The eye of the needle: magnetic survey and the compass of capital in the age of revolution and reform

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This dissertation is submitted for the degree of Doctor of Philosophy

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Jenny Bulstrode

Title: The eye of the needle: magnetic survey and the compass of capital in the age of revolution and reform

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Abstract:

This thesis charts the globalising role of British geomagnetism in the age of revolution and reform. In the earlier decades of the nineteenth century, significant fiscal-military state resources were directed toward linking three momentous magnetic enterprises: Admiralty reform of practical magnetic navigation; novel electromagnetic research; and British engagement in an international campaign to survey the earth's magnetism. From hardware to personnel, these resources were heavily invested with certain principles of labour organisation. In the late eighteenth and earlier nineteenth century industrial materials such as copper, paper, and glass, were remanufactured into new forms designed to depend upon extreme systems of labour extraction. Iron best embodies this transformation. In order to chart the globalising role of British geomagnetism this thesis follows the interests of magnetic administrators and military mathematicians whose situated concerns were navigated by a new kind of iron. Particularly pivotal are the researches of Woolwich Military Academy mathematics master Peter Barlow, who took lessons from timber and torsion to make iron twist and link the three magnetic enterprises in capital bonds. The ferrous focus dictates the compass of this thesis: from Cornish mines to West Indian docks and Greenland fisheries, and its combinations: from Newcastle Town Moor to the Martinique marina. Combination, resistance, and revolution prove critical. The protests of English commons are shown to have fuelled the launch of the magnetic campaign, just as the uprisings of the Black Atlantic formed its material and theoretical infrastructure. Legislation and materials were reformed to reveal apparently natural laws, while the realities of contingency, struggle, and newer subtler forms of exploitation were lauded as inevitable progress. British geomagnetism in the age of revolution and reform charted a particular kind of extreme labour extraction embodied in a new kind of iron: a global metal in globalisation's reconstitution of the globe.

to Mum

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Thanks to my supervisors, Simon Schaffer and Richard Dunn, this doctorate has been the most extraordinary education. Over countless hours I have been privileged witness to Simon's impossible leaps between genres, disciplines, and worlds in spectacular riffs and sketches on the back of paper napkins. Exquisite counterpoise to this, in workshops and hangers filled with the hardware of the technocratic state I was challenged by Richard's clarity to hammer out quite what it was I was to make of this. I wish I could do justice to the combined gift of their teaching: confronting, often excruciating, but always the greatest joy.

To Richard, Rory McEvoy, Anna Rolls, and Emily Akkermans I am particularly grateful for the sessions making compasses and clock-springs in the Royal Observatory's horology workshop. Working with materials, moving between lathe and hand tools, and hearing skilled clockmakers talk unguardedly about their craft, hugely influenced my understanding of what was at stake in magnetic instrumentation. With his genius for precisely what's needed and when, Simon introduced me to Spike Bucklow, who, in a lightning half hour over a tepid hot chocolate, showed rather than dictated entirely different ways of thinking about skill and its communication. Thanks to Spike I met Andrew Lacey and spent time in his Devonshire foundry learning to cast bronze using metal salvaged from historic wrecks. Through Andrew's generosity I saw for myself how iron rots and steel must be seasoned, and how, in contrast to these, bronze was an immortal metal, endlessly rendered and reformed. Together with compass-making at the Observatory this experience profoundly informed my research, helping me to see lumps of metal, from the Whitby Literary and Philosophical Society Museum to the great chains in Greenwich National Maritime Museum's store, in the light of different traditions.

Simon and Richard's patience and ingenuity in guiding my efforts to process these and other experiences has been a feat of coaxing worthy of John Bird. Exchanges with Megan Barford, Michael Bravo, Mary Brazelton, Rohan Deb Roy, Caitlín Doherty, Catherine Eagleton, Patricia Fara, Ed Gillin, José Ramón Marcaida, Dániel Margócsy, Juan Neves, Richard Staley, and Tana West have all been invaluable. I am particularly indebted to Will Ashworth, Eóin Phillips, and Josh Nall. Together with my supervisors they have been my most inspirational teachers. To the unforgettable Anita McConnell, I owe a whisky toast for her support and direction. To Edd Bankes, Eoin Carter, and Nico Rosetti, *thank you*, you have been the kindest and truest of friends through all this. Finally, I must thank my Mum. It has been a profound privilege to share this process with her. No one could have been more loving, generous, and tireless in their support. One of the extraordinary gifts of this experience has been recognising her influence in my work as well as that of my wonderful brothers, extended family, and the loved ones we miss.

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Prologue: Launching a Crusade

In the middle decades of the nineteenth century a powerful alliance of scientific and military administrators undertook a research programme of unprecedented scale and ambition: a state-funded, military-orchestrated, global campaign to survey the earth's magnetism. Dubbed the 'Magnetic Crusade',[1] this campaign had its own icons, among which historians of the so-called 'Crusade' have held up the Fox-type dip circle and enigmatically pronounced this magnetic intensity instrument as 'The reason why.'[2]

In 2014, I completed a master's dissertation in the Department of History and Philosophy of Science, University of Cambridge, which sought to re-interpret this instrument. To understand the Fox-type, not in the celebrated mythos of maritime and, in particular, polar exploration with which it had become identified, but rather in the context from which it emerged: Cornwall's mineral extraction industry, its geophysical researches and its globally-dispersed system of workforce and equipment.[3] In the course of this master's project I began to become familiar with several substantial bodies of work relating to nineteenth century geomagnetic research in Britain, and their marked importance to the historiography of modern science more generally.

Renowned texts by Cannon, Cawood, Carter, Dörries, and Morrell & Thackray, revealed Britain's magnetic researches as a geopolitical response and intervention, and the novel shift in the funding and administration of the 'Magnetic Crusade' as the birth of a new international hegemony for British-led, military-orchestrated, and state-funded, big science.[4] For Kuhn, Miller, Cunningham, and Cunningham & Williams, the reorientation of disciplinary disposition that accompanied this magnetic moment was not only emblematic of a new globalizing character to the organization and ambition of science, but also a new kind of abstraction to its notion of 'modernity'.[5] Cardwell, Gooding, Marsden & Smith, and Wise & Smith showed how some of the most significant of these abstractions were drawn directly from the material resources and personal relations that accompanied the new disciplinary disposition of these magnetic researches.[6] Meanwhile maritime histories by Barford, Cotter, Craciun, Fanning, Lambert, Levere, May, Winter, Savours & McConnell showed how these

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[1] Cawood,1979.
[2] Lambert,2009,pp.61-6,p.430.
[3] Bulstrode,2014.
[4] Cannon,1978; Cawood,1977; Cawood,1979; Carter,2009; Dörries,1994; Morrell&Thackray,1981.
[5] Cunningham,1988; Cunningham&Williams,1993; Kuhn,1976; Miller,1986.
[6] Cardwell,1971; Gooding,1989; Marsden&Smith,2005; Wise&Smith,1989a,1989b,1990; Smith,1998.

same personnel and their novel resources, from printing technologies and navigational hardware to steam engines, were central to major institutional and societal change.[7]

Just as the authority of these literatures was apparent so too was another striking feature. These bodies of work existed with only limited reference or regard to one another, and the significant overlap and correspondence between these literatures had yet to be investigated or developed. This exploration then became the central premise of the proposed doctoral thesis. Where the master's dissertation had followed a well-established route of revisionist histories, to return the Fox-type to its context of origin and use, the doctoral thesis took seriously the implications of these important works and sought to develop this through close engagement.

Focusing on points of overlap and acknowledging the strength of the existing literature enabled intensive historical investigation of a series of relatively well-defined events: the appointment of an Admiralty committee into compasses, the launch of the magnetic campaign the following year, the founding of a 'Compass Observatory'. Further, this approach identified Cornwall, Newcastle, Woolwich and Jamaica as sites of particular activity for the principal actors. Activity which took the form of intense preoccupation with specific industrial materials, namely Cornish copper and a new kind of iron; and their instrument assemblages: The Admiralty Standard Compass and the aforementioned Fox-type. These materials and their assemblages became synecdoche for the integration of the canonical concerns of the renowned works already mentioned, from Cawood to Cardwell and Kuhn. But in becoming the object of study, copper, iron, and the compass exerted the fraught and contested histories of their production and use. They brought to presence the indispensable significance of the powerful and insurgent concerns embodied in their assemblage: enslavement, extraction, displacement, and revolution. Each of the bodies of established literature presented its own structuralist account of nineteenth century science and technology, but in the integration of these structures, iron, copper, the Fox-type and the Standard Compass brought to presence the relational.

While every synecdoche this thesis offers up is a knot of *longue durée* threads drawn together in the account, the result is a web of synchronic episodes bound together by links of copper and iron and the activity of those who forged and broke them. The analytical originality of the thesis lies in this interconnectedness. The contribution lies in the powerful and insurgent

[7] Barford,2015; Cotter,1979; Craciun,2016; Fanning,1986; Lambert,2009; Levere,1993; May,1987; Winter,1998; Savours&McConnell,1982

relations this interconnectedness reveals, and, in turn, what these relations reveal about the character of the alliance between nineteenth century physics and capitalism.

This prologue opened noting the Fox-type became an icon of the so-called ‘Crusade’. The introduction to this thesis opens with another icon: a *Handstein.* Exquisitely crafted to represent the union of subterranean science and industrial economy in the mid-sixteenth century Holy Roman Empire, the *Handstein* presented this imperial order as nature materialised. Its presence frames the way in which the reader encounters the thesis’s objects and invites reflection not only on similarity but also on the differences between them. The *Handstein* drew the most exclusive gaze, but the apparently ubiquitous, uniform and utilitarian Standard Compass engineered individual gaze into global surveillance; while the Fox-type charted the globe as if it were a Cornish mine, powered by a heat engine and shot through with seams of bright copper and iron. As much as anything the claim of this thesis lies in the reflection it asks of the reader, seeing this difference, to ask themselves quite what mundane technology such as the Standard Compass or the Fox-type might mean.

Figure 0.1: Berg Golgotha Handstein, c.1550, Kunstkammer 4167, Kunsthistorisches Museum Wien.

Introduction: The *Handstein*

In the early modern courts of the Holy Roman Empire the microcosm of the mine was one of the most significant manifestations of power, (Figure 0.1).[8] Unlike in England, where subterranean wealth was the property of the landowner, the *bergregal* of the German-speaking lands dictated that untapped mineral resources were the sovereign right of the king. Mine-finds of exquisite quality or extraordinary form were taken as gifts from God, embellished with models of men and machines, and topped with biblical figures to become the tribute of kings to an emperor divinely anointed. *Partem pro toto*, these model economies, where the labour of the mine and its mineral wealth were made the bedrock of the emperor's god-given right to rule, were known as '*Handstein*' for the central spectacular sample of ore large enough to fill the palm. First prominent under the sixteenth century Habsburg imperium, this diplomatic art saw a dramatic revival in the third quarter of the eighteenth.[9] Following the Holy Roman Empire's final dissolution under the onslaught of the French Revolutionary Wars, statesmen of the German-speaking lands seeking restoration and to forge new unity would look back to the economic models of the late empire,[10] and cast covetous eyes to the engine-powered mines of Cornwall.[11]

As one empire was broken up, another was wrought. This thesis is concerned with the global role of British geomagnetism in the earlier nineteenth century. A combination of new and reformed military and naval ordnance,[12] novel twists on electromagnetic research,[13] and a British-led global campaign to survey the earth's magnetism.[14] The links in this combination are crucial. In 1845 Europe's most famous observer, Prussian mining engineer Alexander von Humboldt, would take credit for the campaign's launch in the first volume of his most celebrated work, *Kosmos*. In 1846, as the Tory government reversed their fiscal policy, repealing the Corn Laws with the explicit intention of re-organising colonial production to promote labour extraction and the drain of wealth,[15] a pivotal figure in the British-led campaign, Admiralty scientific advisor Edward Sabine, translated and republished Humboldt's claim.[16] In this way Sabine made an official mandate of a letter Humboldt wrote to the Royal Society in 1836, which sought to persuade the learned society to support the

8 www.khm.at/de/object/b301379d73/
9 Hammer,Hanzer,&Huber,2005.
10 Jackson,1992,p.464; Jackson,1994,pp.415-6,p.424,
11 Hennig,1949,pp.535-6.
12 Fanning,1986; Guillery,2012.
13 Gooding,1989; Miller,1986; Berg,1982.
14 Cawood,1979; Cawood,1977; Carter,2009; Dörries,1994; Morrell&Thackray,1981.
15 Thompson,1841,pp.18-20.
16 Humboldt,1849,p.lxiii

establishment of corresponding magnetic observatories in British colonies. Such an enterprise, Humboldt argued, had a double claim on the Society's attention, promising to link nautical science with the physics of the earth. Following advice from Altona astronomer Heinrich Christian Schumacher, Humboldt had written setting out the respective advantages of two different systems of geomagnetic instrumentation: one established in Paris under François Arago, the other in Göttingen under Carl Friedrich Gauss.[17] Attention to the combination and its crucial links reveals quite what the British adopted - a system of instrumentation to remanufacture the earth in the measure of British global ambition: a handheld microcosm of the Cornish mine and its economy. A gift in time becomes an exchange.[18] What followed the powerful gift of the Cornish mine in microcosm was the global extension of a capitalist cosmology of universal exchange.

Humboldt was torn between Paris and Göttingen models but ultimately favoured the unprecedented precision of Gauss's system over the instrumentation of his long cooperation with Arago. When he wrote, the recently appointed Astronomer Royal, George Biddell Airy, had already committed to Gauss's specification for the new magnetic house of the Royal Observatory.[19] Further, British state science already had a pattern colonial observatory. Built by enslaved labour on the Black River plantation, Jamaica, Scottish astronomer Colin Campbell's eighteenth century observatory had played an important role in transit observations. In architectural terms it was explicitly designed to resemble an imposing colonial residence but in place of the gently pitched roof characteristic of these buildings, it featured a flat roof surrounded by a hand-rail,[20] a design feature associated with lodges in which enslaved people were held captive, and with the surveillance of forced labour. Association became archetype following the designs of eighteenth century French architect Louis Michel Thibault, based at the Cape and responsible for much of the mannered neo-classical architecture there. Most notably, the flat-roofed lodges in which enslaved people were held captive. As the first British state observatory established outside of Britain under the aegis of the Admiralty and the Board of Longitude, the Royal Observatory at the Cape of Good Hope was of huge significance, not least as the model institution the magnetic campaign sought to extend. Founded in the 1820s, it was explicitly built to resemble Thibault's prison-lodges, not only constructed with but also manned by enslaved labour.[21] When Humboldt wrote in 1836, British state science was already heavily invested in a model colonial state

[17] Dörries,1994,p.133; Humboldt,[9/4/1836],**RS**,AP/20/8.
[18] Mauss,2002,pp.14-5.
[19] Gauss:Airy,[24/03/1836],**CUL**,RGO/6/675/45; Macdonald,2018.
[20] Bryden,1970,p.266.
[21] Warner,1995,pp.63,103,114,180-3.

observatory where the relation between physics and labour extraction was built into its walls as into its workings.

