dip circle. Levere has rightly pointed out that a traditional, temporal biography of the dip circle in the long nineteenth century reads largely as one of conservatism and stability of design—as indeed was the case for other magnetic instruments in this period. To read the geobiography of a nineteenth-century dip circle is to read a much more unsettled and uneven biography of the object.

As I have written elsewhere, the Gambey dip circle that Lefroy took with him to North America had previously been used during the British Magnetic Survey, 1833-38. As part of this survey, the Gambey was not only an instrument of observation but of experimentation and standardisation too in the particular spaces of London's Regent's Park and Westbourne Green.[117] Briefly, the Gambey was employed at these sites as an instrument against which to critique English-made dip circles and through which to calibrate

and develop these same circles. These parks were shaped as spaces of site-specific experimentation by the Gambey and by extension helped shape what the Gambey—a French instrument—ironically embodied in this time and place: the emergence of British specialism in the art of terrestrial magnetic observation and the construction of instruments accurate and reliable enough for it to be a credible pursuit. The perspective of this work in many ways follows the precedent set by Jenny Bulstrode's persuasive and cogent study of the geographical entanglements—of Cornwall and Cornish mines—attached to the construction, popularisation, and distribution of Fox's dip circle in the early 1830s.[118]

In like manner, reading the geobiography of Lefroy's instruments, most notably the dip circles, we are able to discern the frequently changing and ultimately changed significance of such apparatus as they related to the places of the survey. As has been demonstrated, the dip circles were frequently rendered unusable or untrustworthy during their time in the often harsh North American environment. And, as has also been shown, these instruments were put back together by local HBC armourers or by Lefroy himself using what resources he could muster in the places he found himself in, and maintained as much as possible in their reconstructed states by Indigenous guides and French Canadian voyageurs. In other words, what the Gambey and the Fox, or indeed several of the other instruments, came to represent, was the physical manifestation of the combination of skills and knowledges of British and continental instrument makers together with local craftsmen, facilitated by Indigenous labour. Seen in this way, these instruments represent a disruption to the traditional dichotomy of the centre and the periphery, the metropole and the wilderness, in which terms nineteenth-century imperial science is sometimes framed. The geobiography of Lefroy's instruments shows that the passage of Lefroy's survey was one taken through hybrid spaces and, in passing through, these instruments were themselves made hybrid.

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Endnotes

1 See Gregory Good, 'Between Two Empires: the Toronto Observatory and American Science before Confederation," *Scientia Canadensis: Canadian Journal of the History of Science, Technology and Medicine* 10, 1 (1986): 34-52; Suzanne Zeller, *Inventing Canada: Early Victorian Science and the Idea of a Transcontinental Nation* (McGill-Queen's University Press, 2009); and Zeller, 'Humboldt and the Habitability of Canada's Great Northwest," *Geographical Review* 96, 3 (2006): 382-398, especially 388-391.

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3 Humphrey Lloyd to Charles J.B. Riddell, 30 December 1839, Royal Society Library and Archives [hereafter RS] Manuscripts General [MS] 119/4 (Vol. I).

4 Edward Sabine, 'Contributions to Terrestrial Magnetism. No. VII," *Philosophical Transactions of the Royal Society of London* 136 (1846): 237-336, 238. Emphasis added.

5 Zeller, *Inventing Canada*; and Zeller, 'Humboldt and Habitability."

6 Ted Binnema, *Enlightened Zeal: The Hudson's Bay Company and Scientific Networks, 1670-1870* (Toronto: University of Toronto Press, 2014): 200

7 Trevor H. Levere, *Science in the Canadian Arctic: A Century of Exploration, 1818-1918* (Cambridge: Cambridge University Press, 1993); and Trevor H. Levere, 'Magnetic Instruments in the Canadian Arctic Expeditions of Franklin, Lefroy, and Nares," *Annals of Science* 43 (1986): 57-76.

8 See, for example, Diarmid A. Finnegan, 'The Spatial Turn: Geographical Approaches in the History of Science," *Journal of the History of Biology* 41 (2008): 369-388; David N. Livingstone, 'The Spaces of Knowledge: Contributions towards a Historical Geography of Science," *Environment and Planning D: Society and Space* 13 (1995): 5-34; David N. Livingstone, *Putting Science in its Place: Geographies of Scientific Knowledge* (Chicago and London: University of Chicago Press, 2003); David N. Livingstone and Charles W. J. Withers, eds, *Geographies of Nineteenth-Century Science* (Chicago and London: University of Chicago Press, 2011); Richard C. Powell, 'Geographies of Science: Histories, Localitites, Practices, Futures," *Progress in Human Geography* 31, 3 (2007): 309-329; and Simon Naylor, 'Introduction: Historical Geographies of Science – Places, Contexts, Cartographies," *BJHS* 38, 1 (2005): 1-12.

