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**INSTRUMENT PROVISION AND GEOGRAPHICAL SCIENCE: THE WORK OF
THE ROYAL GEOGRAPHICAL SOCIETY, 1830–c.1930**

by

Jane A. Wess and Charles W. J. Withers

This paper examines the Royal Geographical Society's provision and management of scientific instruments to explorers and expeditions in the century following its foundation in 1830. Assessment of the Society's directives concerning appropriate scientific instruments for the conduct of geography reveals the emergence (slow and uneven) of policies concerning the assignment of instruments. From examination of Council minutes and related manuscript sources, the paper documents the numbers of instruments acquired by the Society, by whom used, for what scientific purpose, and in which parts of the world. The paper examines the number and chronology of expeditions supported by the Society's instruments, the expenditure upon instruments' repair, and discusses the publications that followed their use in exploration. Correspondence between instrument users and the Society reveals that, on occasion, the use of instruments was adventitious. While geographical knowledge depended upon the use of scientific instruments to measure and to depict the world, geography was not a formally institutionalised survey science as was the case with the Geological Survey or the nation-defining mapping of Ordnance Survey.

Keywords: Royal Geographical Society; geography; exploration; instruments

INTRODUCTION

The Royal Geographical Society (RGS) was established, in London, in 1830. Geography was not then an established discipline, its cognitive content clearly defined, its methods of enquiry agreed-upon and everywhere undertaken in the same way by persons who called themselves ‘geographers’ and earned a living in the practice of that subject.¹ Rather, what was taken to be geography was in a state of disciplinary and epistemological emergence, ‘in formation’ in terms of its main concerns and procedures. Yet, the intention to obtain instruments and guide would-be geographers in their use was clear from the outset. The third of the Society’s stated aims at foundation articulated the need ‘To procure specimens of such instruments as experience has shown to be most useful, and best adapted to the compendious stock of a traveller, by consulting which, he may make himself familiar with their use’.² Despite such declarations and the Society’s aim at discipline—both as scientific knowledge and the ordering procedures necessary to obtain it—little attention has been given to the Society’s purchase and provision of scientific instruments, or to their use in the field, in the century following foundation.³ What sort of instruments did the Society provide? Did the Society’s instrument provision vary over time? Who made use of these instruments, and to do what sort of scientific work? Rather than alone address such empirical lacunae over instrument provision and use, the paper also poses questions concerning the significance of instruments as ‘lively but disorderly’ agents in the making of geography, and over the relationships between instrument use, exploration and publication. We show how geography became more evidently scientific from the 1870s and how instrument use was associated with this change in emphasis.

In examining these issues, the paper makes use of four bodies of source material. RGS Council minutes, and material relating to several ad hoc sub-committees, provide a record of

the Society's business. Although inconsistent in quality of entry, a manuscript ledger entitled 'Catalogue of Instruments' summarily lists, by instrument type, the different scientific instruments purchased by the Society from 1879 and lent to those travellers and explorers whose work was approved by that body.⁴ A second manuscript ledger, 'Instruments Lent to Travellers', itemises which would-be travellers and explorers borrowed which instruments and where in the world the exploration was to be undertaken, from 1860.⁵ Finally, individual correspondence files and, for some explorers, records relating to publication of their work, reveal how instruments sometimes failed: such evidence is noteworthy since many written accounts of exploration and survey belie the breakdown of these recording and measuring devices and, on occasion, their human operatives.⁶ The guidance given to users in the Society's de facto instructional manual, *Hints to Travellers*, first published in 1854, has been the subject of enquiry before now, and is not discussed here.⁷

What follows presents, in four sections, summary findings for hitherto largely unexamined aspects of the Society's instrumental endeavours. The first documents institutional directives on instrument provision: faltering and uneven until the 1870s. The second examines the chronology and character of that provision: c.1500 instruments were purchased by the RGS in the century from 1830. The third assesses the chronology and geography of RGS-supported exploration and expeditionary activity: over 430 'expeditions were supported in their work by RGS instruments. The fourth offers a different scale of analysis. It illustrates for several individuals the results of instrumental use in the field—that is, it highlights the relationships between instruments and their users, the agency of instruments, the emergent culture of instrumentation within geography, and the written accounts of exploration that followed their use. In conclusion, the paper addresses the implications of this evidence for an understanding of geography and its practice as a science of survey in the nineteenth century.

INSTITUTIONAL DIRECTIVES ON THE PROVISION OF INSTRUMENTS

What and whose was the basis in experience hinted at in its stated aim in 1831 is not clear, but it is apparent that the Society was slow to act. A report to RGS Council in 1833 prepared by Julian Jackson, then Secretary, suggests no instruments were acquired in the intervening two years: he reported how ‘The 3rd point, the procuring of approved instruments, that travellers may be familiarised with their use has been completely neglected’.⁸ Jackson had earlier expressed his views on the importance of instruments to travellers and explorers and on their proper instruction.⁹ In this earlier work and in his 1833 report to RGS Council, Jackson advocated exploration as an opportunity to raise the profile of the Society, stimulate the interest of existing members, and encourage recruitment of new members. Instruments were central to this emphasis and, from that, to geography’s emergent identity. Jackson hoped that they might be donated: ‘A small collection of geodetical instruments sufficient to show the general nature of such operations, and of the means taken to accomplish them, besides being distinctly specified in our prospectus as a contemplated part of our establishment, would probably lead to a number of presents being made to us of new instruments as they progressively appear, and thereby, bring these under the notice of intending travellers’.¹⁰

The supply of scientific instruments for use in the field assumed greater importance as the Society began to support expeditions. The first person provided with instruments in this respect was Captain James Alexander, in 1834, for his African expedition.¹¹ If the nature of this provision intended to emulate the contemporaneous practice of Alexander von Humboldt, John Herschel and others in employing scientific instruments to measure natural phenomena in order to establish explanatory laws, the generous financial terms were, later, cited as being partly responsible for the financial downturn of the Society in the 1840s.¹² The Society also approached other institutions and expected that explorers provide their own instruments where they could. In instructions given to Robert Schomburgk for his 1834 Guyana

expedition, for example, the RGS borrowed an Englefield barometer: Schomburgk also used his own.¹³ The same Council meeting that agreed the first expeditions also established the first de facto Instrument Committee, but no minutes of this survive.