Yet when the Council of the Royal Society tasked Airy and their new physical sciences secretary, Woolwich mathematics professor Samuel Hunter Christie, with translating and reporting on the letter the following month, they paid significant attention to engineering its reception.[22] What Humboldt hoped to galvanise, and what the two scientific administrators looked to gain from his vision, illustrates the central concern of this thesis and the significance of this conjuncture between ordnance and electromagnetic theory underwritten by capital. Since its formation in 1831 the British Association for the Advancement of Science had lobbied the Royal Society and British government to provide financial and technical support for British engagement in an existing international magnetic project once led by Humboldt and Arago, now increasingly defined by the extraordinary precision of Gauss. For the Association's members, Airy and Christie among them, Humboldt's letter was a gift. This was more than just about a choice of instruments. As with the men and machines that made the sample of ore into a microcosm of the mine, and the biblical iconography that made this microcosm into a model for divine right of rule, this was also about what each instrument represented in its material assemblage.

Writing from Berlin, Humboldt sought to solicit '*le concours puissant*' of the Royal Society to the international programme of magnetic observations he had long since undertaken in collaboration with Arago and '*la coopération'* of a great many zealous observers. Permanent magnetic stations from Paris to China had just recently been '*établies'*. Now Humboldt proposed the Society should promote the enterprise, '*fondant*' new observatories in the vicinity of the magnetic equator as in the temperate southern hemisphere: formal and informal colonies subject to the conquest or influence of the crown.[23] Christie and Airy's translation altered the nuance in Humboldt's language that distinguished between the existing project, and what British engagement might make of it. The etymology of '*concours'* connotes competition and proprietary claim,[24] while that of '*coopération'* historically referred to a state of grace or theological alignment. That is until the 1820s, when French usage of *coopération* altered in accordance with that of the Welsh cotton-spinning capitalist, Robert Owen, who used cooperation to explain his principles of community as based on a share taken of work done in common.[25] By the time of Humboldt's writing, and in direct opposition

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[22] Airy:Christie,[2/6/1836],**CUL**,RGO/6/675.
[23] Humboldt,[9/4/1836],**RS**,AP/20/8.
[24] CNRTL,2012,'concours'
[25] CNRTL,2012,'coopération;

to proprietary claims, Owen's notion of community cooperation defined the continental concept of socialism in England. For Humboldt to use '*concours*' was to bait the magnetic project as potential capitalist conquest. For the two scientific administrators to translate both '*concours*' and '*coopération*' as the same 'cooperation' was to use the favoured tactic of 1830s politicians, and parse capital interests in the language of radical reform. In his shift from '*établies*' to '*fondant*', the former mine-engineer made clear the nature of this capital appeal. While '*établies*' was straightforwardly established, '*fondant*' recalled the casting of metal.[26]

The transformation of British iron in the late eighteenth and early nineteenth century is a central concern of this thesis, together with the role of such savants, and Airy and Christie specifically, in securing its global dominion in the earlier nineteenth. In using the same 'established' to translate both '*établies*' and '*fondant*', Christie and Airy rejected the Prussian mine-engineer's metal, but took the mine. Faithful to Humboldt's letter, they described observations as undertaken by young mine officers in the great mines throughout the northern hemisphere, in particular those of the Russian empire. Mineral empire was thus coordinated into cosmology. This thesis is concerned not just with understanding how, but also quite what this meant.

Figure 0.2: Frederic Edwin Church, 1865, Aurora Borealis, 1911.4.1, Smithsonian American Art Museum.

[26] Humboldt,[9/4/1836],**RS**,AP/20/8; Airy:Christie,[2/6/1836],**CUL**,RGO/6/675.

In consensus Christie and Airy relayed Humboldt's repeated description of the 'luminous emanations' and 'polar explosions' of the '*Aurorae boreales* [sic]' as 'signals from the interior of the earth' or 'manifestations of terrestrial magnetism at the surface of the globe' (Figure 0.2). Northern mines had long been the locus of auroral studies,[27] but in this account the connexion was physical, the lights themselves a kind of ore. For Humboldt and his interpreters the jewelled blaze that accompanied magnetic storms 'reveal, so to speak, what passes at profound depths in the interior of our planet' in skies lit like the hall of the mountain king. It was a view explicit in the work of Cornish mine industrialist and steam entrepreneur Robert Were Fox, whose physical geology, described in chapter one, was represented in Britain as an important resource for Humboldt.[28] That very same year, Fox not only presented on the formation of mineral veins by voltaic agency to the British Association, he also performed 'an extraordinary experiment' to reproduce the effect. As part of this demonstration and account he described the aurora as the direct extension of the formation of such veins of mineral wealth: 'an exhibition of electric currents at great height, which are connected with others nearly parallel to them, in the interior of the earth'.[29] Together with this claim Fox presented a dip-circle: a magnetic balance, where the needle rested in the horizontal plane and dipped below the horizon in response to the intensity of the earth's magnetism. The subject of the concluding chapter of this thesis, Fox's instrument was unlike previous dip-circle designs because it was developed from and for the specific contingencies of Cornish mines, home of Fox's voltaic mineral formations.

When Humboldt and Fox proposed that the veils of the aurora were not just like veins of bright copper forming in the clouds but direct and parallel consequences of the same forces at work in the interior of the earth, they were presenting an argument that the study of horizontal geomagnetic force must be understood in a spherical coordinate system. This thesis shows how earlier nineteenth century British capitalism was significantly modelled on the economy of the Cornish mine. Humboldt's letter gave a way to ensure magnetic research would be made to measure the dimensions of that capitalist cosmology: not magnetism to navigate below ground without stars, but magnetism to re-characterise the stars in the systematic extension of the mine. Among others, Humboldt cited the work of Christie's fellow Woolwich mathematics master Peter Barlow, who, as chapter three will describe, had only a few years previously performed this metaphysical manoeuvre, from the horizontal point to the sphere, using Admiralty shells (Figure 0.3). The Royal Society initially appointed a magnetic committee including Airy and Christie to further consider the question of

[27] Lindqvist,1993,p.67.
[28] Taylor,1824,pp.119-200
[29] British Association,1837,pp.81-2; Fox,1837,pp.33-34.

instrumentation. However, it was slow to act, much to the frustration of Sabine.[30] The following year the self-styled successor to the Survey of India, Thomas Best Jervis, was appointed by the Admiralty to investigate the state of its compasses, together with five active members of the magnetic lobby:[31] Sabine and Christie; naval officer and polar veteran James Clarke Ross; Admiralty hydrographer Francis Beaufort; and survey officer Edward Johnson. The mandate for their appointment was announced with the publication of a long-cached report by Barlow that had, almost two decades previously, declared an urgent crisis in the state of Admiralty compasses.

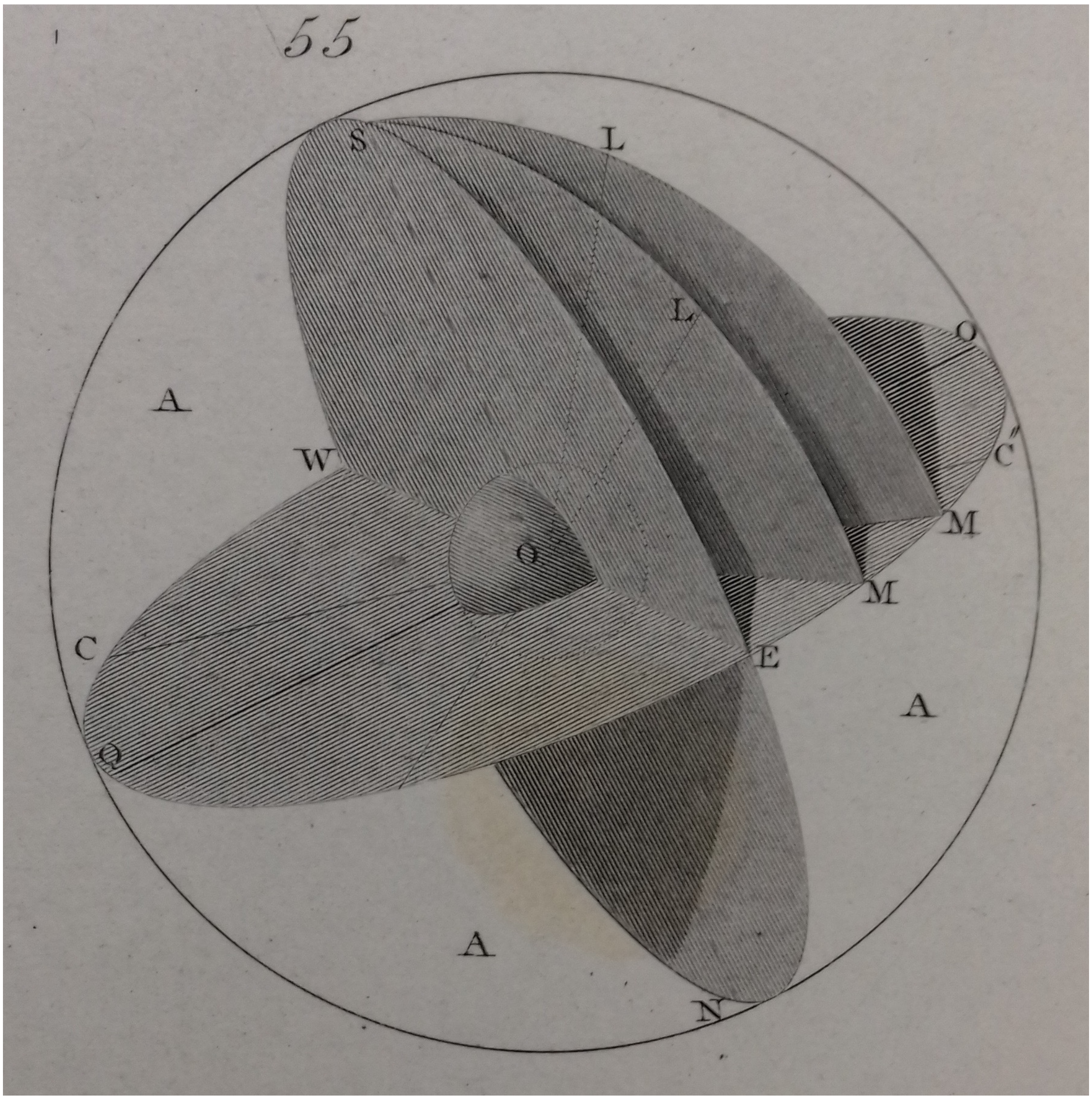

Figure 0.3: 'We have hitherto spoken of these circles as applied immediately to the surface of the ball; but it is obvious that by merely conceiving these planes to be produced, to cut any other sphere circumscribing and concentric with the ball, the same mode may be adopted for defining the situation of any point in space with reference to the centre of the sphere.' Barlow, Peter, 1829, *Encyclopaedia Metropolitana* Vol.I, London: Baldwin and Cradock, 735-845, p.775 and Plate 6 Fig. 55.

[30] Morrell&Thackray,1981,pp.357-8.
[31] Fanning,1986,pp.1-46.

This committee embarked on a programme of material research to define a new Admiralty standard in magnetic navigation: a standard to underwrite the 'grand accumulation' of the British-led campaign.[32] Each compass component was specified with significance, down to the instrument's Cornish copper bottom. Above all, however, was the azimuth ring. As chapter one describes, this was first systematically fitted to Admiralty compasses in line with the magnetic administration of plantation patents in Jamaica, a system introduced from the specific division of property in labour in Cornish mines. As chapter seven will detail, in 1839, on the first expedition of the formal launch of the British-led campaign, this compass would be trialled together with the Fox-type dip circle, the microcosm of the mine. Following this trial, both would be adopted, the former as the standard of Admiralty navigation at sea, the latter as the standard of the expeditionary science of the magnetic campaign. Field complement to the Gaussian system in the colonial fixed observatory, the two instruments constituted the two halves of the spherical projection of a highly specified cosmology of capitalist extraction.

The concluding chapter to this thesis will describe how, in 1846, as the Corn Laws were repealed, and Sabine published Humboldt's claim, extensive covert action by the Tory government succeeded in securing a significant American tariff on British iron. That same year the American Academy of Arts and Sciences published for the first time a report submitted in September 1841 by Harvard professor Joseph Lovering and astronomical observer to the college, William Cranch Bond, accounting for their involvement in the British-led campaign. Detailed in chapter six, it was then president of Girard College, Alexander Dallas Bache, who first recruited Lovering and Bond. Introduced by Bache to British campaigners' globalising zeal and their magnetic instrumentation militantly deployed in the service of prison-lodge observatories arranged around suspended iron crosspieces, Lovering and Bond saw the crucifix atop the *Handstein*, and dubbed the campaign a 'crusade'.[33] The orthodox historiography of the campaign remains indispensable,[34] but no less crucial is the history of the 'crusade' term this historiography assumes. In its own time the magnetic campaign was only ever understood as a 'crusade' in the eastern United States. In Britain it was 'a great combination'[35] directed toward a 'grand accumulation'[36]: cooperation re-organised under a magnetic technocracy in the service of capital.

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[32] Herschel,1839, in Carter,2009,p.129.
[33] Lovering&Bond,1846.
[34] Cawood,1979; Cawood,1977; Morrell&Thackray,1981.
[35] Sabine:Lloyd,[20/12/1839],**RS**/MS/119/80.
[36] Herschel,1839, in Carter,2009,p.129.

In 1849, just three years after Sabine republished Humboldt's claim in *Kosmos*, a fellow Prussian, Karl Marx, arrived in London as a political exile. His latest work, *The Communist Manifesto*, published just the year before, had looked to England not only to define communism, drawing on Owenite cooperation, but also to analyse the historical development of the global capitalism it opposed: an analysis both centred on Europe and laudatory of western colonialism. On moving to England, Marx's thinking would change. Working as a journalist he began to write with new attention to colonial oppression and exploitation, and to colonies as a focus of revolutionary change. In these works, and in his extraordinary scholarship of government papers, from parliamentary debates to select committees and factory reports, Marx developed his celebrated analysis of the system of capital established in the very same decades that concern this thesis.[37] Just as Marx required a history of capital to define communism, so histories of revolution from the English commons to the black Atlantic are indispensable to understanding the system of capital made cosmology.[38] In the 1770s, Britain's infant empire of American settlement and oriental trade appeared to be in decline, by 1783 it seemed nothing short of ruined. Yet in the six decades between the end of the American Revolutionary Wars and the beginning of the First Opium War, the same French Revolutionary Wars that saw the end of the Holy Roman Empire appeared to galvanise a new kind of integration in Britain between the forces of empire, war, economy, science and industry.[39] This thesis follows the principal commentators of the 1830s and 1840s in arguing that this alliance cannot be understood without attending to the revolutions of the black Atlantic, that geomagnetism was at the iron core of this new alignment, and that, in its 'grand accumulation', the 'great combination' of earth and nautical sciences charted not only the birth of Britain as the new dominant world power, but the reconstitution of the natural world as the globe of its free trade imperialism.