9 Simon Schaffer, 'Easily Cracked: Scientific Instruments in States of Disrepair," *Isis* 102, 4 (2011): 706-717

10 Sabine to Lloyd, [?] April 1839, RS:MS/119/66 (Vol. I).

11 Sabine to Lloyd, 8 April 1839, RS:MS/119/49 (Vol. I).

12 Sabine to Lloyd, 23 October 1838, RS:MS/119/58 (Vol. I).

13 Sabine to Lloyd, [?] April 1839, RS:MS/119/66 (Vol. I).

14 Sabine, 'Contributions VII," 239.

15 Lloyd to Sabine, 27 April 1840, The National Archives, United Kingdom, [hereafter TNA] BJ/3/10/151.

16 See, for example, Lefroy to Sabine, 19 October 1840, TNA BJ/3/81/18.

17 Lloyd to Sabine, 15 May 1841, TNA BJ/3/11/201.

18 Riddell to Lloyd, 26 October 1843, RS:MS/119/39 (Vol. II).

19 Binnema, 213

20 John Henry Lefroy, *Autobiography of General Sir John Henry Lefroy*, ed. Lady Lefroy, printed for private circulation (n.p., n.d.): 63. Reducing the data accrued from both the mobile surveys and the fixed magnetic observatories was extremely labour-intensive. As such, only a small part of it was ever reduced in the 19th century, much less analysed, but these data would prove useful in 20th century reductions.

21 Julian A. Smith, 'Humboldt, Sabine and the "Magnetic Crusade:" The Founding of the Toronto Observatory," a research report completed under contract to the Canadian Museum of Science and Technology (1989): 31-32.

22 *Ibid*., 34.

23 Lefroy, *Autobiography*, 64.

24 Lefroy to Charles Wright Younghusband, 25 April 1842, in George F. G. Stanley, ed., *John Henry Lefroy: In Search of the Magnetic North. A Soldier-Surveyor's Letters from the North-West, 1843-1844* (Toronto: Pioneer Books, the MacMillan Company of Canada Limited, 1955): 6.

25 John Henry Lefroy *Diary of a Magnetic Survey of a Portion of the Dominion of Canada chiefly in the North-Western Territories, Executed in the Years 1842-1844* (London: Green and Co., 1883): 2.

26 Lefroy, *Autobiography*, 64.

27 Lefroy's manuscript journal is in Yale University Library, and I have used a microfilm copy found in Library and Archives Canada, John Henry Lefroy MG24-H25, microfilm reel M-2314, *Journals of Sir John Henry Lefroy*, 2 Vols, Vol. I, [hereafter JLVI], 5, 1 May 1843; and 11, 2 May 1843.

28 List and specification of articles taken by Lieut. Lefroy on the magnetic survey, to the northwest, Lachine, 30 April 1843, TNA BJ/3/35/15.

29 Lefroy, *Diary*, 1.

30 All weights from Lefroy's *Diary*, 1; and all prices from Charles J. B. Riddell, *Magnetical Instructions for the use of Portable Instruments adapted for Magnetical Surveys and Portable Observatories* (London: W. Clowes & Sons, 1844): 98-99.

31 Lefroy to George Simpson, Governor-in-Chief of Rupert's Land, forwarded to Colonel Sabine, Montreal, 25 September 1842, quoted in A. D. Thiessen, 'The Founding of the Toronto Magnetic Observatory and the Canadian Meteorological Service," Part V, *Journal of the Royal Astronomical Society of Canada* 35 (1941): 141-150, 146.

32 Lefroy, *Diary*, 1.

33 Levere, *Magnetic Instruments*, 66, f. 39.

34 Anita McConnell, 'Jones, Thomas (1775-1852)," *Oxford Dictionary of National Biography* [*ODNB*], Oxford University Press [OUP], 2004 [http://www.oxforddnb.com/view/article/15096, accessed 20 July 2017]; Sabine to Lloyd, 16 March 1839, RS:MS/119/61 (Vol I.)