The Society did not repeat its initial generosity to Alexander. In 1838, the Society spent only £33 on a sextant and a barometer for a Captain Jervis's expedition to Kurdistan, who, additionally, was advised to approach the East India Company for £150 towards the cost of further instruments.¹⁴ Only six guineas were spent in support of an expedition to Mexico in 1839.¹⁵ In 1840, the Society stated it would merely 'furnish the common instruments for determining Charles Beke's position' in Africa, an attitude it repeated for Austen Henry Layard's Near East work two years later.¹⁶ Evidence for low levels of instrument acquisition in the first twenty years of the Society's activities points to a gap between the Society's stated ambitions and actual practice and suggests instrument acquisition was carried out in a haphazard manner. By the late 1840s, the financial situation had deteriorated to the extent that, for nearly a decade, the Society virtually ceased to lend instruments to explorers.¹⁷

The first listing of instruments appears in the Society's *Journal* in 1851. Of forty-two instruments listed, twenty were bequeathed by the late Robert Shedden; two were a gift from Mansfield Parkyns, the explorer of Abyssinia; four were lent, in 1849, by the British Vice-Consular official at Whydah in West Africa: the remainder had been purchased by the Society.¹⁸ If this listing suggests that the Society by then regarded these scientific devices (mainly chronometers, compasses and barometers but which also included mathematical and drawing instruments and a 'Case of Surgical Instruments') as its instrument collection, it was still considered inadequate by some. In the Expeditions Committee on 18 November 1852, Francis Galton (returned only recently from two years' travels in south-west Africa) drew attention to what he called the 'want of proper instruments for travellers'. This, with others' work, led Council 'to draw up a set of general instructions for the use of travellers, to be laid

before the Committee as early as convenient'.¹⁹ The proper use of instruments was a key part of these instructions—what, from 1854, became *Hints to Travellers*.²⁰

The Society formed a committee to investigate the state of its instruments in 1859. At its first meeting on 18 February 1859, it oversaw a circular to the main suppliers of the type of scientific instruments used in field research. Echoing Jackson's 1833 report, this circular invited suppliers to 'forward specimens of various meteorological instruments for inspection by the Committee'.²¹ At its meeting of 25 February 1859, the Instrument Committee examined the existing instruments and produced a report upon them. This report—which has not survived: we know of it only from surviving minutes—made clear the poor state of RGS instrument holdings: 'The Committee are clearly of opinion that the instruments in the possession of the Society are very defective and they recommend that a set of the meteorological instruments specified in the accompanying list should be purchased and kept as examples of what they recommend travellers to take'.²² Even as the Society was identifying which instruments it wished to make available for the instruction of travellers in association with *Hints*, moves were made to dispose of instruments not up to scratch. Instructions over disposal first appear in the Finance Committee minutes for 19 March 1860: the reason given was lack of space within the Society's rooms.²³ The following week, a list was prepared, following that of 1851, with, unnumbered, other instruments acquired since. In spite of assessing the condition of the instruments as 'poor', the committee recommended retaining thirty of the total thirty-seven. From 1857, the Society listed instruments out on expeditions in its *Journal*. From 1860, the manuscript ledger 'Instruments Lent to Travellers' details the expeditions to which instruments were lent. This suggests that, by about 1860, the Society had begun to take seriously the listing of its instruments and the need to keep records of their condition, and of the persons to whom, and for what purpose, instruments were lent. From this date, we can be more certain over institutional initiatives.

In August 1866, the Map Committee set down the duties of the Society's map curator and formally acknowledged his role as keeper of the Society's instrument collection and his responsibility to accession new instruments and keep a register of instruments lent.²⁴ In February 1870, the Finance Committee recommended that the Expedition Committee, and not it, should have responsibility for selection of instruments. In December 1872, an Expedition Sub-Committee proposed limiting the types of instruments purchased by the Society to those recommended in *Hints to Travellers*, namely, sextants, artificial horizons, half-chronometers, compasses (both prismatic and ordinary), lanterns, thermometers (both ordinary and boiling point), aneroid barometers, and mapping instruments.²⁵ In earlier periods in particular, traverse surveys were routinely carried out with triangulation only taking place infrequently: in later decades, greater mention of theodolites suggests the more common use of triangulation.²⁶ In one sense, the instruments emphasised in earlier years bore a closer resemblance to those used in navigation than those used in geodetic survey. From 1879, acquisition data are more systematically recorded providing date, source and, usually, cost. This was driven by a need to limit expenditure—on instruments and on the instructional guidance given to intending explorers by the map curator.²⁷

Evidence on RGS strategy concerning instrumental provision thus allows us to advance several points. The early intimation over instruments' importance in developing geography was not matched in systematic and coordinated ways by patterns of purchase. There was not an immediate uptake in instrumental provision in the wake of *Hints to Travellers* (1854). A relative 'peak' in 1861 may reflect better record keeping consequent upon the establishment of the Instruments Committee in 1859, just as that in 1879 may indicate the fuller record evident in the *Catalogue of Instruments and Instruments Lent to Travellers* (see below). Yet, the existence of this Committee did not have an immediate effect on acquisition (perhaps because it met only twice in the five years following its foundation). Because expenditure on

instruments could be high, the Society would borrow when it could. Before 1879, acquisition information was not recorded consistently. From 1879, the greater consistency of record must be weighed against a sense that, in its more meticulous recording of expenditure, the Society had belatedly come to the view that instruments were items of scientific worth rather than objects provided only grudgingly when they could not be sourced elsewhere.

THE CHRONOLOGY AND CHARACTER OF INSTRUMENT PROVISION

Between 1879 and 1930, the Society acquired 1156 individual instruments (overall, it is likely it acquired about 1500 instruments in the century from 1830).²⁸ Presenting instrument acquisition by year is illuminating, but also potentially misleading. A fuller picture emerges if we consider the relationship between acquisition and expenditure (Figure 1). Differences between acquisition and expenditure reflect levels of borrowing from other institutions, such as the Admiralty, and donations (that from Shedden in 1850–1851, for example, is evident in figure 1). An increase in spend in 1861 followed the use of money for instruments from the Petherick fund.²⁹

<Figure 1 about here: half page, landscape>

Interpretation of figure 1 requires a note of caution. Between 1860 and 1872, the instruments out on loan were listed, but no audit was kept of instruments in the Society's possession. Between 1872 and 1879 there was further inconsistency in record keeping in that no information was provided regarding individual instruments, merely a list of the expeditions to which they were lent.³⁰ While purchasing was more prevalent in and from the 1870s, this evidence suggests that loan was preferred where that was possible.³¹ Noting these caveats, there were various 'peaks' of instrument acquisition—in the early 1860s, in the later 1870s and the early 1880s, in the early 1890s, the 1910s and the late 1920s—and these moments were differently constituted as instruments were either bought, lent, or donated.