Chapter one introduces the central importance of the Cornish mining economy to the development of geomagnetism in the first half of the nineteenth century, not least the interests and concerns of statesman and mine administrator Johann Wolfgang von Goethe and his disciple Humboldt. To understand this significance it details peculiarities of late eighteenth and early nineteenth century Cornwall that provided the copper currency of the British colonial trade, and gave rise to a particular organisation of labour within its mines, based on the divisions of the miner's dial or compass and dubbed 'The Cornish System'. In turn this Cornish System not only provided the model for the administration of Jamaican plantations, and, under mine-engineer John Taylor, British high capital mineral extraction

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[37] Drapeau,2017; Brandon,2018.
[38] Williams,1944; James,2001; Blackburn,2010; Blackburn,2013; Beckles,2013.
[39] Bayly,1989,p.1-15.

globally, but also for mathematician Charles Babbage's famous political economy. While surveys of Cornish mines provided crucial observations and techniques for international efforts to establish the earth's central heat, the principles of Babbage's economy developed the Cornish System with his research into geological temperature differentials. The heated relations between politics, labour, and international geophysics irrupted into presence in Newcastle in 1838 with a mass protest on the Town Moor immediately before the British Association's launch of the magnetic campaign under Humboldt's apparent mandate.

While the concerns of Chapter one were bonded in Cornish copper, the focus of Chapter two is a new kind of iron, and what this iron meant for the development of a particular physical tradition at Woolwich Military Academy in early nineteenth century Britain. To understand this iron it is first necessary to attend to the long history of West African trade with Europe, the highly adaptive and innovative quality of West African metallurgy, and its transposition, through the human trade, to the Atlantic diaspora. The maintenance of the Atlantic system and enslaved labour on plantations in the Americas and the West Indies depended on the exploitation of this skill and in particular its adaptive flexibility, just as the system was threatened by the cohesion this skill forged. These concepts would prove seminal for the *physique* of colonial engineer and *Polytechnicien* Charles Augustin de Coulomb, who, in his famous torsion researches, begun as an attempt to refine the magnetic compass, recalled his formative years stationed in Martinique. In turn, the subsequent incorporation of Atlantic ferrous culture into Woolwich ordnance and dockyards in the late eighteenth and early nineteenth centuries shaped Woolwich Military Academy tradition and what its disciples saw in Coulomb's researches. This tradition, this chapter argues, was a disciplinary architecture heavily indebted to some of the most notorious systems of surveillance and extraction, and its disciples would come to dominate the practice and administration of the physical sciences in earlier nineteenth century Britain.

Chapter three considers the extension of the Military Academy ferrous culture introduced in chapter two to the study of electromagnetism, in particular by mathematics master Peter Barlow and his colleague, Woolwich chemistry lecturer Michael Faraday. In earlier nineteenth century Britain there existed a powerful and prevalent analogy between cotton and iron, where debates over machine exports, artisan movement, and the property of skill in manufacture were among the most intense polemics of the day. Drawing on this cultural capital, Barlow first tested ships' timbers by treating them as torsion threads, where the axis of rotation provided a neutral point for the theoretical abstraction of these industrial instruments, then extended this treatment of timber to the study of the new iron. His subsequent magnetic researches were preoccupied with finding the axis of magnetic influence in iron as he had the axis of movement in timber, while characterising magnetic action with the techniques and technologies of textile capitalism. In dialogue with his colleague's spinning, Faraday's early articulation of electromagnetic field theory described a textile cosmology.

The account of a particular physics of textile capitalism presented in chapter three concluded with James Clerk Maxwell's proposal that the universe might be modelled in a penny. The money's form could serve as such a model precisely because it was a microcosm of the universal exchange by which inalienable human properties may be transformed into commodities. To understand the dimensions of this base coin, chapter four considers the dimensions of nineteenth century Britain's global capitalism that Maxwell was born into. A transatlantic trade in African lives that was not triangular but quadrilateral; a so-called end to British involvement in this trade that was, in reality, no less than a violently enforced British state monopoly; and the emergence of surveys and centralised state-sanctioned trading standards as the weapon of choice in securing this distinctly British concept of the global.

Chapter five analyses the fraught and often frustrated experimental development of the magnetic survey and its instrumental standards to be just such a weapon as, with characteristic Woolwich subtlety, Barlow turned the compass into a gun; and, with colonial consistency, the British government took the figurative weapon to colonised Ireland to test it. This research then became the basis for founding the Admiralty Compass Committee, who first declared Barlow's compass-cum-cannon concept as their mandate, then summoned Britain's authority on the quadrilateral trade, whaler William Scoresby, to the Admiralty Library to advise. Nothing in these developments was determined by the physical laws described in chapter three, every event was fraught with contingency and administrative failure. Yet, when Scoresby joined the Committee in the Library he brought the quadrilateral trade to the table, and the Committee violently enforced its monopoly.

Chapter six is concerned with the Compass Observatory, the institutionalisation of the Committee detailed in chapter five and an Admiralty department devoted to technical surveillance, which used magnetism to enact a social contract between the British fiscal military state and its global construct. To understand this, the chapter begins with researches into the parliamentary length standard undertaken in and around Portland Place, culminating in an 1824 Act to construct new weights and measures. Initially an outsider of the British Association, in the mid-1830s Sabine would mobilise his intimate relation to this research to annex the magnetic lobby such that, by the 1838 launch, he was in command, and the magnetic standards represented British trading standards. Through the second half of the

1830s the evangelism of the magnetic lobby and campaign – 'a great combination' in the industrial political sense used by Sabine and Dublin astronomer Humphrey Lloyd – was deployed to persuade rival trading nations, not least the United States, to adopt British magnetic standards. In practice, this meant that British fiscal rule and the British concept of the global, its capitalist cosmology, was established well beyond the reach of its formal empire. In the early 1840s the Compass Observatory was founded, reproducing this relation at every level of its design and organisation, down to the copper of its construction. The Observatory served as a centre for the regulation of iron where iron was the fabric of Britain's global power.

The Compass Observatory had two adjutants in the field, two halves to the spherical projection: The Admiralty Standard Compass and the Fox-type dip circle. Chapter seven considers the development and career of this latter, the campaign's expeditionary instrument, as a *Handstein* microcosm of the connections set out in this thesis. The conclusion then brings together the evidence of the previous chapters to show how the Compass Observatory, the magnetic campaign and the globalisation of a particular ferrous economy were allied in the administration of a global system of enclosure. Not by transforming the enclosure - a form of extraction deeply situated in the history of British capitalism - into a universal principle. But by reconstituting the globe to fit the abstraction of the enclosure.

The progression of this thesis is synchronic. In each chapter the same years and often the same events are reconstructed and reinterpreted in the light of different traditions, as those traditions are revealed through material cultures of production. In this approach the thesis follows the fundamental preoccupation of its protagonists, concerned with the reconstitution of the global in novel materials, above all iron, remanufactured to embody and depend upon certain principles of labour extraction. It is this remanufacture that is crucial to this thesis, a word that emerged in the latter half of the eighteenth century to describe the process by which some British and 'Hollandaise' itinerants would purchase used tea and, through 'dextrously tinging, rolling and drying', render it for the purpose of re-sale 'to those who are fond of bargains'.[40] Remanufacture was born colonial: a parasite industry of parasitical plantation production that reconstituted its reality. By the mid-1820s, when civil engineer and patent agent John Farey published *The Operative Mechanic and British Machinist*, dedicated to Barlow's collaborator George Birkbeck and with a preface praising Barlow's Woolwich patron Olinthus Gregory, remanufacture was no longer about tea, but rather

[40] Sutherland,1764,p.289.

specifically associated with the recycling of scrap iron sold by dealers in marine stores.[41] Farey's account, appearing under the pseudonym of John Nicholson, carried a frontispiece and lengthy description of a new steam engine constructed by Messrs Taylor and Martineau (Figure 0.4). John Taylor was the same much-celebrated mine engineer then engaged in the global extension of the Cornish system.[42] A long-standing client of Fox and his steam manufactory,[43] the engine design Taylor and Martineau had designed was for use in sugar plantations. For Farey's account as for the Cornish workshop floor, the colonial essence of remanufacture was now integral to the structure of iron and steam. Just two years before his celebrated *Treatise on the Steam Engine*, considered by many the finest work on technology published during the industrial revolution,[44] Farey's *Operative Mechanic* is revealing of his and his contemporaries' understanding. Steam engines were defined by plantation production, and remanufacture by the parasitical mechanism of that system of extraction. The remanufacture of copper, iron, steam, and coal were powerful tools in globalising the interests of the British fiscal military state. This thesis follows the methods of its protagonists, and finds in the remanufacture of their materials, iron links to move analytically between the fine grain of situated concerns and the vision of the mine cosmically projected.

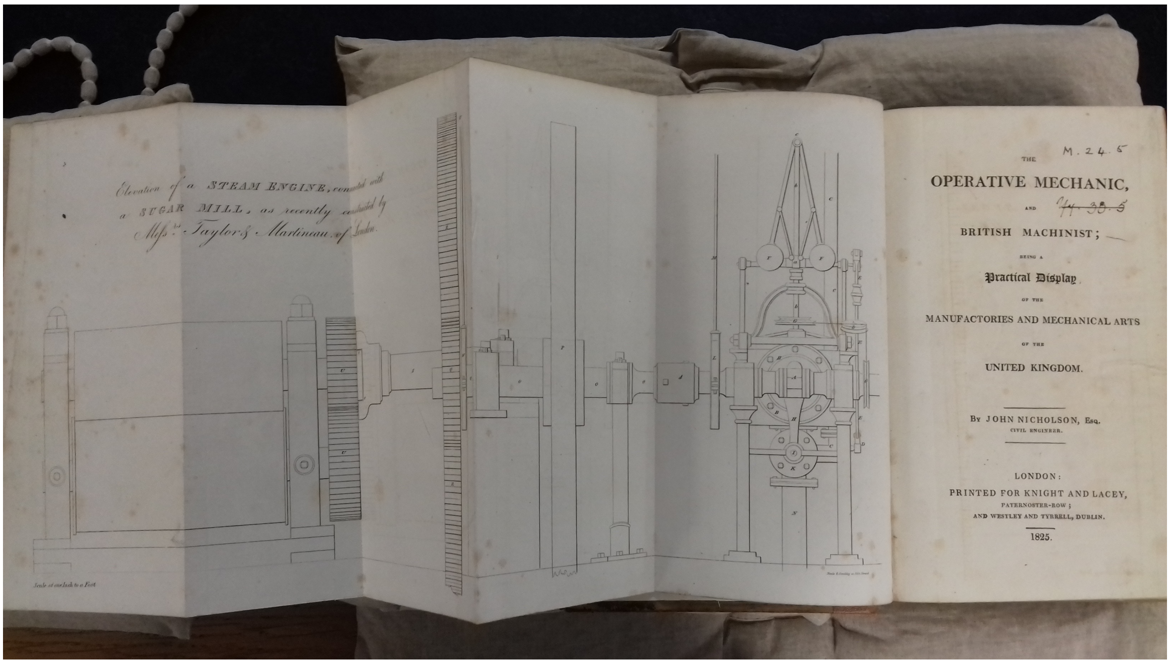

Figure 0.4: 'Elevation of a STEAM ENGINE connected with a SUGAR MILL as recently constructed by Messrs Taylor and Martineau of London', Nicholson, John, 1825, *The Operative Mechanic and British Machinist*, London: Knight and Lacey, frontispiece.

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[41] Nicholson,1825,p.viii,p.338
[42] Burt,1977,p.9,p.27.
[43] Ince,2001,pp.54-5
[44] Farey,1827; von Tunzelmnn,1978,p.2.

Chapter one: A Cornish *kunstkammer*

Figure 1.1: Forbes, John, 1822a, Map of the Land's End District, *Transactions of the Royal Geological Society of Cornwall*, II, frontispiece.

At a casual glance the blue of Figure 1.1 shows sea. Attend to the labels and the illusion resolves - the map is geological, the sea is of slate. Yet with the labels in mind the image has changed again – marks reveal mines and villages with respect to 'Gentlemen's seats', they situate resource and labour in relation to governance. This map navigates industry, social order, and political economy.[45]

The author of the image was John Forbes, a physician and until recently secretary to the Royal Geological Society of Cornwall. Forbes's 'Map of the Land's End District' was part of a wider move amongst the members of Cornish scientific societies to recruit iconography to establish a status and identity for Cornish science. The image served as frontispiece for an 1822 volume of the Society's *Transactions*, a special issue devoted to a particular concern of Forbes's - the temperature in mines, and the contemporary debate over whether that deep heat came from the centre of the earth or from labour.[46]

Forbes came to Cornwall after Professor Robert Jameson, his former geology lecturer and staunch disciple of the father of German geology Abraham Gottlob Werner, was asked to recommend an Edinburgh physician with an interest in geology for a medical practice in Penzance.[47] The optical illusion of the map is a profoundly Cornish expression of Forbes's training in Jameson's Neptunism, the Wernerian theory that rocks formed from the crystallisation of minerals in ancient seas. In Cornwall, where constant inundation and the pumping of the heat engine defined both human and physical geography, the mineral wealth of the earth's natural history crystallised from ancient seas through work. Similarly, in 'the land of tin', the rival theory to Neptunism, Plutonism, acquired a particular form. Where Neptunists looked to the sea for the generation of mineral veins, Plutonists argued such veins were the product of a great fire in the centre of the earth. In the thermometry of Cornish geologists, the debate over the existence of central heat was reconceived and meted out in terms that naturalised the heat of labouring bodies and the action of the engine.

This question, and the situated expertise of Cornish mine-managers, is acknowledged to have been key to the international recognition of Cornish Science.[48] This chapter goes further, looking to show how Cornish mining cosmology influenced the development of a particular global physics most associated with the famous traveller and aristocratic mining engineer, Alexander von Humboldt. The influence was not only formative, but also revisionary.

[45] Naylor,2010,pp.69-70.
[46] Gilbert,1822,p.vii-ix.
[47] Agnew,2002,p.28.
[48] Lawrence,1974,p.265

Through Humboldt and others, notably the author, statesman, and mine administrator, Johann Wolfgang von Goethe, imported Cornish mining technology was incorporated into the cosmology of these unifying states: a synthesis of sciences, statecraft, and industrial economy that reproduced the status of natural law.

Engineered into Cornwall's high capital mining was a particularly significant system of labour extraction dubbed the Cornish system and made famous by the Devonshire mathematician, Charles Babbage. Founded in the Cornish copper coinage of its mine economy was a certain mercantilism made general throughout British imperial influence by the famous industrialist, Matthew Boulton. Together these provided essential material resources in securing unequal trading relations within purportedly open markets, and the extension of capitalism to the displacement of other economic systems. They provided the foundations of what historians have subsequently dubbed the imperialism of free trade.[49]

To understand Humboldt and Babbage's most famous works it is necessary to understand the global export of the Cornish system, and in particular the significance of the Cornish diaspora and Cornish thermometry. Together with Babbage's specific relation to Cornwall and global finance, this extension is crucial to the development of the thesis as a whole. It points to the direct connection between Cornish labour economy and the management of plantations: shared organising principles sustained through the specific magnetic compasses and heat engines that concern this thesis. It is these concerns that were mobilised in the launch of the British magnetic campaign in 1838, by delegates overlooking the epicentre of Tyneside political convulsions: the Newcastle Town Moor. This chapter is a study of rising temperature and rising water where coal, heat, and deluge describe the changing nature of protest, in dynamic relation with the changing nature of capital.