35 Lefroy to Sabine, 20 May 1843, TNA BJ/3/35/24.

36 Paolo Brenni, '19th Century French Scientific Instrument Makers I: H-P. Gambey," *Bulletin of the Scientific Instrument Society* 38 (1993): 11-13.

37 Denise Crook, 'Fox, Robert Were (1789-1877)," *ODNB*, OUP, 2004 [http://www.oxforddnb.com/view/article/10042, accessed 20 July 2017]; Anita McConnell, 'Jordan, Thomas Brown (1807-1890)," *ODNB*, OUP, 2004 [http://www.oxforddnb.com/view/article/15123, accessed 20 July 2017].

38 'List," TNA BJ/3/35/15.

39 JLVI, 22, 9 May 1843.

40 Lefroy to Sabine, received 10 August [1842], TNA BJ/3/35/7.

41 Sabine, 'Contributions VII," 238.

42 The dates and places of Lefroy's survey can be found in Lefroy, *Diary*; Lefroy, *Autobiography*; and Thiessen, Part V, 149-150.

43 Lefroy to Younghusband, 13 December 1843, quoted in Stanley, *John Henry Lefroy*, 69.

44 Lefroy, *Diary*, v.

45 George Simpson to the Gentlemen in charge of Districts and posts in the Service of the Honorable Hudson's Bay Company, 26 April 1843, in Thiessen, Part V, 148.

46 Lefroy, 5 May 1843, *Diary*, 61.

47 Lefroy, 1 June 1843, *Diary*, 79.

48 Lefroy to Younghusband, 20 May 1843, quoted in Stanley, *John Henry Lefroy*, 13.

49 JLVI, 138, 20 July 1843.

50 Lefroy, 21 June 1843, *Diary*, 90.

51 JLVI, 253, 19 September 1843.

52 JLVI, 30, 14 May 1843; and 62, 11 June 1843.

53 JLVI, 256, 20 September 1843.

54 JLVI, 122, 12 July 1843.

55 JLVI, 31, 14 May 1843.

56 JLVI, 118, 10 July 1843.

57 *Ibid.*; and swampy ground from JLVI, 136, 19 July 1843.

58 Lefroy, *Diary*, 38

59 JLVI, 150, 26 July 1843.

60 JLVI, 17, 7 May 1843.

61 JLVI, 21, 9 May 1843.

62 JLVI, 43A, 24 May 1843.

63 JLVI, 254, 19 May 1843. The moose got away.

64 JLVI, 61A, 11 June 1843.

65 JLVI, 41, 22 May 1843; Lefroy, 16 June 1843, *Diary*, 87.

66 Lefroy to his mother, 6 June – 1 July 1843, quoted in Stanley, *John Henry Lefroy*, 27.

67 JLVI, 42A, 24 May 1843.

68 JLVI, 15, 6 May 1843.

69 JLVI, 33, 15 May 1843.

70 Lefroy to Sabine, received 10 August [1842], TNA BJ/3/35/7.

71 JLVI, 49A, 30 May 1843.

72 JLVI, 248, 16 September 1843.

73 JLVI, 220, 2 September 1843.

74 JLVI, 79, 20 June 1843.

75 Lefroy, 20 June 1843, *Diary*, 89. To an extent, this accident was fortuitous. Had the calf not blundered in and broken the Gambey, Lefroy would not have altered his route to take in the Red River Settlement and would then not have bumped into Sir George Simpson, North American Governor of the HBC. It was Simpson at the Red River would advised Lefroy to head not for Moose Factory as originally intended but instead to make for Fort Chipewyan and overwinter there. See Lefroy, *Autobiography*, 74; or John Henry Lefroy and Sir John Richardson, *Magnetical and Meteorological Observations at Lake Athabasca and Fort Simpson…and at Fort Confidence in Great Bear Lake* (London: Her Majesty's Stationery Office, 1855): ix-x.

76 JLVI, 34A, 16 May 1843.

77 JLVI, 150, 26 July 1843.

78 JLVI, 145, 24 July 1843.

79 Lefroy, *Diary*, 30, 31.

80 Lefroy, *Diary*, 20.

81 Jutta Schickore, 'Ever-Present Impediments: Exploring Instruments and Methods of Microscopy," *Perspectives of Science* 9, 2 (2001): 126-146, 136.

82 For some attempts to do so though, see Schaffer, 'Easily Cracked"; David Edgerton, *The Shock of the Old: Technology and Global History since 1900* (London: Profile, 2008); and Simon Werrett, 'Recycling in Early Modern Science, *BJHS* 46, 4 (2013): 627-646.