The level of instrumental acquisition in the early 1860s was largely from loans and donations. The peaks of acquisition and expenditure in the later 1870s and in the early 1880s reflect moves made by the Society and by Section E, the geography section, of the British Association for the Advancement of Science, towards a ‘scientific geography’. It was also a consequence of the work of John Coles from 1879 in managing the Society’s instruments in his role as map curator and in giving instruction in their use.³² At the 1872 Association meeting in Brighton, for example, Francis Galton—whose reputation was in part established by his African travels—argued that ‘the work of exploration was reaching its final limit, and that the future labours of geographers would have to be directed to obtaining a truer knowledge of the effects of soil and climate upon the physical condition of countries’.³³ Later peaks reflect the acquisition of instruments for Harry H. Johnston for his African work, polar exploration (chiefly Antarctic)—the peak of 1902 is the equipping of the *Discovery* expedition—and that for 1909 partly by a Balkan expedition.³⁴ The last peak reflects the society’s concern to re-establish expeditionary work after WW1.³⁵ The year of single greatest expenditure, 1926, reflects the Society’s purchase of a Wild photo-theodolite for £98 10s.

The chronology and expenditure of provision summarised in figure 1 masks a further element concerning the Society’s instrument holdings, namely, evidence of repair (Figure 2). Here, too, data is variable in date and quality: minutes record evidence of repair only from about 1864; the timing of repair could post-date an instrument’s breakdown in use and delay their further use; it is not always clear that the repair costs indicated were always carried through upon—instruments were quite commonly ‘written off’ as irreparable following exploratory use. There were peaks of repair—in the late 1880s, the late 1890s, and the turn of the century. In general, the chronology and magnitude of the levels and costs of repair mirrors that of acquisition and expenditure: the Society ‘recycled’—re-activated—repaired instruments where it could (a point returned to below).³⁶

<Figure 2 about here: half page, landscape>

EXPLORATION CHRONOLOGY, GEOGRAPHY, AND INSTRUMENT USERS

The Royal Geographical Society lent instruments to 436 expeditions between 1830 and 1930. The number of expeditions was low until the 1870s but rose thereafter, peaking in the mid-1890s (Figure 3): the level of expeditionary activity and the numbers of instruments in use exhibit similar chronologies (*cf.* Figures 1 and 3). The majority of early expeditions were ‘open-ended’ in character, that is, exploration was undertaken in order to fill, from a European perspective at least, ‘blanks’ on maps of the regions in question. From the later 1870s and 1880s, expeditions were more focused, their end-in-view specific aspects of physical geography, natural history, or ethnography, and in mapping particular parts of the world. Here, too, the chronology and geography of expeditions from the mid and later 1870s was a reflection of, and a stimulus to, a more evidently scientific geography. This point is exemplified in correspondence from African explorer Keith Johnston to Henry Bates, then Secretary of the RGS, in November 1875: ‘The geography upon which the Society depends, and which will give occupation to its Fellows, must then gradually turn from that of discovery of new lands to the questions of physical geography’.³⁷ It is evident institutionally, as Max Jones has shown, in the work of the Society’s Scientific Purposes Committee, which, in May 1879, prepared a ‘Memorandum on a plan for training travellers to make useful scientific observations’.³⁸ This emphasised the importance of instructional training in instruments and prompted revisions to the Society’s *Hints to Travellers*. The Memorandum also identified the categories of traveller who would benefit from instruction: military officers; clerks employed in merchants’ houses; planters and settlers; colonial officials; collectors; and ‘sportsmen and ordinary travellers, who visit little-known regions for their own amusement’.³⁹

<Figure 3 about here, half-page, landscape>

Individuals did not always so self-identify when seeking use of RGS instruments. In general, the number of ‘gentlemen’, some of them colonial agents in one sense or another, increased from the 1870s, as did the numbers of churchmen/missionaries and military officers (Figure 4). We have found that medical doctors—not a ‘target category’ in the 1879 Memorandum—were also involved. Very few female explorers received expeditionary support: one in each of the 1880s, the 1890s and the 1920s. This is consistent with the Society’s general exclusion of women from geographical science until the early twentieth century.⁴⁰

<Figure 4 about here: half page, landscape>

From the mid nineteenth century, the focus for the majority of the expeditions was sub-Saharan Africa, chiefly central and east Africa. Much of the heightened activity from the 1870s was characterised by a specificity of purpose and, for several, by targeted funding designed either to address a particular problem (of geology, or hydrography) or to produce more accurate topographic maps. Expedition work, as Dritsas has documented, also helped solve debates in the metropole between ‘critical geographers’—sedentary book-led theorists—and ‘field-based’ explorers, by addressing questions of topography, sometimes using indigenous knowledge, in the colonial periphery.⁴¹ The turn toward Antarctic exploration from the 1890s may have been in direct response to the twice-made call, in 1895, of Clements Markham, President of the RGS, who—at the British Association meeting in Ipswich and in London at the International Geographical Congress—proclaimed that the last great geographical endeavour to be undertaken was exploration of the Polar regions.⁴² In the early twentieth century, expeditions were more widely dispersed, with a high proportion centred upon the Middle and Near East.

Analysing the data by the phenomena measured reveals that more instruments were used to measure height than any other physical phenomenon, followed by temperature, position-finding, direction-finding and drawing (Figure 5). The emphasis on height reflects contemporary interests in topographic survey, in the connections between plant assemblages, topography and altitude, and in what contemporaries such as Thomas Huxley called physiography, as well as a concern for planimetric accuracy in maps.⁴³ Large numbers of thermometers were used because of their ease of use and general applicability, which included height measurement, but also because they were fragile and so easily broken. Meteorology was frequently a secondary consideration after the dimensions of latitude, longitude, and height. Throughout the period, while a small minority of instruments was not mobilised, many were repeatedly sent out —‘reactivated’ in different hands and, often, a different part of the world. The maximum number of expeditions by one scientific instrument was eighteen: the average between three and four. In this sense, instruments had an active ‘liveliness’, a repeat mobility traceable from individual entries in the ‘Instruments Lent to Travellers’ volume.