Today, acknowledgment of rising temperature and rising water is often greeted with one of two extremes: drastic geo-engineering projects, or technological regress. Both positions treat capital as natural law, both lose the lesson of the historical analysis. This chapter seeks to contribute to a recent, radical, body of literature that exposes the historical origins of climate change in the rise of fossil capital.[50] In his 2003 article 'Future City', Professor of Comparative Literature Frederic Jameson made a truism of the Faustian stakes here at play, stating 'Someone once said that it is easier to imagine the end of the world than to imagine the end of capitalism'.[51] It is fundamentally the task of the historian of science to pick apart the fabric of

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[49] Gallagher&Robinson,1953,pp.1-15.
[50] Malm,2016a;Malm,2016b.
[51] Jameson,2003,p.76.

such universal claims. The global dominance of technocratic capitalism was deliberately and explicitly constructed, so too the purportedly universal science with which it was reciprocally sustained. In the nineteenth century the meaning of 'data' changed, from the rhetorical and logical gift of a pre-existing premise, to a raw material resource, extracted and rendered into the basis of 'fact', that is, something made, with the authority of incontrovertible truth.[52] Historians have taken the global nature of the massive data collection that characterised the magnetic campaign as given. But this thesis shows that in the same decades that the meaning of data changed, the global was also manufactured, not context but consequence of this vast distributed orchestration of labour: not taken as given, but taken.

§1: 'nature, and her living industry'.

> Anaxagoras: Hast thou ever, O Thales, in one night, brought such a mountain out of mire?
> Thales: Never was nature, and her living industry, referred to day, and night and hours. She forms and regulates every shape...
>
> *Faust.* [53]

From as early as the mid 1790s, Humboldt was strongly influenced by his friend and acquaintance, Goethe. One of the most effective popularisers of Neptunism in the late eighteenth and early nineteenth centuries, Goethe's political economy was a science intimately developed with his study of nature. Along with his peers in the statecraft of the German lands, Goethe despised French mechanical philosophy that undermined theories of natural order, in particular the French depiction of organisms as complex machines. He sought, rather, to elucidate natural laws over matter as a powerful proxy for the naturalisation of state laws over people.[54]

Significantly, the *Hofmeister* of Saxe-Weimar-Eisenach mines subscribed to the prevalent view that the wealth of a ruler and his people was a function of the flow of cash and of metals, and that export of metals to other regions would galvanise trade. The mines under his administration were to Goethe the source of such flow, and the model micro-economy for Weimar.[55] Further, the movement between mine model and economy was a gesture best exemplified in 'the magnet'. It was, in his words, 'an *Urphänomen* that one only needs to

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[52] Rosenburg,2013,p.18.
[53] Goethe,1839,pp.81-2.
[54] Jackson,1992,p.464; Jackson,1994,p.416.
[55] Jackson,1994,p.415,p.424,

mention in order to explain it. Thus, it also comes to symbolize everything else for which we need to seek neither words nor names'.[56] But if the mines of Weimar were the model economy, it was a model economy under siege. These same mines that depended on the flow of water as the source of power for works, were constantly inundated and drained of profit. In his struggle against the destructive force, Goethe specifically employed a slippage between Werner's natural water cosmology, and the artificial water economy of the mine. Where Werner argued water was generative of the earth and specifically mineral wealth, Goethe sought to harness water as the formative force of the mine and the source of the model economy's wealth.[57]

By 1796, water had won. Massive engineering works plagued by leaks leading to fatal collapses and closures rendered his administration a complete failure. Goethe was so frustrated and disappointed by the experience, he would not return to these mines for twenty years.[58] When, he did, in 1815, in post-Napoleonic wars Weimar, he saw a mine water economy managed for profit, by steam engines imported from Cornwall. If Goethe could not tolerate the law of the machine espoused by French mechanical philosophy, neither could he do without it. But Cornwall also provided the solution: in Britain's most isolated county, defined and delineated by water, the steam engine was naturalised as ubiquitous resource in the service of the water economy.

In 1815, the same year he returned to Weimar, Goethe became intensely preoccupied with Cornwall, the source of Weimar's imported engines and above all its supply of coal for the engine-powered works.[59] In Cornwall, Goethe found a place where steam was already naturalised in a political economy and order, wholly subject to the order of water economy. Further, and of significance to this chapter, the tin and copper of Britain's most south-westerly peninsula were exemplary of Goethe's metallic vision of princely wealth and the flow and excitation of trade.[60] From 1815, following the circulation of trade metal, Cornishmen began to leave Cornwall *en masse*, subsidised by Cornish mining entrepreneurs who sought to implant high capital mining above all into recently independent South American countries.

Goethe's known appetite for specimens and written accounts of Cornish mineral works encouraged his agents to write to him promising 'Any thing this Country [Cornwall] or Brazil

[56] Goethe in Hennigfeld,2015,p.158.
[57] Jackson,1994,p.427,p.424.
[58] Jackson,1994,p.428.
[59] Hennig,1949,p.534.
[60] Jackson,1994,p.415.

produces and which I either possess or can procure, I am willing freely to exchange for the mineral productions of the Continent.' On 24 November 1817 Goethe recorded in his diary spending the night 'translating [British mineralogist John Mawe]'s essay on the brown coal deposits of Bovey'. Three days later he wrote to his son 'That winter day, which will bring me *Zinnstufen* [tin specimens] from Cornwall, shall be marked in red.'[61] Cornwall had become *kunstkammer* in Goethe's *kameralwissenschaften*. In the early years of the nineteenth century Jena mineralogist Johann George Lenz had named a crude iron oxide after Goethe, the best crystals of which were found in Cornwall. Goethe dated his interest in mineralogy in general as originating in the 1770s, but it was in the early decades of the nineteenth century, specifically 1815-16 onwards that the products and industry of Cornwall, the region of his eponymous crystal, became the focus of his intense interest and study.[62] In December 1816, with his mind on the coal powered pumps of Cornish works, he wrote the draft outline of Part II of his greatest work, *Faust*,[63] in which he set out the Neptunist-Plutonist debate, using the drama to project his committed Neptunism.

The particular conjuncture and direction of Goethe's interest in Cornwall are critical to the argument in this chapter. Goethe, together with his contemporary, the mathematician, Carl Friedrich Gauss, was one of Humboldt's greatest influences. This section looks to show that the force of that influence was the 'living industry' of Cornwall: inundated mines kept alive by the pumping of coal-powered steam engines. Humboldt's great multi-volume work *Kosmos* was the reification of Laplacian celestial physics through a globally extended Cornish cosmology of metal extraction.

The introduction to this thesis described how Humboldt claimed in the first volume of *Kosmos*, published in 1845, that he was responsible for the launch of the 1838 magnetic campaign. This chapter shows the influence worked both ways. Immediately translated by Elizabeth Sabine under the editorship of her husband, military engineer and the magnetic campaign's then leader, Edward Sabine, the volume was in distribution, in English, by 1846.[64] In representing the campaign, the Sabines made sure to set out an umbilical connexion with Humboldt's global physics of metal. But the thesis introduction also described how much more material and mercantile promises were the winning motivation: assurances about iron and its instrumentation. This chapter is concerned with what it was in Humboldt's industrial natural history that was so valuable to the scientific administrators of 1830s Britain.

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[61] Goethe in Hennig,1949,p.537.
[62] Hennig,1949,pp.535-6.
[63] Mason,1967,p.21.
[64] Humboldt,1849,p.lxiii.

The statesmen of Prussia and Weimar in particular looked to the internationally famous Cornish mines in their efforts to unify the German lands. Above all, their attention was drawn to Dolcoath, one of the very deepest, colloquially known as 'mother' and more formally christened Bullen Garden, she was eulogized for her man-engines and considered 'the glory of the fabled West/ The Queen of her compeers'.[65] At the same time, between 1815 and 1850, Prussian architects constructed naturalistic 'English style' gardens in Potsdam and Berlin. In the capital, at the centre of these little Englands, were steam engines.[66] Yet in 1816 Berlin there were no engine-builders and only one engine: a Boulton & Watt - a Cornish engine. Seen by Humboldt at the Royal Porcelain Manufactory, the edifice of import substitution, as early as 1789, the young engineer described it as 'the best vindication of theoretical mechanics if ever one were needed.'[67]

Desire and dearth stimulated a revival in the pre-war culture of industrial tourism or espionage,[68] when access to steam engines had been not only synonymous with England, but through long history extended by James Watt's notorious patent, with Cornwall. In the 1780s, chasing overly curious dignitaries from their works had been a regular preoccupation for the firm of Boulton and Watt, with Boulton warning his agent most particularly against the notorious Prussian statesman, Baron Heinrich Friedrich Karl Reichsfreiherr vom und zum Stein.

> I belive[sic] Baron Stein is set out to Cornwall remember what I told you before he is the most dangerous of all the spies that have come to Cornwall. He hath an excellent Miner & Engineer with him. He must not go into our Engines particularly the Modern ones.[69]

The partners were still smarting from the previous year, when two Prussian engineers had visited from Berlin. In a moment of Watt's absence 'they got into the engine-room, and carefully examined all details of "Old Bess" making notes.'[70] These early forays led to the first German built engines, made in Cornish-style, with copper boilers.[71] Nonetheless, where steam power existed in Prussian industry it was overwhelmingly as a British import. As Europe opened up with the end of the Napoleonic Wars, Goethe was just one of many German statesmen whose attention turned once again to Cornwall. Ever alert to their market, in 1815

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65 Harris,1856,pp.154-5.
66 Wise,1999,p.107.
67 Löwenberg,Avé-Lallemant,&Dove,2012,p.123,ft.1,p.66.
68 Wise,1999,p.112.
69 Boulton:Wilson,[17/03/1787],**CRO**/AD1583/2/39.
70 Smiles,1874,pp.193-4.
71 Redlich,1944,p.122.

Watt invented apparatus to heat spaces by the circulation of boiler-heated water through pipes - a method rapidly and extensively adopted for garden-houses.[72] Filled with steam, such gardens were used to imagine and construct the farthest reaches of British imperial dominion, a representation Humboldt described as 'aesthetic empire'.[73]

Humboldt was a central figure among those architects and engineers who sought to make Prussia like Weimar through the aesthetic integration of steam engines into Prussian culture. He looked to represent the engine in the visual language of past and present Prussian ideals and by identifying engine power with Prussian power.[74] While Michael Dettelbach has emphasized the role of Laplacian physics in the development of Humboldt's science, M. Norton Wise has shown how Humboldt's work on the engine gardens was both the expression and development of his application of physics to natural history, and his view on the relationship between political economy and landscape. Both historians describe Humboldt's attempts to resolve the apparently insoluble conflict between his greatest mentors, Laplace allied with Gauss on the one side, and Goethe on the other. Goethean science was a natural history composed of statecraft, the power of which hinged on the extraction of mineral wealth. By contrast, and in extension of the French mechanical philosophy Goethe so detested, Laplace's celestial mechanics proposed that given enough data to determine the fleeting moment, a single mathematical equation could express all past and future states of the universe.[75] For Humboldt, the geothermal cosmology of Cornwall provided the solution as he sought to realize Laplace's *système du monde* through Goethean mining sciences, thermometry and magnetometry, figured in lines. From the beginning of the 1800s he pioneered extensive and systematic isoline cartography, predominantly in heat and magnetism. These lines connected disparate space and time through points of equal mean value. Like Laplace's perfect equation, Humboldt's ideal line, the engine in the garden collapsed past, present and Prussian future into a single equation of power.

§2: Cornwall's fluid capital

Cornwall was a county defined by water. To the north, the Bristol Channel; to the South the English; until Isambard Kingdom Brunel's Saltash bridge, completed in 1859, the peninsula was almost severed from the English mainland by its eastern boundary: the Tamar river. Prior to the mid-1850s it was claimed more Englishmen had been to the continent than to

[72] Smiles,1874,p352.
[73] Wise&Wise,2002,p.155.
[74] Wise,1999,p.107.
[75] Dettelbach,1992,p.135.

Truro, while those that did, came by sea.[76] When in June 1826 two Cambridge mathematics lecturers, George Biddell Airy and William Whewell, made a pilgrimage to carry out pendulum experiments in Dolcoath mine, they took the sea-route, from London via Devonport and Falmouth.[77] The strength of its maritime connections made Cornwall more an independent corporation in a system of global trade than an annex to England. From the late seventeenth century Falmouth had been one of the most important stations of the Post Office Packet Service, the administrative structure of British formal and informal empires; and, with the shift to steamship packets in the early decades of the nineteenth century, further cemented its importance as the locus for their maintenance and repair.[78] When Airy and Whewell returned to Dolcoath in 1828, the former now Plumian professor of astronomy, the latter now Cambridge professor of mineralogy and a celebrated translator of Goethe, they attempted to secure the transport of the fragile instruments by just this steam packet service, from Chatham to Falmouth.[79] This was an inundated land: water streamed from the granite hills and no location in the most remote parish was more than eighteen miles from the sea. Dig down, and, as every Cornish miner knew, the sea would rise to meet you.[80]

From this peculiar physical geography emerged a particular political economy. Cornwall's principal domestic industries - fishing, shipbuilding, and mining – all required the outlay of relatively high capital investment on equipment and materials, speculation that often carried high risk, but also the potential for dramatic returns. Above all in mining, the cost of purchasing and running pumping engines, without which the mines would flood and fail, made fluid capital an absolute necessity. For many landowners hoping to exploit the underground wealth of their estates such accessible capital and immediate outlay required investors: anyone with money, independent of social standing.[81] While this supposedly fostered a culture of social mobility, in fact it favoured the professional classes, whose regular employment and comfortable income provided the capital to lend, and security if a venture failed. Landowners increasingly became the property of their investors.[82] By the second half of the nineteenth century Cornwall had the lowest percentage of aristocratic landowners of anywhere in Great Britain and Ireland, bought out and displaced by the sudden extreme wealth of a rising middle class.[83]

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[76] Jaggard,1999,pp.7-10.
[77] Airy,1896,p.68.
[78] Parliament,1841a,pp.86-7.
[79] Airy,[1828],**CUL**/CUO/GBR/0265/Obsy/H.1.1.I.
[80] Jaggard,1999,pp.7-10.
[81] Nicholson,1951.
[82] Rowe,1953,p.23.
[83] Jaggard,1999,pp.10-24.