83 See Caitlin DeSilvey, 'Object Lessons: From Batholith to Bookend," in *The Wiley-Blackwell Companion to Cultural Geography*, eds. Nuala C. Johnson, Richard H. Schein, and Jamie Winders (Chichester, Wiley-Blackwell, 2013): 146-158. DeSilvey gives a concise summary of the kinds of things these works have focused on, from Cornish harbours to post-Katrina New Orleans.

84 Fraser MacDonald and Charles W. J. Withers, 'Introduction: Geography, Technology and Instruments of Exploration," in *Geography, Technology and Instruments of Exploration*, eds Macdonald and Withers (Farnham: Ashgate, 2015): 1-14, 10.

85 Schaffer, 'Easily Cracked," 708.

86 Lefroy, *Diary*, 30.

87 JLVI, 48A, 29 May 1843.

88 JLVI, 220, 2 September 1843.

89 JLVI, 50A, 31 May 1843.

90 Lefroy, 29 June 1843, *Diary*, 94.

91 JLVI, 101, 1 July 1843.

92 JLVI, 104, 3 July 1843.

93 Lefroy to his mother, 6 June – 1 July 1843, in Stanley, *John Henry Lefroy*, 31.

94 Lefroy to Sabine, 31 August [1840?], TNA BJ/3/81/16; and Lefroy to Sabine, 17 November 1840, TNA BJ/3/81/20.

95 Lefroy to Sabine, [1839?], TNA BJ/3/81/2.

96 Lefroy to his mother, 25 April 1843, in Stanley, *John Henry Lefroy*, 4. Emphasis added.

97 Lefroy, *Autobiography*, 75.

98 JLVI, 237, 11 September 1844; and Lefroy to his mother, 30 September 1843 – 2 January 1844, in Stanley, *John Henry Lefroy*, 65.

99 Lefroy to his sister, Isabella, 18 October 1844, in Stanley, *John Henry Lefroy*, 129.

100 Stanley, *John Henry Lefroy*, xx. Emphasis in original.

101 MacDonald and Withers, 'Introduction," 9-10; Richard Dunn, 'North by Northwest? Experimental Instruments and Instruments of Experiment," in *Geography, Technology and Instruments of Exploration*, 57-75; and Simon Naylor, 'Weather Instruments all at Sea: Meteorology and the Royal Navy in the Nineteenth Century," in *Ibid*., 77-96.

102 JLVI, 204, 25 August 1843.

103 Binnema, 31.

104 Lefroy, 18 June 1843, *Diary*, 88; Lefroy to his mother, 6 June – 1 July 1843, in Stanley, *John Henry Lefroy*, 28.

105 Levere, *Science and the Canadian Arctic*, 4.

106 Smith, 'Humboldt," 36. Weyprecht quoted by Smith from Dictionary of National Biography, II, 841.

107 Davis Baird, *Thing Knowledge: A Philosophy of Scientific Instruments* (Berkeley: University of California Press, 2004): 19.

108 Bruno Latour, *Pandora's Hope: Essays on the Reality of Science Studies* (Cambridge, Mass. and London: Harvard University Press, 1999): 304.

109 Stephen Graham and Nigel Thrift, 'Out of Order: Understanding Repair and Maintenance," *Theory, Culture and Society* 24, (2007): 1-25, 2, quoted by DeSilvey, 'Object Lessons," 150.

110 Schaffer, 'Easily Cracked," 710.

111 Lefroy, *Diary*, 18.

112 'Socio-spatial biography" is a term found in Pike, A., 'Placing Brands and Branding: A Socio-Spatial Biography of Newcastle Brown Ale," *Transactions of the Institute of British Geographers* 36 (2011): 206-222; 'Spatio-temporal" is a term found in Hill, J., 'Travelling objects: The Wellcome Collection in Los Angeles, London and Beyond," *Cultural Geographies* 13 (2006): 340-366

113 Pike, 'Placing Brands and Branding," 206

114 See DeSilvey 'Object Lessons," 147.

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117 Matthew Goodman, 'Proving Instruments Credible in the Early Nineteenth Century: The British Magnetic Survey and Site-Specific Experimentation," *Notes and Records of the Royal Society* 70, (2016): 251-268.

118 Jenny Bulstrode, 'Men, Mines and Machines: Robert Were Fox, the Dip-Circle and the Cornish System," (Unpublished MA thesis, University of Cambridge, 2014).