<Figure 5 about here: half page, landscape>

In sum, RGS instruments were widely used in topographic survey, in the preparation of accurate maps, and, from the later 1870s especially, to aid in more exact scientific work. This was terrestrial survey work, but it was not institutionally-driven and formalised in the style of Ordnance Survey, the Geological Survey, or the Great Trigonometrical Survey of India. The results of individual exploration and expeditionary activity certainly contributed to advances in geographical science, but such geographical work was not equivalent to the ‘research school’ that Secord has seen in Britain’s Geological Survey between 1839 and 1855, or others for national surveys in Canada, India and the United States.⁴⁴ There, national survey was a form of national (or colonial) identity through science: political initiative led to

coordinated institutional activity, in the field and in the drawing office, and did so using agreed-upon practices of metrological standardisation and cartographic representation as a means to civic governance and self-identity. This is not to say that the RGS did not support and so extend British governmental interests in its provision of instruments for expeditions and exploration. Geography as exploration was widely interpreted as the queen of the imperial sciences in this respect.⁴⁵ It is to note that the RGS did not act as a formal branch of imperial government (although many of its practitioners, especially in and from the last decades of the nineteenth century, were colonial administrators or military officers). Its policies and practices of instrument provision did not act to promote an already certain sense of what geography was by persons we can describe as ‘professional geographers’ (in contrast, say, to geologists, hydrographers, or military map makers). Rather, the reverse was true: instrument provision was haphazard, uneven over time and in the type of instruments involved, and was part of tentative gestures toward what, only later, would become geography’s disciplinary reach and significance. The men involved were professionalised practitioners of one sort or another, doing geographical work, but they were not geographers in any formal subject-evident sense.⁴⁶

POST-USE GEOGRAPHIES: EXPLORATION PUBLICATION AND THE REPORTED ROLE OF INSTRUMENTS

Of the 436 exploratory expeditions that made use of RGS instruments between 1830 and 1930, 252 led to publications in a peer-reviewed journal: a rate of 60%. The rate of publication varied over the period, but for earlier decades especially, the numbers were low so percentages are not always an accurate guide. In general, over half—sometimes considerably more—of those persons who borrowed instruments in the period 1830–c.1900 turned their exploration into print: there was a noticeable decrease in the twentieth century

(Figure 6a). What is also the case is that there was, from the 1890s, an increase in the number of papers published other than in the journals of the Society—that is, several explorers and expeditionary leaders made use of non-geography periodicals to publish their work despite having made use of the Society’s instruments to conduct it (Figure 6b).

<Figure 6 about here: full page, portrait>

Two cautionary notes are necessary in considering the ‘conversion rate’ of exploration into publication. Without detailed interrogation, it is not possible to know if and how instrument use was a necessary or merely attendant factor in securing the publication of geographical exploration—that is, was instrument use a required sign, a warrant of credibility for any claims made consequent upon their use? Evidence from the 1870s and later would suggest this to be generally the case. Recent studies have shown, too, how raw numbers disguise variable cultures of scholarly adjudication: ‘reviewing’ in modern parlance has its own history and geography.⁴⁷ Turning exploration journals into printed narratives, in journal or book form, was a complex process. Many explorers travelled well but wrote poorly, or not at all. As the Society developed its practices of disciplinary identity, several explorers presented the results of their instrumental work at evening lectures to the RGS. Yet, often, what appeared in print redacted what was spoken: the complex relationship between ‘speech space’, text, and reception—that is, between what was said, what (if anything) was the subject of commentary by members of the audience, and what, later, was reported upon—cannot always be identified.⁴⁸ Nevertheless, our findings point to possibilities for further work examining the connections between exploration, instrumentation, and publication.

This is particularly apposite given evidence on the fate of instruments in exploration and, on occasion, that of their users. Correspondence between individual explorers and the Society affords insight into the lives of travellers and of their instruments. Consider, for example, the Rev. T. J. Comber, an intending missionary, who first wrote to Henry Bates, RGS Secretary,

on the question of instruments in February 1879. As Comber explained, ‘Being about to start on a Missionary Expedition to Congo, W. Africa, with the object of forming Missionary stations . . . and, if possible, to reach the river above the Livingstone Falls, and to place a steamer upon Stanley Pool to navigate the upper waters; I write to ask the Society to lend me some instruments, to assist me in carrying out this object, and to enable me to transmit to the Soc^y reliable geographical information about any new country we may explore. Will you my dear Sir, be kind eno’ to lay my request before the Council?’⁴⁹

If his request was successful, his management of the devices was less so. Over a year later, Comber informed John Coles, the RGS’s instrument instructor, that ‘I am sending back my Half Chronometer, which I am unable to insure here. . . . I am sorry to say I have got it broken. After going on board a vessel here to find its error, I put it in my pocket ‘pro tem’, and going to wind it in the even^s found it stopped and on examination found the balance wheel ricketty, I didn’t remember any accidental knock or anything of the kind’.⁵⁰ Later, discussing his paper on the Upper Congo, first aired at an evening meeting of the Society in April 1885, Comber reported that ‘A set of observations was taken by us for longitude with a chronometer belonging to this Society, which were to be verified afterwards by a set of observations to be taken at Stanley Pool, where however unfortunately, on account of illness, the chronometer was allowed to run down’.⁵¹ Two years later, the thirty-five-year-old Comber was dead—‘worn out by fever and the sad experiences through which he recently passed’—outlived by his instruments and his publications.⁵²

Consider also the example of Henry Forbes, who, in planning his trip to East Asia, wrote to the Society in October 1878 about what he needed: “I should esteem it a great favour to obtain a loan, if it should appear good to the Council to grant it to me, of some mountain-height registering instruments, viz a set of boiling point thermometers and an aneroid Barometer by which I may check the working of my own”.⁵³ He had occasion to write again,

in April 1879, then in Batavia, lamenting that “They are not yet to hand but I expect them shortly”.⁵⁴ The fact that with this communication Forbes sent his manuscript notes and his map of Keeling Island suggest that he undertook his work and the writing of it without use of the Society’s instruments, despite their being promised him.

In short, getting instruments into the field was not straightforward. Making them work properly was often a matter of contingency. Writing about one’s travel and instrument use afterwards did not always give agency to the processes and practices of instrument use. Published reports of exploration often elided the tools themselves. Instruments, like their users, could and did break down and go slow in the field, with consequences for accuracy of record and completeness of coverage. Calibration could be effected against another device of the same sort (as happened with Henry Forbes). But for the unfortunate T. J. Comber, no calibration was possible—and no verification of observed results either—given the fact of his chronometer’s ‘running down’. In the field, making the relevant device work depended upon safe hands and a healthy body. This last point was not lost on Francis Galton when, in 1881, he looked back on 50 years of change in the equipment of exploring expeditions. To Galton, ‘The equipment of a modern exploring expedition differs in many respects now from what it was in or about the year 1830, with the general result of increased efficiency and rapidity of execution. The standard instruments—namely, the theodolite, the sextant, the chronometer, and the azimuth compass—have not received any great improvements in the interval, and the best of those made in 1830 would be valued now’.⁵⁵ What had improved in the meantime were explorers themselves: “The *personnel* of a travelling party is decidedly improved. Whatever may be the physique of the lower orders of the population, there can be no doubt that the upper orders are physically better developed than they were. They are, . . . taller, they achieve greater feats in running, leaping, walking, and other athletic performances than their grandfathers did. They lead healthier lives from the discontinuance of the heavy eating and

hard drinking of old days, from the better aired sleeping rooms, the existence of proper means of washing, and the seaside or Continental summer vacation".⁵⁶

CONCLUSION

This paper has presented summary evidence of a century of activity concerning the place of instruments in nineteenth-century geographical science. It has also highlighted possibilities for future work on the topic. Here, we summarise the principal findings and address wider implications.