The Cornish economy puts a different light on the fluid professional and disciplinary boundaries that characterise mid-through-late Georgian bourgeois society. In Cornwall, the demands of high capital investment led to the formation of co-operatives between distinct but interdependent industries – for example, leading representatives of coal and metal extraction, iron and copper founding, marine engineering, and shipping industries, converged as partners with shares in a mining company or even under the heading of a bank. Such conglomerates would then act as a venture capital firm, pooling capital to make high-risk investments in speculative industries such as mining. By ensuring each link in the chain of supply, production, and demand was represented in the friendly and familial make up of shareholders' apparently distinct interests, risk could be regulated.[84] By monopolising each stage of production, such corporations could significantly control the market price of wages and intermediate goods. Indeed, it was massive corporations competing for these monopolies that generated the devastating Cornish recession of the late-eighteenth century.[85] In terms of legal and managerial structure, size and source of investment funding, size and nature of investments, and riskiness of said investments, two firms in particular exemplified this behaviour. The first, Praed and Co. of Truro, were a notoriously high-risk investment bank, with particular emphasis on financing the dominance of Cornish engine-building.[86] The second were the large and extended Fox family of Falmouth, owners of Dolcoath mine and heavily invested in almost every metal-based industry, not least banking.[87] Both were significant backers for Boulton & Watt, shoring up this risky investment by, in effect, owning South Wales coal and iron extraction and import into Cornwall, and the export of engines overseas, to provide the high-capital heavy industry of enslaver's plantations.[88] Banker Charles Babbage and the industrialist Robert Were Fox were directors within these two respective firms, and their work and interests have an especial relevance to this thesis. Fluid boundaries were essential to securing the interests of fluid capital, above all in waterlogged Cornwall.

This peculiar Cornish human and physical geography, specialising in shipping, metal extraction, engine building, and high-risk speculative investments, had significance that extended well beyond the bounds of the county. The transatlantic trade of the late-sixteenth through early nineteenth centuries transported enslaved people, cash crops and manufactured goods between West Africa, the Caribbean and American colonies, and the European colonial powers. At the beginning of the seventeenth-century the east coast of

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84 Brunt,2006,74–102; Ince,2001,p.14,20.
85 Ince,2001,p.16.
86 Brunt,2006,74–102.
87 Ince,2001,pp.25-69.
88 Williams,1944,pp.98-106.

North America was colonised by the Plymouth Company, an association of wealthy Cornish merchants chartered to the crown. Many of the seventeenth century British colonial officials who oversaw the productivity of Caribbean plantations transformed with high capital investment were latterly granted major Cornish estates after serving as governors of Jamaica.[89] Others, who also served as governor, had strong pre-existing ties among the political and merchant elite of Cornwall.[90] Successive members of the ancient and powerful Trelawny family governed Jamaica for several decades through the mid-to-late eighteenth century, precisely the period of increasing mechanisation and the massive escalation of the British human trade. Between them this Cornish family exerted enormous influence over the development of British labour extraction in the Caribbean. Similar Cornish influence can be traced for South American and Newfoundland plantations.

More telling even than this Cornish representation was what was represented in the metal. The markets that helped revive Cornish copper production at the end of the seventeenth century were ordnance, coinage, plantations, and the human trade.[91] By the eighteenth and nineteenth centuries, and under the influence of the Trelawny family, the export of copper had paved the way for the export of Cornish steam. The development of the transatlantic trade was closely tied to the development of Cornish heavy industry, and venture capital firms. As was the mechanisation that would make abolition of the traffic in enslaved Africans a lucrative prospect for early nineteenth century British industrialists looking to secure market monopolies.[92] Via investments in heavy industry, from coal extraction to shipping, and in particular the engine building of Boulton & Watt, Babbage and Fox's respective fathers had played a critical role in financing the industry of the transatlantic trade. Now the sons, Charles and Robert Were Jnr, took decisive action in rebranding this global system of production. Moral questions over human bondage were displaced onto the apparently autonomous action of the engine, as indenture to the machine reproduced many of the forms of the enslavement economy.

Alongside its increasingly wealthy middle class and powerful connections with plantation management and productivity, late-eighteenth century Cornwall was notorious for its over-representation in the House of Commons. In 1790, the county returned forty-four members to Westminster, two for the county, forty-two for twenty-one small boroughs. Of these, mining had its own member specifically appointed to represent the interests of the industry.

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[89] Zahedieh,1986,pp.205-222; Kelsey,2008; Burke,1868,p.717.
[90] Zahedieh,2008.
[91] Ince,2001,p.12.
[92] Williams,1944,pp.98-106.

The long three-life leases on the majority of estates made for weak influence of landowners over tenants, while the votes in the twenty-one boroughs were notoriously for sale to those with fluid capital.[93] In sum, not despite but significantly because of their water-locked isolation, the mining industrialists of the Cornish middle classes held markedly disproportionate influence over industrial revolution Britain and the productivity of its colonial possessions. To fully appreciate the nature of this influence, it is necessary to understand the economy of the Cornish mine.

§3: a dial to 'survey' extraction

Mining entrepreneur and engineer John Taylor was born in Norwich in 1779, but by his death in 1863, his global extension of Cornish high-capital industry and the labour economy that accompanied it had seen him acclaimed 'the patriarch of British mining.'[94] In 1814, the *Transactions of the Geological Society of London* carried an article by Taylor detailing the labour economy of Cornish and Devonshire mines. His account of the Cornish economy would have a seminal legacy in the work of Charles Babbage, specifically in the development of his principle of the minimisation of production cost through labour specialisation. As the introduction noted, in 1832 Babbage would name this the Cornish system. Sections five and six will consider this coining of terms in conjunction with the contemporary 1830s parliamentary reform, Cornish thermometry, and the global extension of Cornish high capital. This section, however, is focused on understanding this peculiar labour economy that crystallised around the pumping of Cornish engines. In particular, Taylor's account, from which Babbage quoted directly, described the 'survey':

> The work of the mines, on the surface as well as underground, is universally performed by contract… The plan of making the contracts with the miners, which it is believed is peculiar to Cornwall and Devon, and which holds a distinguished place in the economy of the mines, is that of periodically bringing all the work to a kind of public auction… the auction is denominated a *survey* [original emphasis].

The survey within the Cornish system was a public auction of mining contracts whereby workmen were excited into fierce competition to offer the lowest price for their labour. Any 'danger to be apprehended from a combination of the men' was 'effectually prevented' by the mining captains reserving the power of offering the final price, or to withdraw the contract altogether if the price did not go as low as they wanted. 'It is understood' wrote Taylor, that the man who won the survey 'is only entitled to the option of closing the contract upon the terms to be named by the captain… if refused, these terms are tendered to the others in order

[93] Jaggard,1999,pp.21-22,p.11.
[94] Burt,1977,p.9.

of their offers.'[95] Like the notorious sweating system, such bidding down imposed a furious and often fatal rate of industry on the worker.

The contracts themselves were tendered for three different categories of work, tribute, tutwork and dressing, which categories were divided on the understanding of the level of skill involved. Tribute, the most skilled class of work, afforded the best contracts to raise and dress ore.[96] Nonetheless payments were still governed by the market value of the material raised, and varied drastically according to the quality of the ground worked.[97] Miner's dials - magnetic instruments otherwise known as a surveyor's compass, and comprising a magnetic needle, graduated circle, and line of sight - were used to settle disputes over ground. A miner caught concealing good ground from 'the next Taker' could be held to account by the magnetic instrument.[98] From as early as the seventeenth century this system was understood as a means to perform commutation between land, labour, and quantitative value, above all on plantations.

Section two noted the Cornish character of the governance of colonial Jamaica. This was true in particular of its administration. Since its earliest British colonisation every land grant had carried a diagram attached to the patent (Figure 1.3 and Figure 1.4). These diagrams were distinct from actual surveys of the land (Figure 1.5), because they ignored the true meridian and showed only the magnetic meridian. Boundary lines were marked using cuts into hardwood trees,[99] and disputes over boundaries were resolved using the Cornish system of the miner's or surveyor's compass, and by comparing these lines with the patent record of magnetic meridians. The comparison worked, argued James Robertson, author of the most complete survey of Jamaica (Figure 1.5) prior to that by the enslaver Henry de la Beche in 1827, because magnetic variation in the longitude and latitude of Jamaica was so small as to be negligible. This system of division by magnetic compass underpinned the inheritance, sale, and management of Jamaican plantations in the metropole as on the island itself.[100]

Significant for this thesis, it was also salient within the Admiralty from 1794, when the Jamaican enslaver and machine designer Ralph Walker submitted his improved compass design to the Board of Longitude. A design Walker developed in accordance with the Cornish

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[95] Taylor,1814,pp.316-9.
[96] Taylor,1814,p.317-8.
[97] Dunkin,1999,p.58.
[98] Hardy,1748,p.115,p.85.
[99] Gibson,2016-, field notes August 2019 interview with a Maroon hardwood specialist.
[100] Robertson,1806,pp.348-56.

system: for the purpose of surveying plantation boundaries.[101] Unlike Robertson, Walker considered the magnetic variation of Jamaica to be changing over time such that, by 1854, true and magnetic meridians would coincide, and predicted significant consequences for enslavers' patents (Figure 1.6). Walker claimed his elaborate design, essentially a universal sundial fitted to a compass bowl (Figure 1.2), could not only obviate this concern by always finding true north, but further determine longitude at sea. The Board rejected it as a longitude solution, but following the recommendation of Captain Cook's astronomer William Wales decided to award Walker £200 for the design's utility as a reference compass to calibrate crude ships' compasses: specifically because, like its antecedent the Cornish miner's dial, it had an azimuth function. With an eye to the cost and complication of the instrument, only fifty were initially ordered, restricted for use on ships bound overseas and by an officer with a certificate of proficiency, gained from the Naval Academy at Portsmouth. While Walker's subsequent career has relevance to chapter two, and the Admiralty legacy of his compass to the remaining four chapters, here it is the close identification of the Cornish system with the variation compass, widely distributed in British maritime and merchant culture that is most relevant. In 1815, the year after Taylor published his article describing the Cornish system, the Admiralty restrictions were lifted and a surge in demand followed, so that, by August 1819, over 500 of Walker's 'Meridional Compass' accumulated, unused, on the shelves of Admiralty stores.[102]

[101] Walker,1794,pp.211-26.

[102] May,1987,pp.149-65; The European Magazine,1803,pp.331-3

Figure 1.2: Walker, Ralph, c.1793, Meridional Compass, NAV0263, National Maritime Museum, Greenwich, London.

In his article, Taylor gave a detailed account of the divisions of labour over which the variation compass ruled. Tutwork referred to underground work understood to require little skill, such as sinking shafts and clearing. In accordance with the purported low skill, it was also low value, unprofitable work. Finally, dressing was considered lowest skill of all and 'seldom for more than the waste or leavings of the *tributors*', who could only afford to focus their time on the most valuable ore.[103] In dressing the rough waste-ore was broken or crushed and arranged in heaps according to an estimated value based on purity. The contracts for dressing generally went to a man who managed a team of women and children. Magnets were often employed in the dressing process, both to gauge purity and to filter the metallic material. In different capacities a group of mines could employ nearly an entire neighbourhood. The nature of the small contracts, meted out in surveys repeated every two months, required vast quantities of small denomination base coin for the payments.[104] The advantage, as Taylor saw it, was that the mining captain was paid only in proportion to the market value of the work done. This proportion of market value was divided among the men in proportion to their skill. Because of this, and in particular because of the bidding down driven by the survey, workers within a particular skill class could only increase the value of their contract by increasing their rate of work. A rate ultimately dictated by the steam engine.

Taylor was explicit in his claim that the mines of Britain had no government assistance, and at every level, from management to the worst paid dressers, depended on the risk, industry and competition of individuals. Work was incentivized by the glimmer of a possibility of great individual gains, and the threat that the next man might bid for a lower contract.[105] As the subsequent sections will show, in particular section seven, what Babbage admired in the Cornish system was not just its division of labour, but that this particular division of labour inherently produced free trade open market competition at every level of society and economy. Taylor's central argument that individual entrepreneurs' 'calculations of real profit are often more unquestionable than in government undertakings', was consistent with a strong commitment to the relation between the movement of metal and public welfare.[106] The view that the wealth of a state depended on the flow of metals, and that by the export of metals further trade would be galvanised, was favoured not only by Goethe but had long been a feature of mercantilism in general.[107] It was a system well developed in eighteenth century Cornish mining, where contracts portioned out in vast quantities of small denomination coin

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[103] Taylor,1814,p.318.
[104] Dunkin,1999,p.58.
[105] Taylor,1814,pp.309-10.
[106] Taylor,1814,p.309.
[107] Jackson,1994,p.415.

defined the internal economy.[108] Further, the manufacture and circulation of such coin and of trade metal, even and especially in the form of ships' hull sheathing, was the crucial driver to the industry, setting the market value of Cornish copper. At the same conjuncture the East India Company was making a policy of establishing local mints as the first step to subjugating markets,[109] while the currency of African colonies was being coined in Britain, by Boulton, using Cornish copper.[110] By the late eighteenth century, Britain's international trade, the material construction of a particular cosmology, was gilt in Cornish copper.

§4: ships of state sheathed in coin

When Goethe used the *Urphänomen* of the magnet to move between the mine and generalised economy,[111] he was describing precisely this construction: the manufacture of the globe by the union of metal mercantilism with magnetic science. Metal had long been an important component in the composite construction of British ships, but its incorporation became salient with the large-scale circulation of trade metal in the Pacific, in particular Cornish copper traded as coin and ships' fittings. With the new economic salience of ships' metal, came new attention to its influence over ships' compasses. 'Local attraction' was both the presumption behind the European trade with newly encountered peoples,[112] and the quantification of this presumption as a natural phenomenon. Cook's celebrated voyages, between 1768 and 1779, combined the inauguration of metal as the governing principle for the instigation of trade in the Pacific, with the first documentation of the influence of local attraction on ships' compasses. These voyages would become the model for nineteenth century navigation directions and voyages of exploration. That Cook's voyages were undertaken on Whitby coal ships is a further reminder of how much of British domestic economy was based on ocean going trade.[113] The assumption that coal vessels were robust enough to travel anywhere provided vital assurance for the security and efficacy of those pioneering voyages. Before coal became the motive and means for exploration and global domination, coal ships were indispensable in the politico-economic construction of the globe.

In preparation for the second of these voyages, the famous collector Joseph Banks ordered a number of earrings, wristlets, beads, and even metal replicas of Maori *hei tiki,* referred to as

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[108] Dunkin,1999,p.58
[109] R.S.,1877,90-92
[110] Eagleton,2016,pp.203-5.
[111] Hennigfield,2015,p.158
[112] Newell,2010,pp.40-44.
[113] Gascoigne,2007,pp.52-3.

'Grean Gods [sic Green Gods],' from Boulton.[114] These metal 'trinkets' were commissioned with the intention of using as gifts or presentation items,[115] in keeping with a complex system of exchange at the heart of European navigation practice.[116] In addition, Banks's numismatist sister, Sarah Sophia, directed her brother to order medals from Boulton; two specimens in gold, over a hundred in silver for Banks's friends, and 2,000 in bronze or brass gilt for distribution on the voyage. These were Boulton's first attempt at medal making, and his first introduction to numismatic arts.[117] They were cast in Cornish copper.[118]The following year, in 1773, the Treasury appointed Boulton to act as Birmingham agent for the receipt of worn-out coin, a post he held for three years.[119] Indeed, coin was central to Boulton's early work on the remanufacture of metals.

From the mid-1770s, renewed interest in the possibility of copper sheathing for ships' hulls prompted Boulton to experiment on the production of copper alloy bolts for fixing the sheathing in place.[120] Initially he worked closely with the Copper King, Thomas Williams, who stoked demand for his Welsh copper by alternating between domestic and foreign contracts for sheathing.[121] Shipping in the West Indies was particularly vulnerable to the ravages of the *teredo* worm, and under the pressure of the American War of Independence colonial governments and trading companies vied for the fastest, most manoeuvrable ships.[122] War-profiteering brought Williams close to a monopoly over the entire copper trade in late-eighteenth century Britain, a significant concern to Boulton, who sought to break Williams' hold with innovations in coining.[123] In 1777 Boulton & Watt took shares in Fox family mines as part payment for an engine, and so became directly involved in the extraction and smelting of copper. From this point Boulton & Watt had a commitment to Cornish copper, and there developed a close friendship between the two firms. The Foxes subsequently acted as agents for Boulton & Watt in both senses – promoting the use of their engines in Cornwall, and informing on attempts to circumnavigate their patent, or other developments in Cornish engine building.[124] In 1787, Boulton having been coining for the East India Company for a year, and Williams monopolising the production of trade tokens used by British industrialists

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[114] Westwood,1926,p.8; Coote,2008,pp.53-54.
[115] Westwood,1926,pp.1-2.
[116] Bravo,1999,pp.199–235.
[117] Westwood,1926,pp.3-4.
[118] Tungate,2010,p.30;74.
[119] Powell,1993,pp.49-55.
[120] Quickenden,Baggott,&Dick,2013,pp.1-18.
[121] Harris,1966,pp.562-3.
[122] Harris,1966,p.560; Solar&Rönnbäck,2015,p.811.
[123] Boulton:Banks,[24/12/1798],**Sutro**/Banks/Co.5:61; Boulton:Banks,[29/11/1799],**Sutro**/Banks/Co.5:75.
[124] Ince,2001,p.29-30.

to pay their workers, the two came into direct competition for a mooted contract to mint regal copper coinage. In effect a competition arose between Cornish copper and the cheaper Welsh material. When the contract failed to materialise for either entrepreneur, Boulton began to compete with Williams for his customers, displacing the Copper King in his own market within the year.[125] It was not until the late 1790s, and with Banks's backing, that Boulton finally won the royal contract for legal tender,[126] when it was suggested that copper recovered from dry-docked ships of war should be used for coinage.[127] This was an experimental branch of a programme for the remanufacture of ships' metal, in which the Admiralty had been heavily invested since the early 1780s.

With the trade along the Northwest Coast initiated by the celebrated voyages of Captain Cook, these tokens were distributed there in huge numbers. The introduction of trade copper, in particular in the form of tokens and sheathing, disrupted the traditional manufacture of copper in the Pacific Northwest. Indigenous metal-working practice had developed around 'native' copper, that is, extremely pure, naturally occurring un-smelted metal. This native copper was qualitatively different, much softer, and required different techniques of production, to the brittle impure smelted trade copper produced in Britain and used in sheathing and coin. The introduction of huge quantities of trade copper led to a confluence and progressive displacement of native copper with the cheap and plentiful alternative; and a concomitant impact on metal-working technique.[128] Just as mercantilist theory and East India Company policy proposed, coin and metals could excite trade, but more than this they re-organised existing economies and societies.

A significant part of this re-organisation took place within the metropole. With this in mind, it is worth remembering the relative novelty of small denomination currency in industrial revolution Britain; the poor representation in Parliament of the new, vast industrial cities; and the disparate trading standards of each region, that, previous to the reform of Britain's weights and measures, produced, in effect, distinct trading states. Concurrent with the Cook voyages and Boulton's regal contract, the military state launched the Ordnance Survey: its first coordinated survey of Great Britain and Ireland. This campaign saw cartography crucial to the enclosure of the Highlands, extended to the survey of all Britain's domestic territories; and through this the development of the fundamental eighteenth and nineteenth century

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[125] Dykes,2003,pp.160-74
[126] Liverpool:Banks,[10/7/1799],**Sutro**/Banks/Co.5:73.
[127] Northover&Wilcox,2013,p109.
[128] Witthoft&Eyman,1969,pp.15-6.

techniques of imperial military occupation and rule.[129] The Ordnance Survey was concerned with the commutation of land and labour into quantities: into watch chain lengths and the base coin that paid the wages of a rural population displaced into industrial cities. According to many contemporary reformers, Westminster was in an imperial relation to Britain's industrial cities, and following Boulton's pioneering innovations, it was into these cities that the state directed the flow of Cornish copper coin.

Among numismatists, Boulton is widely acknowledged as the father of modern coinage. The innovations that won him this accolade are of significance to this chapter and the thesis as a whole. From his first experience of coining for the Cook voyages, Boulton's interest became focused on developing novel techniques against counterfeiting that would depend on the use of steam power, his explicit purpose was to make steam power indispensible to minting money.[130] With the end of the Boulton & Watt engine design patent imminent, the steam engine manufacturer sought to revolutionize coin to create a new Boulton & Watt steam monopoly through money. The process was far from straightforward. From his first steam-powered press in 1789,[131] the first anywhere in the world, it took Boulton a further decade to achieve a reliable means of steam-striking heavy coins;[132] while even to the final batch of tokens in January 1850, the famous Soho coining processes were never fully steam-driven. Indeed, in the fundamental process steam was an adjunct to the prime mover of waterpower.[133] It was specifically through the development of a particular form of detail as protection against counterfeit that Boulton was able to actively and deliberately manufacture steam as indispensible.[134]

His achievement of a reliable steam-powered press coincided with winning the regal contract in 1797,[135] and, that same year, a new central preoccupation. Where he had previously been concerned with the uniformity of the coins manufactured, with the regal contract he became determined to bring the dimensions of the newly authorized copper coinage into correspondence with the weights and measures held by the Royal Society.[136] These were the same standards then in use for the Ordnance Survey of Britain, and, as Boulton himself noted,

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[129] Edney,1991,pp.14-20.
[130] Doty,1990,p.179.
[131] Selgin,2008,p.270.
[132] Boulton:Committee of Council of Coin,[25/12/1798],**Sutro**/Banks/Co.6:34; 'corporation of Moneyers',[1798],**Sutro**/Banks/Co.6:38.
[133] Selgin,2008,pp.89-90.
[134] Boulton:Banks,[24/6/1808],**Sutro**/Banks/Co.1:39-41; Doty,1990,p.179.
[135] Boulton:Banks,[29/7/1797],**Sutro**/Banks/Co.2:42; 'notes on Boulton's erecting presses',[1797],**Sutro**/Banks/Co.4:35.
[136] Boulton:Banks,[17/12/1798],**Sutro**/Banks/Co.5:66.

at that moment under analysis in an attempt to impose more uniform weights and measures over the disparate and devolved trading standards of Britain and Ireland.[137] Further, Boulton was emphatic that the regal copper coinage's metallic value, plus its cost of production, should, as far as possible, equal its stated value.[138] In this way, through copper coin, Boulton brought attempts to extend the Royal Society's weights and measures nationally, the ongoing Ordnance Survey, and experimental physics of Royal Society members, into direct correspondence with the state of the British metal extraction industry and steam engine manufacture.

§5: political currency

Leading figures in the Royal Society dominated calls to reform the variable weights and measures of Britain into a uniform, centralized system. Among these a pivotal figure was the Cornish engineer of science, mathematics and politics, Davies Gilbert, formerly Giddy, who was principally concerned with the 'duty' on steam engines. This 'duty' was a measure of efficiency, originating from Cornwall, and traditionally calculated by conceiving of the engine as a balance that weighed the consumption of a bushel of fuel against pounds of water lifted one foot high.[139] Such raising of water referred to the action of pumping out flooded mines, but also, in Cornwall where water was power and *leats* crowded the land competing for a share, it also entailed the maintenance of the mill stream. As such 'duty' not only varied with the size and quality of coal, or even the parochial size of a bushel, but it also remained a reminder that steam was adjunct to, rather than displaced, water power. Gilbert's interest was specifically motivated by the Boulton & Watt monopoly, which the firm maintained by levying duty on their engines, much like a system of royalties. Boulton had referred to Royal Society standards and sought to develop designs against counterfeiting to make his steam engines indispensable. It is therefore significant that just after Boulton's regal contract, Gilbert represented the problem of variable standards as a problem of fraud. He made this part of a wider campaign for free trade and Corn Law repeal.[140] The trust and precision that had once been embodied in the heroic philosophers and instrument makers of the seventeenth and eighteenth centuries, was now to be fetishized onto the engine, not for any apparently objective qualities it might offer, but as part of an institutional effort to protect the heat engine to displace water power.

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137 Prosser,1913,pp.379-80.
138 Doty,1990,p.179.
139 Nuvolari&Verspagen,2007,p.169.
140 Waring,2014,p.70.

One further innovation has led numismatists to dub Boulton the father of modern money: the mechanical globalization of his coin standard. As noted earlier, Boulton contracted to the East India Company in 1786, to manufacture copper coinage for Sumatra. By 1791 he was striking coin for Sierra Leone and for the Bombay Presidency, rapidly followed by Madras, by the mid-1790s he was engaged in secret negotiations with the *Directoire* to provide copper coinage for revolutionary France. Significantly, in 1796, the year before Boulton was awarded the regal contract, he began to manufacture, sell, and internationally export, minting machinery. The first three decades of the nineteenth century saw Boulton & Watt contracts for the export of steam-powered presses to Russia, Denmark, Brazil, Mexico, and the United States. Many of these ventures were in some measure frustrated, such as one of the five Mexican facilities, Guanajuato, changing its order to a hand-press after realizing a steam-powered mint still required running water, while successive attempts to equip the Philadelphia Mint in the United States ended in failure. Nonetheless, Boulton provided, among other essential and defining components, the steel dies and the raw copper.[141] Boulton's export of coin, of machinery and even of tools and raw materials, was itself the global export of the Royal Society's weights and measures, and of the British metal extraction industry.

Attention to Boulton's manufactures and exports highlight the free trade imperialism of this important moment in globalization, but also the way in which Britain's industrial towns were re-organised as proxies for the establishment of the free trade empire. Between 1787 and 1797, as Boulton competed with and displaced Williams in his own market, he used the manufacture of trade tokens for industrialists to refine the developments with which he sought to make steam indispensable. In particular it was the novelty of his design measures against counterfeiting that succeeded in luring away Williams's customers. These innovative techniques revolutionised the state of numismatic arts such that these trade tokens not only represented a more accurate weight of metal than legal tender, but also intricate, exciting designs, often including political or commercial slogans that served as advertisements to further the interests of the industrialists. Within just a few years, by the early 1790s, the techniques of coining these metal advertisements were turned back onto the industrialists and political elite with ribald commentary. Unlike other contemporary objects printed with caricatures, such as pottery, textiles and snuffboxes, these satirical tokens carried, almost without exception, wholly original designs. Unfettered by reference to more respectable print-based visual satire and their audience more proletariat, these designs went further: their satire more biting, their agenda more radical.[142]

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[141] Doty,1990,p.184.
[142] Crowther,2013.

Of the radical token makers of the late-eighteenth century, the Newcastle-born Thomas Spence was one of the most notorious and prolific. His politics - developed in the 1760s condemning taxation, land enclosures, and British policy in North America - crystallised around the fierce campaign to prevent the enclosure of Newcastle's Town Moor in 1771. The same Town Moor would play a significant role in the history of Chartist protest and is described in more detail in section eight of this chapter. For Spence the Town Moor protests would help found his famous doctrine of common land ownership.[143] The Newcastle Town Moor, so formative for Spence, would not attain its full status in Chartist history until some 24 years after his death in 1814. Likewise, Spence's satirical tokens, materially formed with the politics he founded in the fight for the Moor, would attain their most dramatic significance in 1838, with the publication of a national petition for the electoral representation of working men, *The People's Charter*, written by the Cornishman, William Lovett, founder of the London Working Men's Association. For the later nineteenth century commentator, journalist Karl Marx, copper tokens and pittance factory wages were the origins of this unified proletariat: 'the indispensable means of holding up the spirit of the laboring classes, of combining them into one great association against the encroachments of the ruling class.'[144] For Marx, united protest and resistance in the call for 'universal suffrage' was a direct extension of his analysis of the money form that brought qualitatively incommensurable labour into quantitative universal equivalence in the origin of capital. Marx focused on gold, and the economic status of the gold standard, but attention to copper here has great significance. The reform of Britain's weights and measures was explicitly a process of establishing national equivalence in trading standards. The global export of Boulton's small change, of weights and measures made to correspond with the Royal Society's centralised standards and the market value of Cornish copper, constructed a material universal equivalent. It is this globalisation that preoccupies sections six and seven, from Humboldt, through Babbage, to Taylor, and the Cornish diaspora.

§6: deep heat to navigate labour

Section one pointed to Werner and Goethe's understanding of the world as governed by a natural universal order modelled on the mine economy and the flow of metals.[145] Humboldt's unification of the sciences was an extension of these concerns. His famous isomaps, made up of lines joining points of equivalence across the globe, were developed first in magnetism and then most fully in heat. By these two phenomena, heat and magnetism, miners navigated

[143] Crowther,2013.
[144] Marx,1853a.
[145] Jackson,1994; Jackson,1992; Dettelbach,1992.

below ground, without stars. In his efforts to develop a mathematical theory of the distribution of heat and magnetism on the earth's surface, Humboldt saw a direct continuation of Göttingen astronomer Tobias Mayer's lunar tables.[146] Mayer's work was the argument and basis for the *Nautical Almanac*, a publication established in 1766 for the purpose of applying celestial observations to position finding at sea; and a crucial resource for British astronomers' attempts to impose order on navigation worldwide. It was no simple consequence of natural laws that such efforts concentrated on Barbados and the Caribbean. Mayer's celestial accountancy would underwrite Britain's free trade imperialism from the late-eighteenth century for decades to come. Where Mayer's tabulation set down the spatial relation of the moon and stars, Humboldt navigated the magnetism of mineral wealth and the heat of labour. This section is concerned with how, in the 1830s, Humboldt's *physique* of mines would be mobilised in the naturalisation of the political economy of this global power.