The RGS provided instruments for loan from 1834, several years after the Society in its foundational aims declared instruments important to the conduct of geography as a science of exploration. An early reliance on borrowing and donations was superseded, gradually, by willingness to purchase. The Society undertook repairs as part of the management of its collection. The majority of instrument users were individuals and gentlemen, not formal government-organised expeditions and survey parties. Military personnel were involved, increasingly from the mid nineteenth century, notably from the 1870s. Height, temperature, direction and position were the phenomena most frequently measured, topographic information and relationships and positional accuracy common ends in view. The number of expeditions supported by provision of instruments was low in the first four decades, and increased from the later 1870s. The decade of maximum activity was the 1890s, with a relative resurgence in activity in the 1920s as the Society sought to re-establish exploratory activity after WWI. The most popular exploration destination was Africa, especially central and east Africa. Exploration in these regions dominated the energies of the Society from the second half of the nineteenth century before, later, interest turned to Antarctica and to the Middle and Near East. The change in the nature and number of expeditions from the later

1870s was driven by several circumstances: institutional directives including the Memorandum of 1879; recognition by contemporaries that geography needed to be more scientific, thematic and regionally focused; and the work of John Coles as instrument instructor in initiating programmes of training in instrument use. Sixty per cent of those who borrowed instruments subsequently published their work, the majority in the Society's publications but with evidence of a wider regime of publishing by the early 1900s. The enhanced provision of instruments, and training in their use, was associated with revisions to the Society's *Hints to Travellers* as well as to Coles' role as instructor. Being provided with instruments and being trained in their use did not always equate to accuracy of result or longer-term survival, as T. J. Comber found to his cost. The provision, use, and 'liveliness' of instruments was chronologically uneven and always contingent.

Placing instruments more centrally in our understanding of exploration and the work of terrestrial survey—what, in part, nascent geographers did in the 'long' nineteenth century—allows us to see exploration as an accumulative, even somewhat error-strewn, process rather than an unproblematic accomplishment. It enriches our understanding of geography and how it was undertaken in a period when it, and the other sciences, were establishing those practices of in-the-field work, mapping, measurement, and observation that would come to 'define' the subject.⁵⁷ It enriches too our understanding of the RGS as a formative body in the development of geography in the nineteenth century, one where an evident lack of unanimity over instrument provision, and changes in provision over time, have now to be considered part of the institution's history. It also exposes the need to know more about geography's methods and instrumental practices as an 'imperial science' in this period, and how geography's development as a science may have echoed or differed from the experience of geology in its scrutiny of the earth's age or in mineralogical survey, or, in botany, the emphasis afforded regional distribution and economic utility.

Nature does not speak for itself. The study of nature through scientific instruments—in the form of what was becoming ‘geography the subject’—required training in their use, trust in their workings and readings, and faith in the results. It also depended upon others’ trust in the truth of what one was told.⁵⁸ For these reasons, geography in the guise of exploration (terrestrial survey after a fashion) was something begun before ‘explorers’ encountered the field. Securing instruments could take time: the instrument may have travelled before, been repaired, become ‘reactivated’ for use in a different place. Exploration involving instrumentation had to tolerate breakdown and slow moving in the field. It was often completed long after return from the field (assuming one did): as Himalayan explorers returning their instruments to London in 1937 observed, ‘the completion of a survey takes about as long in the office as it has taken in the field’.⁵⁹

To focus in these ways upon instruments and geographical exploration complicates that oft-utilised distinction in the historical geographies of science and of technology between ‘the laboratory’ and ‘the field’ as discrete spaces for the conduct of science.⁶⁰ Others have considered ‘the role of local people and intermediaries, such as interpreters and guides, in making journeys of exploration possible’.⁶¹ We endorse these sentiments but here direct them at the instruments as intermediaries—between nature and its representation, between observation and measurement, between exploration and publication. Rather than be concerned overmuch with what scientific instruments were, giving greater agency to instruments in the ways we have is to focus more on what they did, what work they expected to achieve.⁶² Analysis of the RGS in this way is to illustrate what is possible because of the records of instruments’ management and of their social use and spatial mobility (instrument geographies), rather than as lists of them either as a collection in situ or as narratives of one instrument type over time (instrument histories). Because nature never speaks for itself, but is dependent for its revelation upon instruments of one sort or another, it is important that

instruments be given an active agency in accounts of the making of science. Recently, calls have been made for a ‘machine-based ‘big picture’ in the history of science (and of technology)—a putative return to Grand Narrative that focuses on the clock, the balance, the steam engine and the computer.⁶³ We do not discount the potential of such work. We would observe, however, that the work of revealing and understanding the world through geography and exploration in the nineteenth century was accomplished in rather faltering ways by numerous smaller devices whose many stories—of purchase, use and re-use—have been signalled to in this paper.

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INSTRUMENTAL PROVISION AND GEOGRAPHICAL SCIENCE: FIGURE CAPTIONS

Figure 1: The annual levels of instrument acquisition (shaded columns) and levels of expenditure (black line) on instruments by the Royal Geographical Society, 1830–c.1930.

Source: RGS-IBG ‘Instruments Lent to Travellers’ and Council Minutes, 1841–1930.

Figure 2: The chronology and expenditure on repair of instruments by the Royal Geographical Society, 1864–1930.

Source: RGS-IBG ‘Catalogue of Instruments’ and Council Minutes, 1831–1930.

Figure 3: The user characteristics of persons borrowing instruments from the Royal Geographical Society, 1830–1930. [Diagonal fill = ‘Gentlemen’; Black = Medical Doctors; Grey = Military Personnel; Horizontal fill = Churchmen; Blank = ‘others’].

Source: RGS-IBG ‘Instruments Lent to Travellers’ and Council Minutes, 1831–1930.