In his isomapping Humboldt was dogged by the persistent question of how best to take averages, and by the standing of his work with respect to the precision and sophistication of the French *écoles supérieures*. In the face of these challenges he sought and welcomed mechanical solutions, not only directly to measurement and analysis, but to confer precision on representation, through the use of innovative printing techniques.[147] In doing so he informed the development of geology in Britain, in particular its prolific deployment of iconography. This has been analysed by Martin Rudwick as a 'visual language,' entailing all the framing of thought and expression, coded meaning, and communication internal to a specific community that the term 'language' suggests. The emergent discipline of British geology achieved this expression by recruiting technological developments in the printing of images, namely lithography, a novel means of printing, invented in Bavaria, that enabled a greater number of print runs per template, so reducing both the proportion of skilled labour and the worker's control over the rate of labour.[148] Lithography, crucially, drove a new equilibrium between the respective contributions of the skilled hand artist and the de-valued labour of the hand-press operator. Forbes's 'Map of the Land's End District,' (Figure 1.1), is an example of one such lithograph. Humboldt, for whom lithography was both geological formation and mechanical process, understood the hand press together with the Boulton & Watt steam engine at the Berlin Royal Porcelain Factory, as the archetype and vindication of theoretical mechanics.[149] In Humboldt's isolines, as in the visual language of British geology, the lithographic process extended the language of power beyond figurative expression to the

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[146] Dettelbach,1992,p.144.
[147] Dettelbach,1992,pp.145-7.
[148] Rudwick,1976,p.156
[149] Löwenberg,Avé-Lallement&Dove,2012,p.66.

literal enactment of political economy. If lithography was both geological formation and mechanical process, the heat it represented was, for the aristocratic mine-engineer, both geological causation and labour economy. Humboldt's 'general picture of nature', the form, warmth, and electromagnetic power of the earth, indeed, his *physique du monde,* were the product of a cosmological power: the heat of the earth's core.[150]

By the publication of the first volume of *Kosmos* in 1845, Humboldt's confidence in the doctrine of central heat was explicit.[151] The empirical research of Cornish mine-managers had formed a key foundation in preparing popular and scientific circles for a return to this hitherto discredited question, and its role in dynamic geological processes.[152] Among those Cornish industrialists contributing to the contemporary heat debates, Fox was one of the foremost. Historians have remembered Fox for designing the dip circle that would become iconic of the magnetic campaign following the notorious disappearance of the 1845 Franklin Northwest passage expedition; and subsequently specified by the Admiralty in 1849 as the standard instrument for measuring magnetic inclination at sea. But Fox developed his dip circle through thermometrical experiments down mines.[153] Long before the uptake of his instrument, he was known as a steam engine entrepreneur,[154] and for his work on deep heat.[155]

As mentioned, the Fox family had a close partnership with Boulton & Watt from as early as 1777. In 1791 they founded their own ironworks at Perranworthal, between Truro and Falmouth, which, according to Gilbert were 'the first constructed of any magnitude in Cornwall.'[156] With their leasehold of Neath Abbey in Dyffryn Clydach, Wales, the Fox family used the two ironworks together to manufacture parts for the construction of whole steam engines, exploiting their Neath coal monopoly and arbitrage between Cornwall and Wales.[157] In 1812 Fox was awarded a joint patent for improvements to the steam engine.[158] By the 1820s Fox works were supplying Cornish mines and marine steam market with engines.[159]

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[150] Humboldt,1849,pp.189-90.
[151] Humboldt,1849,pp.189-90.
[152] Lawrence,1974,pp.263-5,p.265
[153] Fox,1828,pp.313-328; Fox,1832a,pp.310-311
[154] Fox&Lean,1813.
[155] McConnell,1986b,p.37
[156] Gilbert,1838,p.305.
[157] Ince,2001,p.50,53.
[158] Fox&Lean,1813.
[159] Ince,2001,p.38.

Under Fox's management the Perran foundry was developed such that by 1830 it was producing whole engines, of pioneering size and power, independently.[160]

It is significant that this period of rapid and intense development of local Cornish steam engine construction directly coincided with the rapid and intense development of Goethe's interest in Cornwall and his dramatization of the Neptunist-Plutonist controversy: the debate between deluge and central heat. Among elites, notably Cambridge geologists and mathematicians such as Adam Sedgwick, William Whewell and William Hopkins, this question was largely guided by the views of Joseph Fourier, a highly influential French mathematician also interested in the native heat of the earth.[161] What Fourier lacked, and what figures such as Fox offered, was privileged access to the world's deepest mines, not least Dolcoath. Fourier's scientific work and reputation were particularly focused on characterising the behaviour of heat in mathematical terms, with his earlier work describing the distribution of heat in thermal systems. It was not only Humboldt who found the steam engine the best vindication of theoretical mechanics: Fox's experiments on heat-engines had extended to interest in the possibility of 'internal heat' in the earth's core, and it was in Fox's data that Fourier found his evidence.

Fox was at the forefront of a concerted and autonomous programme to demonstrate central heat empirically. This was a project that the British Association for the Advancement of Science would attempt to calibrate nationally in the 1830s, with geologist John Phillips distributing standard thermometers to men such as Fox and Forbes, at the Association's expense.[162] Fox's campaign for experimental rigour within the Royal Geological Society of Cornwall preceded this effort by about a decade. His industrial interests provided privileged access for his empirical studies and opened new frontiers for him through his intimate mining connections. The virtuosity and quantity of his observations, and those of the Cornishmen he encouraged, went far beyond previous efforts.[163] It was the 'true philosophic character' and the rigorous, systematic aggregation of Fox's observations,[164] which met Fourier's immediate need for empirical evidence. François Arago, editor of *Annales de Chimie* and Fourier's close ally in driving the reappraisal of heat theory, published Fox's observations, providing Fourier with the empirical verification necessary to take his statements beyond hypothetical mathematical theories.[165]

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160 Barson,2002,p.10.
161 Smith,1989,pp.35-39; Smith,1998,p.112.
162 Morrell,2005,p121
163 Lawrence,1974,p.265
164 De la Beche:Enys,[27/03/1836], **RS**/MS/710/31; Lawrence,1974,p.265.
165 Fox,1821,pp.78-81; Arago,1821,pp.81-2; Fourier,1821,pp.82-5.

Lest the scientific community fail to take sufficient notice, John Taylor, the international mine manager and secretary to the Geological Society of London introduced in section three, made the connexion between Cornish thermometry and Humboldtian global physics direct and explicit. In 1824, after his son aided Fox's deep-heat observations,[166] Taylor produced one of the most widely read editions of Humboldt's works, translated and annotated *Selections from the works of Baron de Humboldt relating to the climate, inhabitants, productions and mines of Mexico*. In dressing the tribute of the 'peculiarly gifted traveller', Taylor took travel-writing propelled by the logic of the Weimar mine economy under Cornish influence, and rendered it into a treatise devoted to earth-science, mining, steam-engines and society. Taylor made Humboldt's travel narrative of Mexico into a report on the state of the Mexican mining industry and in doing so promoted his concurrent campaign to apply Cornish heavy industry to Mexican mines. In particular, Taylor's notes for Chapter VIII, 'On the geological description of mining districts of Mexico', make repeated reference to Cornwall, extending a Cornish model – high capital, highly developed division of labour - to bring distant places into universal equivalence. Humboldt's famous cosmology became, in Taylor's popular edition, a cosmology of the Cornish system. Indeed, Taylor went so far as to represent Humboldt's conclusions as bearing out those already reached by the expertise of Cornish mining men.[167]

Taylor published his selection in 1824. The following year, in 1825, he and his close friend Charles Babbage began to dine regularly together at the Smeatonian society, a ritual they would maintain for the next fifteen years.[168] From the first these dinners took place while Babbage wrangled with the eminent geologist Charles Lyell on the question of the antiquity of the earth. Since winning funding in 1822, Babbage had been engaged in the construction of his 'Difference Engine', a device to reduce polynomial functions to mechanical addition using the method of finite differences, and so build on Mayer's tables, as a critical aid to navigation at sea using the lunar-distance method of determining longitude. Now, motivated by his scepticism of Lyell's claims, Babbage followed Taylor's empirical Cornishmen and began to investigate temperature differentials on bricks. Bringing these observations together with his work on mechanical analysis by difference and combination, he developed his own theory of the much-discussed work by Fourier: a model of the earth as a heat-engine.

Babbage took the same general thermometrical ratio established by Fox and used by Fourier, then drew on Humboldt's theory of isothermal lines to treat rock types as distinct isothermal

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[166] Fox,**CUL**/MS.Add.9942/29/i/p.5.
[167] Taylor,1824,p.i,pp.119-200.
[168] Smeatonian Society,[1825-1840],**BL**/Egerton/MS.3758.

surfaces in a series of highly practical and industrially orientated experiments.[169] Though he identified expansion and contraction characteristic to type, he was able to show that, with the differences taken relatively and in the organisation of the whole, Fox's widely published thermometrical relationship of 1° for every 50-60 feet still held.[170] He also persuaded engineer George Rennie to carry out experiments with industrial pyrometers on differential expansion of stone types in response to varying heat.[171] Employed by the Admiralty in the 1830s to manufacture naval engines[172] and responsible for assessing Fox's engines for publication in scientific periodicals,[173] Rennie was also a regular dining companion of Babbage and Taylor at the Smeatonian Society.[174] Babbage recruited him to make an engine-based experimental system and derive an engine-based conception of uniform heat. Presenting this study to the Geological Society of London, Babbage combined the engineer's industrial data with careful iconography, enlisting Humboldt's abstract representations of isothermal lines.[175]

Not only was Babbage's analysis of temperature differentials in direct articulation with the mechanics of his Difference Engine, but so too was his representation of isothermal lines. The mechanical production of his diagrams was fundamental to the convincing representation of accuracy in the empirical data from Fox and his colleagues. Babbage stressed his woodcuts were 'stereotypes from *one* block,' so that the variant isothermal lines stemmed from a single template. This mould would produce a relief stamp, from which the isothermal ridge could be successively cut away to create a series of images. 'This table' claimed the mathematician 'was computed by the Difference Engine […] the numbers are always true to the last figure, a compensation made by the engine itself.'[176] According to Babbage, this iconography of economy and accuracy had a mechanical author. He then proposed the method should be taken up generally for geological maps, linking engine development to geology.[177]

§7: the Cornish system

Through the late 1820s and early 1830s Babbage revised and extended an essay he had first

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[169] Babbage,1847,p.204.
[170] Babbage,1847,p.207; Dolan,1998,pp.305-6,p.319,p.311.
[171] Dolan,1998,p.318;p.310.
[172] Saint&Chrimes,2004.
[173] Henwood:Fox,[22/06/1830],**RS**/MS.710/52.
[174] Smeatonian Society,[1825-1840],**BL**/Egerton/MS.3758.
[175] Dolan,1998p.318.
[176] Babbage,1847,p.208,p.215
[177] Dolan,1998,p.316

drafted in 1827, under the title 'on the application of machinery to manufactures'.[178] Critical for this latter development was Taylor's 1814 'On the Economy of Mines in Cornwall and Devon', which described not only the Cornish system but also Taylor's ambition to export it overseas. Babbage's object in revising the 1827 essay was explicitly to understand the effects, advantages, and action of machines calibrated against the labour of men. In seeking to optimise profit by driving down costs he identified a particular '*division of labour'* as important and 'appear[ing] to [him] to have been unnoticed before.' This division of labour, Babbage was explicit, drew on what he called Taylor's Cornish system.[179]

Babbage revised his 1827 'machinery to manufactures' with Taylor's 'On the Economy of Mines' and published the result as *On the Economy of machinery and manufactures* in 1832, crediting Taylor's Cornish system, its division and ambition, as the basis for his theory of political economy.[180] In doing so he took care to lose none of the politics or particular labour relations of the Cornish mine. Together with *The Times* newspaper, pressman Thomas Hansard's official report of all parliamentary debates were not only the first to employ Charles Dickens, the significance of which will be developed in chapter three, but, of critical importance here, the first to employ a steam-driven press. Using the Hansard Manuscripts as his principal example, Babbage took the Cornish system's reorganisation of labour around steam to the printers. At every level the arrangement of his text was polemical. A section on 'Printing from wooden Blocks' explicitly referenced the action of the workman. By contrast, a section on 'Lithographic Printing' described the interactions of materials and apparatus as if self-acting.[181] Moving between printing engines, powered by steam and designed to manufacture identical forms, and his Difference Engine built to reconstitute divisions,[182] Babbage physically built the Cornish system into the text itself.

Through his thermometrical research, Babbage had previously characterised the earth as a heat-engine.[183] Now he developed the living verification of the steam cosmology, Fox's Cornish mines, with the labour economy peculiar to them. Drawing on Taylor's Cornish system and the *wheal*, Babbage presented natural systems as an aspect of thermal economy, social systems as an aspect of machinery, and linked the two together through political economy parsed as natural law. What his efforts forged was an engine metaphor for political economy, of huge significance for nineteenth-century Britain, and explicitly based on the

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[178] Schaffer,2003,p.279**.**
[179] Babbage,1832,p.1,pp.iv-v,pp.177-9.
[180] Babbage,1832,pp.iv,pp.177-9
[181] Babbage,1832,p.55,p.58
[182] Johns,2007,pp.403-430.
[183] Dolan,1998,p.316; Wise&Smith,1989b,pp.414-5.

globalising principle of Cornish mines. Four successive editions between 1832 and 1835 further extended and generalised his analysis of the Cornish system, while the work itself went global, with translations into German, French, Italian, Spanish, Swedish and Russian.[184]

Cornwall was not the only British region with a mining economy developed around the division of labour, or for such labour economy to become embodied in the metal. Like the tribute system in Cornwall, cope contracts in Derbyshire mining were a form of piecework.[185] As with the Cornish system's relation to coin and steam, the Derbyshire system had long been embodied in the material culture of labour organisation. Cope provided the name for the outer part of the bell mould in bell casting. The founding of time discipline was itself an industry where the division of moulds defined the division of labour.[186] Further, the cope system of moulds within bronze casting would prove seminal for the early origins of Boulton's business model, whose early ventures developed in intimate relation with Derbyshire mineral extraction, and the human labour economy of casting complex forms.[187] The significance of the Cornish system, that set it apart from other similar divisions and made it of particular interest to Taylor and to Babbage, was precisely what Cornwall brought to the equation of labour.

Babbage and Taylor's frequent correspondence sheds some light onto what it was Babbage wanted about Cornwall. Their exchanges focused on politics – specifically their interests in politically representing mining towns and the details of mining production.[188] In 1832, the same year as *On the Economy*'s first publication, Babbage used the text to stand for election in the London constituency of Finsbury.[189] On Thursday 22 November that year he canvassed at the Canonbury tavern, Islington, announcing that 'he held the principle of monopoly to be highly adverse to the general weal' and therefore advocated the abolition of tithes, Corn Law repeal, and throwing open the trade with the East Indies and China, breaking the charters of the Bank of England and the East India Company. He would latterly attribute the success of *On the Economy* to parliamentary reform. Despite his professed 'abhorrence' of enslavement on plantations, he advised against its immediate abolition, arguing 'immediate emancipation of the negro would be dangerous, if not fatal to himself and the planter.'[190] Babbage's use of weal, the Cornish term for mine, as an evocation of wealth is significant. From as early as

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184 Swade,2004.
185 Burt,1977,p.26.
186 Diderot,1771,Plates I-V.
187 Goodison,1974,pp.19-45.
188 Taylor:Babbage,[1832-1845],**BL**/Add.37188/Fol.374;Fol.384.
189 Hyman,1982,pp.82-3.
190 Elections,1832.