Figure 4: The number of expeditions supported with instruments borrowed from the Royal Geographical Society, 1830–1930.

Source: RGS-IBG Council Minutes, 1831–1930, and from analysis of the *Journal of the Royal Geographical Society* (1831–1880), the *Proceedings of the Royal Geographical Society and Monthly Record of Geography* (1879–1892), and the *Geographical Journal* (1893–1930).

Figure 5: The scientific purposes of the instruments borrowed from the Royal Geographical Society, 1830–1930.

Source: RGS-IBG ‘Catalogue of Instruments’ and Council Minutes, 1831–1930.

Figure 6: Publication statistics relating to those persons who borrowed instruments from the Royal Geographical Society, 1830–1930: Graph (a) shows, by percentage, the proportion of persons, by decade, who borrowed RGS instruments and who published their work. Graph (b) shows, by total number of publications, those persons who published in non-Royal Geographical Society publications, 1830–1930.

Source: Journal of the Royal Geographical Society (1831–1880), the Proceedings of the Royal Geographical Society and Monthly Record of Geography (1879–1892), and the Geographical Journal (1893–1930).

¹ In a wide literature on the development of science and the sciences in the nineteenth century, see D. Cahan (ed.), *From Natural Philosophy to the Sciences: Writing the History of Nineteenth-Century Science* (University of Chicago Press, Chicago, 2003); J. B. Morrell, ‘Professionalisation’, in *Companion to the History of Modern Science* (eds. Roger C. Olby, Geoffrey N. Cantor, John R. R. Christie and Martin J. S. Hodge), pp. 980–989 (Routledge, London, 1991); R. Yeo, *Defining Science: William Whewell, Natural Knowledge and Public Debate in Early Victorian Britain* (Cambridge University Press, Cambridge, 2003). On debates over the nature of geography as an emergent subject (in which exploration and survey were key features), and on the Royal Geographical Society (hereafter RGS) as the key body charged with its promotion, see F. Driver, *Geography Militant: Cultures of Exploration and Empire* (Blackwell, Oxford, 2001). As Driver notes, contemporaries such as Bernard Becker regarded the RGS as a modern vibrant scientific institution, the source of information for government officials, even as the subject ‘geography’ was still not defined: B. Becker, *Scientific London* (King, London, 332–333) and Driver *op. cit.*, 44–45. On geography’s place in the British Association for the Advancement of Science (founded in 1831 and so virtually contemporary with the RGS), see C. W. J. Withers, *Geography and Science in Britain, 1831–1939: A Study of the British Association for the Advancement of Science* (Manchester, Manchester University Press, 2010).

² [Anon.], *Journal of the Royal Geographical Society of London* **1**, vi (1831).

³ For a fuller account of the work of the Royal Geographical Society in this regard, see Jane A. Wess, ‘The Role of Instruments in Exploration: A Study of the Royal Geographical Society 1830–1930’, PhD thesis, University of Edinburgh (2017).

⁴ The ledger volume ‘Catalogue of Instruments’ is given no further identifying shelf-mark within the Society’s archive. The first section, of thirty-five handwritten pages, contains a record of the instruments purchased, when purchased, from whom (which manufacturer), and at what cost. The second section, pages 40 to 122, is a brief history of the use of these instruments. In between these two sections (on un-numbered pages) is a two-page index. Each entry in the first section contains a reference to a page number in the second section. The first section lists nearly 100 types and variations of types of instruments. Classification of the instruments is by type and their essential principal purpose from direction/position/altitude-finding surveying devices such as compasses, sextants, artificial horizons, aneroid barometers and hypsometers to meteorological devices such as rain gauges and anemometers. Records are kept inconsistently in each section and of each instrument type.

⁵ In this manuscript source (similarly without further shelf-mark in the Society’s archives), instrument loans numbering from 1 to 460 are listed. A further sixty un-numbered loans are recorded after the numbered items. The records are of variable quality and, where they are incomplete, can be supplemented by reference to the other sources identified here. The first recorded loan, in March 1861, is to Dr John Rae, the Orkney-born Arctic explorer, for his use in Canada and British Columbia. The last recorded loan is for July 1936, to Francis Rodd for his work in North Africa. Towards the rear of the volume, an un-numbered section—whose first entry dates from November 1883—records the monetary value of the instruments lent against their monetary value at their return. Reasons for any depreciation figures indicated are not given. This section particularly is incomplete: not all the instruments lent were returned, and entries were inconsistently kept. Yet, this information does reveal that many instruments had a long working-life, and were used by different geographers and in different parts of the world, sometimes for several years and, in some cases, decades.

⁶ In the archives of the Royal Geographical Society (with the Institute of British Geography)—hereafter RGS-IBG Archives—correspondence files are listed as ‘CB’ [Correspondence Block], by name (usually, the recipient of the correspondence) and date; records of publications are listed in the ‘JMS series’ [journal manuscript sources].

⁷ F. Driver, ‘Scientific exploration and the construction of geographical knowledge: *Hints to Travellers*’, *Finisterra* **65**, 21–30 (1998); C. W. J. Withers, ‘Science, scientific instruments and questions of method in nineteenth-century British geography’, *Transactions of the Institute of British Geographers* **38**, 167–179 (2013); E. Rae, C. Souch and C. W. J. Withers, “‘Instruments in the hands of others’”: the life and liveliness of instruments of British geographical exploration, c.1860–c.1930’, in *Geography, Technology and Instruments of Exploration* (ed. Fraser MacDonald and Charles W. J. Withers), pp. 139–159 (Ashgate, Farnham, 2015).

⁸ Royal Geographical Society (with Institute of British Geographers) Archives (hereafter RGS-IBG Archives), MSS Additional Papers, AP 8, 8.

⁹ Driver, *op. cit.* (note 1), 51, 53, 59 (and note 7); Withers, *op. cit.* (note 7).

¹⁰ RGS-IBG Archives), AP 7, 2.

¹¹ RGS-IBG Archives, Council Minutes 1831–1840, 18 October 1834. On the use made by Humboldt of the latest scientific instruments in geographical exploration and in establishing deductive hypotheses about the inter-relationship of natural phenomena, see S. F. Cannon, *Science in Culture: The Early Victorian Period* (Dawson, New York, 1978); M. Dettelbach, ‘The face of nature: precise measurement, mapping and sensibility in the work of Alexander von Humboldt’, *Studies in History and Philosophy of Biology and Biomedical Sciences* **30**, 473–504 (1999).

¹² Evidence for the claim that earlier funding was generous in this respect comes from C. R. Markham, *The Fifty Years Work of the Royal Geographical Society* (Murray, London,

1881), p.112. In August 1834, Council allocated £200 to equip expeditions, and, in October that year, provided a further £27 11s. for instruments: RGS-IBG Archives, Council Minutes 1831–1840, 14 August 1834, 18 October 1834.

¹³ RGS-IBG Archives, Council Minutes 1831–1840, 27 February 1837, 12 February 1838. Schomburgk's Guyana work is the subject of D. G. Burnett, *Masters of All They Surveyed: Exploration, Geography and a British El Dorado* (University of Chicago Press, Chicago, 2000).

¹⁴ RGS-IBG Archives, Council Minutes 1831–1840, 12 February 1838, 28 May 1838.

¹⁵ RGS-IBG Archives, Council Minutes 1831–1840, 11 November 1839.

¹⁶ RGS-IBG Archives, Council Minutes 1831–1840, 3 April 1840, 27 April 1840, 8 June 1840; RGS-IBG Archives, Council Minutes 1841–1865, 9 May 1840.

¹⁷ RGS-IBG Archives, Council Minutes 1841–1865, 23 November 1846.

¹⁸ *Journal of the Royal Geographical Society* **21**, xlv–xlvi (1851); see also RGS-IBG Archives Council Minutes 1841–1865, 10 November 1851.

¹⁹ RGS-IBG Archives, Council Minutes 1841–1865, 56, 57, respectively.

²⁰ Withers, *op. cit.* (note 7); Rae, Souch and Withers, *op. cit.* (note 7). Further stimulus to the production of *Hints* came from Henry Raper, RGS Fellow and naval authority on navigation, to whom the Society's Founders' Medal was awarded in 1841 for his text of instrumental guidance and instruction, *The Practice of Navigation and Nautical Astronomy* (1840).

²¹ RGS-IBG Archives, Council Minutes 1841–1865, 157.

²² RGS-IBG Archives, Council Minutes 1841–1865, 160. The accompanying list includes maximum and minimum thermometers, wet and dry bulb hygrometers, Regnault's hygrometers, hypsometers, barometers and aneroids. Included with this minute is a small sketch showing a design for a thermometer carrying-case.

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- ²³ RGS-IBG Archives, Council Minutes 1841–1865, 191.
- ²⁴ RGS-IBG Archives, Council Minutes 1865–1873, 24 August 1866.
- ²⁵ On this evidence, see *Hints to Travellers* (Murray, London, 1883, fifth edition), pp. 2–24.
- ²⁶ For a discussion of the role of traverse survey and instrument use in early exploration in work supported by the RGS, see D. G. Burnett’s analysis of Robert Schomburgk’s British Guiana work in his *Masters of All They Surveyed*, *op.cit.* (note 13). A note of caution is merited here: Schomburgk’s use of traverse survey stemmed from the complex terrain he encountered which hindered his lines of sight, not from any failure to understand triangulation using theodolites or from the shortcomings of the devices.
- ²⁷ This is clear from the Catalogue of Instruments MS (note 4); see also Rae, Souch and Withers, *op. cit.* (note 7), 146–151.
- ²⁸ It is not possible, when early Council Minutes simply report ‘the purchase of instruments’ without specifying either type or number, to be certain what was bought or acquired by other means.
- ²⁹ RGS-IBG Archives Council Minutes 1861–1870, 28 January 1861, 25 March 1861, 16 June 1862; *Journal of the Royal Geographical Society* **28** (1858), 169; Sub-Committee on Instruments, 12 November 1861.
- ³⁰ RGS-IBG Archives Council Minutes 1861–1870, 8 April 1861, 10 June 1861.
- ³¹ RGS-IBG Archives Council Minutes 1871–1880, 9 December 1872.
- ³² RGS-IBG Archives Council Minutes 1871–1880, Scientific Purposes Committee 27 June 1879.
- ³³ Bodleian Library, British Association Ms. Dep. BAAS 142, *Brighton Daily News*, 16 August 1872; see also Withers, *op. cit.* (note 1), pp. 153–155. Even as he noted this, Galton commented also in his Brighton talk upon the ‘sensational geography’ of the African explorer

Henry Morton Stanley whose exploits at once fascinated and appalled contemporaries: see F. Driver, 'Henry Morton Stanley and his critics: geography, exploration and empire', *Past and Present* **133**, 134–166 (1991).

³⁴ RGS-IBG Archives Council Minutes 1901–1910, 29 June 1908.

³⁵ RGS-IBG Archives Council Minutes 1891–1900, 14 November 1892.

³⁶ On the failure and maintenance of scientific instruments and operators' tolerance in using faulty devices, see S. Schaffer, 'Easily cracked: scientific instruments in states of disrepair', *Isis* **102**, 706–717 (2011).

³⁷ RGS-IBG Archives, CB 6, Keith Johnston to Henry Bates, 30 November 1875.

³⁸ RGS-IBG Archives Council Minutes 1871–1880, 26 May 1879, 9 June 1879. M. Jones, 'Measuring the world: exploration, empire and the reform of the Royal Geographical Society, c.1874–93', in *The Organisation of Knowledge in Victorian Britain* (ed. Martin Daunton), pp. 313–336 (Oxford University Press, Oxford, 2005).

³⁹ RGS-IBG Archives Council Minutes 1871–1880, 9 June 1879; Jones, *op. cit.* (note 37), p. 319; Rae, Souch and Withers, *op. cit.* (note 7).

⁴⁰ This is the subject of A. Maddrell, *Complex Locations: Women's Geographical Work in the UK, 1850–1970* (Wiley-Blackwell, London, 2009).

⁴¹ L. Dritsas, 'Expeditionary science: conflicts of method in mid-nineteenth-century geographical discovery', in *Geographies of Nineteenth-Century Science* (ed. David Livingstone and Charles W. J. Withers), pp. 255–278 (University of Chicago Press, Chicago, 2011).

⁴² Withers, *op. cit.* (note 1), pp. 152–153.

⁴³ T. H. Huxley, *Physiography: An Introduction to the Study of Nature* (Macmillan, London, 1870). In his book, which went into numerous editions in the last thirty years of the

nineteenth century, Huxley saw measurement of natural phenomena as part of the law-seeking (and aesthetically-sensitive) survey of nature as a whole.

⁴⁴ J. Secord, 'The Geological Survey of Great Britain as a research school, 1839–1855', *History of Science* **24**, 223–275 (1986); R. A. Stafford, 'Geological surveys, mineral discoveries, and British expansion, 1835–71', *Journal of Imperial and Commonwealth History* **3**, 5–32 (1984); W. H. Goetzmann, *Exploration and Empire: The Explorer and the Scientist in the Winning of the American West* (Knopf, New York, 1966); A. K. Ghosh, 'Geological Survey of India (1851–1951)', *Science as Culture* **16**, 307–313 (1951).

⁴⁵ Driver, *op. cit.* (note 1); Dritsas, *op. cit.* (note 40).

⁴⁶ The military, male, and imperial emphasis to patterns of fellowship in the RGS before the early twentieth century is discussed in D. R. Stoddart, *On Geography* (Blackwell, Oxford, 1986), especially pp. 41–76. On the characteristics of 'professionalisation', see Morrell, *op. cit.* (note 1).

⁴⁷ On this point, see M. Baldwin, *Making Nature: The History of a Scientific Journal* (University of Chicago Press, Chicago, 2015); A. Csiszar, *The Scientific Journal: Authorship and the Politics of Knowledge in the Nineteenth Century* (University of Chicago Press, Chicago, 2018).

⁴⁸ On these issues, see A. Craciun, 'What is an explorer?', *Eighteenth-Century Studies* **45**, 29–51 (2011); I. M. Keighren, C. W. J. Withers and B. Bell, *Travels into Print: Exploration, Writing, and Publishing with John Murray, 1773–1859* (University of Chicago Press, Chicago, 2015); D. A. Finnegan, 'Finding a scientific voice: performing science, space and speech in the nineteenth century', *Transactions of the Institute of British Geographers* **42**, 192–205 (2017). It is possible to know something of how explorers' accounts were received, and by whom comments were made, as early numbers of the Society's publications record the post-talk observations of leading members of the audience, albeit that many of the

observations comment more upon the contribution made to geographical knowledge by the explorer than upon their use of instruments or the accuracy of their instrumentally-derived claims.

⁴⁹ RGS-IBG Archives, CB6 Rev. T. J. Comber to [Henry] Bates, 26 February 1879. On the reverse of his letter, Comber itemised in a ‘List of Instruments’ what he hoped to borrow:

‘Two Hay Chronometer Watches, water tight cases; 6 inch radius Sextant; 2 Pocket Aneroids; Hypsometrical apparatus & 2 B. P. [Boiling Point] Thermometers; 1 Ordinary Thermometer; 1 George’s Artificial Horizon; 1 Prismatic Compass/1 Tripod Stand’.

⁵⁰ RGS-IBG Archives, CB 6, John Coles, to A. de Bloeme, Banana, So. W. Coast of Africa, 14 April 1880.

⁵¹ RGS-IBG Archives, JMS 2/238. This work appeared as G. Grenfell and T. J. Comber, ‘Explorations by the Revs. George Grenfell and T. J. Comber, on the Congo, from Stanley Pool to Bangala, and up the Bochini to the junction of the Kwango’, *Proceedings of the Royal Geographical Society and Monthly Record of Geography* 7, 353–373 (1885).

⁵² The words on Comber’s death in West Africa, on 27 June 1887, are from *The Baptist Quarterly* 8, 379–385 (1937), at p. 379. See also ‘Obituary: T. J. Comber’, *Proceedings of the Royal Geographical Society and Monthly Record of Geography* 9, 583–584 (1887).

⁵³ RGS-IBG Archives, CB6 Henry Forbes, 5 October 1878 [to Henry Bates].

⁵⁴ RGS-IBG Archives, CB 6 Henry Forbes to Henry Bates, 15 April 1879.

⁵⁵ F. Galton, ‘The equipment of exploring expeditions now and fifty years ago’, *Report of the Fifty-First Meeting of the British Association for the Advancement of Science* (Murray, London, 1882), pp. 738–741, at p. 738.

⁵⁶ Galton, *op. cit.* (note 53), p. 740. It is possible, of course, that Galton is here displaying his eugenicist beliefs, reading the ‘fitness’ of certain men for the rigours of exploration as environmentally and physiologically mutually conditioned by their social class. For fuller

appraisal of Galton's life and work, see N. W. Gillham, *Sir Francis Galton: From African Exploration to the Birth of Eugenics* (Oxford University Press, Oxford, 2001).

⁵⁷ On this point about the formative practices of the natural sciences especially, see Cahan, *op. cit.* (note 1) and J. Golinski, *Making Natural Knowledge: Constructivism and the History of Science* (Cambridge University Press, Cambridge, 1998).

⁵⁸ On these points, see S. Shapin, *The Social History of Truth* (University of Chicago Press, Chicago, 1994), and Keighren, Withers and Bell, *op. cit.* (note 48).

⁵⁹ E. Shipton, M. Spender and J. B. Auden, 'The Shaksgam Expedition', *Geographical Journal* **91**, 313–336 (1938), at p. 334.

⁶⁰ For discussion of this topic and a review of relevant literature, see C. W. J. Withers and D. N. Livingstone, 'Thinking Geographically about Nineteenth-Century Science', in *Geographies of Nineteenth-Century Science* (ed. David N. Livingstone and Charles W. J. Withers), pp. 1–19 (University of Chicago Press, Chicago, 2011).

⁶¹ F. Driver and L. Jones, *Hidden Histories of Exploration: Researching the RGS-IBG Collections* (Royal Holloway, University of London with the RGS-IBG, London), 5. On the human intermediary, see *The Brokered World: Go-Betweens and Global Intelligence, 1770–1820* (ed. Simon Schaffer, Lissa Roberts, Kapil Raj and James Delbourgo) (Science History Publications, Sagamore Beach, 2009) and K. Raj, 'When human travellers became instruments: the Indo-British exploration of Central Asia in the nineteenth century', in *Instruments, Travel and Science: Itineraries of Precision from the Seventeenth to the Twentieth Century* (ed. Marie-Noëlle Bourguet, Christian Licoppe and H. Otto Sibum), pp. 156–188 (Routledge, London, 2002).

⁶² On this issue, see D. J. Warner, 'What is a scientific instrument, when did it become one, and why?' *British Journal for the History of Science* **23**, 83–93 (1990), and F. MacDonald and C. W. J. Withers, 'Introduction: Geography, technology and instruments of exploration',

in *Geography, Technology and Instruments of Exploration* (ed. Fraser MacDonald and Charles W. J. Withers), pp. 1–13 (Ashgate, Farnham, 2015).

⁶³ See the articles making up the ‘Viewpoint: Clocks to Computers’ essays in *Isis* 107 (2016) and the initial essay there: Frans van Lunteren, ‘Clocks to computers: a machine-based “Big Picture” of the history of modern science’, *Isis* **107**, 763–776 (2016).