1768 Jamaica had pioneered the use of rotary steam power to grind sugar cane, using innovative engines developed and erected locally with local expertise. By the end of the eighteenth century Jamaica was a steam-powered centre of mechanisation in manufactures, and Boulton & Watt were battling patent pirates of the Caribbean.[191] Precisely because Babbage sought domination of overseas markets by the domestic British machine-building industry, before that market could be opened it had to be secured.[192]

Above all, free trade and the hierarchy of skill were the foundations of Babbage's radical platform, as the *Mechanics' Magazine* summarised in their strident campaign on his behalf:

> if you are a manufacturer, harassed and obstructed in your operations by fiscal regulations, and would see industry as free as the air you breathe – *Go and vote for Mr Babbage*. If you are a mechanic, depending on your daily bread on a constant and steady demand for the products of your skill.... – *Go and vote for Mr Babbag*e.[193]

Taylor's Cornish system offered Babbage an economy into which free trade imperialism had already been fully embedded. However radical Babbage's position among parliamentarians, it was a far cry from the radical politics then emerging on the ground. Within six years there would be a mass working class revolt of a scale and cohesion never seen before. Babbage's position, reforming and apparently anti-establishment, was still fundamentally the position of the venture capitalist, whose wealth came from securing as much as possible the risk in production, whether in the West Country or the West Indies. Through the 1820s Taylor had been busy exporting Cornish mining to South America and Mexico,[194] extending the Cornish system physically as he did literarily in the very same years, through his selection and annotation of Humboldt's work.[195] By the 1830s, a global machine of Cornish high-capital mining had been assembled. The Cornish system physically performed an extension of Babbage's text: from factory economy to a political economy of universal production. This global machine was a Cornish diaspora.

From 1815, the Cornish population began to leave in vast numbers. In the second half of the nineteenth century alone, over a quarter of a million emigrated overseas in a mass exodus of a very particular mining culture: notoriously recalcitrant but highly skilled in intensive, high-capital, steam-powered mining. From Africa to Oceania, Asia, and the Americas, the human diaspora followed the global trade in Cornish copper. With the end of the Napoleonic wars, Taylor and other mine adventurers sought to do as Boulton had with minting machinery: to

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[191] Satchell,1995,pp.221-231; Sheridan,1989,59-70.
[192] James,2001,pp.41-4; Williams,1944,pp.98-106.
[193] J.G.,1832,p.159.
[194] Burt,1977,p.27
[195] Taylor,1824.

turn global metal trade into the global export of the industry itself, to monopolise home and world markets by monopolising the sale of the means of production.[196] While, as Taylor claimed, the mines themselves were not subsidised, the mass emigration of skilled Cornish labour was heavily sponsored by the British government.[197] The circulation of metal carried with it a particular protected, mercantilist culture. The open market of the Cornish system, that contained its 'open' competition within the mine and a vast global web of mines, developed this culture with aggressively extractive principles. Alloyed together, the two formed the physical material structure – the steam, metal, and bodies - of free-trade imperialism.[198]

Previous sections have considered some of the ways in which Cornish copper came to carry with it specific systems of labour extraction and political discourse. From the late-eighteenth century, Taylor made his career through refining the traditional divisions of this mining economy, to develop a high-capital, intensive mining industry in Cornwall. In promoting his work he claimed Cornwall as a peculiarly challenging environment and because of this, 'the mines of Cornwall should take a lead in the means of overcoming the difficulties that nature presents.'[199] The skill of these Cornish miners, as well as their steam power and their mechanization, were presented as natural extensions of the inundated rock. Taylor's promotion of the Cornish miner was not just rhetorical, it was a process of physical movement of men. By the early 1820s Taylor had established a domestic empire of several consultancies and nearly forty large mining companies under his direct control. This sovereignty over the extraction industry rested on the Cornish system, and as early as 1819 he sought to extend it overseas.[200] Purportedly independent, the massive global campaign he undertook attracted significant government subsidies promoting the emigration of Cornish miners that fed the human machinery of this high capital industry.

These years were critical in the development of globalised steam economies. In Prussia, for example, this conjuncture saw the founding of a domestic steam-engine construction industry. At the same time, what had been a long gestation of a 'culture of mobility' in Cornwall was developed, through Taylor's interest in recruitment, into an emigration industry. Increasingly, advertisements filled the *West Briton* and the regional press, offering brighter prospects than the dwindling seams of Cornish copper. The ventures of emigrants were reported with

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[196] Berg,1982,p.205,209.
[197] Payton,2005,pp.106,107; The West Briton,[26/03/1824]; [01/04/1825]; [07/04/1826]; [23/03/1838], **BL**/MFM/M59517-M59545.
[198] Gallagher&Robinson,1953,pp.1-15.
[199] Taylor,1829,pp.383-4
[200] Burt,1977,p.39.

relentless bombast and the people of Cornwall pressed with a heroic myth of themselves as peculiarly skilled and hardy to the rigours of long ocean voyages and settler life.[201] Emigration agents sprang up across the county in key locations for recruitment. These agents transported tens of thousands of Cornish emigrants over the following decades; and with them, demand for Cornish mining technology. Even basic equipment, 'from rope and chain to rivets and pressure gauges, was obtained direct from Cornwall.'[202] An 1837 satire of Fox and of Cornish mining journals, detailed in chapter seven, is eloquent of the development of this global Cornish man-machine market, including an advertisement for 'an engineer well skilled in the use of the solid carbonic acid engine[,] wanted by the British-Irish-American-Australian-Polynesian-mining association.'[203]

The reputation that Taylor and others claimed, was propagated by a culture of cronyism. Cornish mine captains overseas specified the need for Cornish workers, and reserved the best positions for them. This has been characterized as 'The myth of the Cousin Jack' – 'the self-belief that insisted that the Cornish were innately qualified above all others as skilled hard-rock miners.'[204] Meanwhile, back in Cornwall, entire towns, such as St Day, the centre for the production of Fox-type dip circles, were sustained by remittance payments.[205] This was a tiny stream compared to the great drain of overseas wealth secured by Cornish industrialists and investors since the earliest British plantations, but nonetheless a stream that intimately connected the flow of cash to the rhetoric on skill and technological advance. Such rhetoric emerged as a way of monopolizing labour, first by mobilizing men and machines for export and second by restricting the high-value, skilled positions to 'mythical' individuals, that facilitated dependency on said machines.[206] The wage form has long been held powerful because it appears to exchange for something that is innate: this innate property of skill.[207] Here Cornish isolines and Cornish wages reproduced one another, defining the world in a universal equivalence that rendered innate and apparently inalienable human skill an abstract and general principle of human labour: a standard commodity that could be exchanged; that could be moved from one place to another and work always as if in the same place. More than simply the Cornish system writ on a global scale, this was the reconstitution of the world such that the Cornish system was made integral to its construction. The chapter

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[201] Payton,2005,pp.106,107; The West Briton,[26/03/1824]; [01/04/1825]; [07/04/1826]; [23/03/1838], **BL**/MFM/M59517-M59545.
[202]Payton,2007,p.81
[203] De la Beche,[2/2/1837],**RS**/MS.710/124.
[204] Payton,2007,p.32
[205] Cahill,2001,p.5.
[206] Payton,2007,p.32
[207] Rule,1987,p.107.

and thesis as a whole are concerned with precisely this: not the presumption but the production of the global.

§8: to rule the storm.

Globalisation, built on the extension of the Cornish system, re-organised overseas economies to optimise labour extraction and the drain of wealth to devastating local effect. Through industrial material innovation, parliamentary reform, and the new global physics of late-1830s Britain, and in particular the magnetic campaign, this specific crippling form of labour extraction was made natural and universal. In this convergence the survey was key. Whether isomap, ordnance cartography, or public auction of mining contracts, surveys not only commuted inalienable human labour but also its human social relations into cash. This commutation was the central preoccupation of the new order of statisticians, a group that for all their individual differences nevertheless held certain principles in common. Writers on political economy as opposed as Babbage and Whewell both sought to produce effective governance through quantification.[208] In seeking to characterise this commutation, Babbage's 1832 engine economy, and Whewell's 1840s discussion of 'labouring force',[209] found a direct analogy between civic unrest and friction or waste.[210] The Age of Reform was the age of mass protest: fights for common rights, and against their commutation, by survey, into cash relations. Babbage made a direct analogy between protest and resistance; and just as he built the Cornish division of labour into the parts of his Difference Engine, so he built resistance into their articulation as threat. Section five pointed to the importance of the money's form in making the proletariat, but also in making the protest. To understand what was at stake, it is necessary first to consider some history of protest, and in particular a protest in 1838 when nearly seventy thousand assembled on Newcastle Town Moor in support of *The People's Charter*. The campaign to survey the earth's magnetism, launched that same year at the Newcastle meeting of the British Association for the Advancement of Science, from a meeting hall overlooking the moor, must be understood not simply in context but, in significant ways, as consequence.

Since 1357, Newcastle Town Moor had been held as common land granted with 'the privilege of digging coals, stones, mines, minerals &c therein for the use and benefit of the burgesses.' As mentioned in section five, on 31 December 1771, council magistrates attempted the enclosure of the Town Moor. The response of the burgesses focused on protest by legal

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[208] Wise&Smith,1989a,p.285.
[209] Wise&Smith,1989b,pp.410-20,pp.420-3;
[210] Wise&Smith,1989b,p.399; Wise&Smith,1990,p.233-237.

action, but it was action only brought by first raising money, then committing 'sufficient trespass for the lessee and magistrates to ground an action of trespass'.[211] The success of the burgesses' legal action was cemented in 1774, with the Newcastle Town Moor Act, that placed the decision to lease the Moor in the hands of the freemen, and the profits of leasing to be distributed among freemen in reduced circumstances and their widows. Spence himself acknowledged the victory as seminal for his politics and historians have since identified his famous utopia, 'Spensonia', as 'little more than the Newcastle Town Moor Act writ large.'[212] For Spence, 'the moneys' were the critical factor: 'Revenue', he argued was to 'the overbearing power of Great Men' as 'hair' to the 'power of Sampson'. Such Great Men 'be dangerous companions in Society till they be scalped of their Hair, or Revenues'.[213] His satirical coinage performed such a scalping. His Newcastle protest, where he explicitly compared the treatment of workers as like that inflicted on colonial subjects, was the invention of a new kind of resistance, focused on the respective occupation and co-option of the fundamental instruments of capital: enclosures and coin.[214] This was protest against quantification, protest against a technocracy of mathematicians.

Section five described the entangled development of base coin and political voice, above all through the work of Spence. It was observed that for Marx the united front in the fight for universal suffrage came about directly through the unifying influence of the money form that brought qualitatively incommensurable labour into quantitative universal equivalence. The reform of parliament in 1832, ostensibly to eliminate rotten boroughs, produced in effect the extension of the Cornish political system whereby powerful industrial interests bought votes and influence. Starving wages and the mockery of the promised reformed representation in parliament converged with the new wage-driven unity, to win mass support for *The People's Charter*, finally realised in 1838. Inaugurating this momentous event, Chartists, notably the Cornish William Lovett and Birmingham toolmaker John Collins, adopted the slogan of American protest against British colonial rule: 'no taxation without representation.'[215] For both capital and its resistance, metal had become political voice in a colonial imbalance of power.

As with base coin so with land use rights: 1831 saw the last major urban riot in England before modern times.[216] Through the Chartist period, protests grew dramatically in scale and

[211] Mackenzie,1827,pp.710-11.
[212] Knox,1977,p.88.
[213] Spence in Waters,1917,p.47,note 5.
[214] Chase,1988,pp.30-34.
[215] Lovett&Collins,1840,p.62.
[216] Rudé,1988,p.176

where once a demonstration might have centred on a market square, the Chartists marched *en masse* to occupy common land, making direct analogy with their demand for representation in parliament. On Sunday 2 August 1846, in what was, for Marx, the first great open-air meeting, [217] radical poet Ernest Jones addressed some 30,000 individuals assembled on Blackstone-Edge mountain, on precisely the commutation of human rights into coin:

> What? Are pounds sterling or living souls to be represented in our House of Parliament? What? Are the interests of a man possessing a million pounds to be cared for a million times more? This – this is what their argument involves. This, then is their philanthropy! Out upon them! They have but legislated for their money bags – we will legislate for our fellow-men. The interests they tried to promote was the interest of their vested capital – the interests we will further shall be those of humanity all over the world.[218]

The following day Jones composed a verse in tribute to the event, that described the 'smoke of mill and city' at odds with nature, and made devotion to the bleak granite outcrop of Blackstone Edge, 'With no cold roof twixt God and man', as the platform from which the world would hear the cry for radical change. [219]

On 1 July 1853 Marx reported a return to the mountain of Blackstone-Edge. In his account he explained that while the delegate council congregated none so much as hoped for the possibility of a general meeting, 'the weather being terrific, the storm increasing hourly in violence, and the rain pouring without intermission.' Yet, against all expectation, appearing over the ridge of the surrounding valleys, 'streams of people... as far as the eye could carry, through the base pelting of the rain'. Here, 'far removed from any village or habitation, and… notwithstanding the most violent deluge of rain', the assembly stood fast to hear Jones, who called on them to 'rule the storm, instead of being tossed by it' and 'to raise a strong beacon of Chartism to light us through the chaos of tempest'.[220] Marx's journalism reflected the Chartist culture: just as capital was actively made natural and elemental, so too and in direct response, protest and struggle became the deluge, protesters both relentless like the rain, and relentlessly inundated.

Blackstone-Edge in 1846 was far from the first such open-air rally. On Thursday 28 June 1838, while a coronation took place in Westminster, over sixty thousand workers from Tyne and from Wear marched to Newcastle Town Moor under the banners and music of their

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[217] Marx,1853a.
[218] Saville,1952,p.89.
[219] Jones,1846.
[220] Marx,1853a.

respective trades. They came in lines six deep to the common land on the northern edge of old Newcastle town in support of *The People's Charter*, published just a month before.[221] The moor was spiked with the stacks of ventilation shafts, beneath their feet the ground was hollow with coal tunnels in a land perfused with heavy industry.[222] The local Chartist paper, *The Northern Liberator,* reported how the militant display was met with military force as the public assembly found themselves surrounded, encircled by fixed bayonets, 'cannon pointed in the very teeth…'; the sixty thousand breathed out with a hiss.[223]

That Saturday, two days later, a meeting of the Radical Reformers gathered in the Music Hall in response to the constitutional outrage. By eight o'clock the Hall was 'crowded to excess', stifled with bodies. The chairman, Thomas Doubleday, son of a Newcastle soap-boiler and author of *The Northern Liberator*, opened with a telling denunciation, 'The House of Commons – the *reformed house* – no more represents the needs and wishes of the people of this country than it does the people of *China* or *Nootka Sound*'.[224] His statement traced the trajectory of the search for the Northwest passage, and, as he had done before in the months building up to the protest on the Town Moor, placed the contributions of the proletariat alongside the discoveries of Cook on his coal ships, and the brutal exploitation of workers, with the treatment of 'primitive' or colonised peoples.[225] He pointed to the Peterloo massacre of 1819 and called for a petition to the House of Commons. For the second speaker the time for protest had passed, in seeking representation in parliament the necessity of meeting force with force had become apparent to all.[226]

Just two months later another rally filled the Music Hall. Here, surrounded by representatives of Newcastle industry in the form of material exhibits - instruments, models and machinery - hundreds of members of the British Association for the Advancement of Science converged for the eighth annual meeting of the society.[227] That the products of local manufacture were expounded by metropolitan elites to the exclusion of Newcastle experts caused some comment, given the acute tension of the question of representation.[228] Among the models on display was one of the House of Commons. The model showcased the physician Dr David Boswell Reid's scheme of ventilation then in use in the parliamentary house,[229] a scheme Reid

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[221] Doubleday,1838b.
[222] Clark,1808,p.70.
[223] Maehl,1963,pp.390-1;p.392,ft.2;p.393; Doubleday,1838b; Doubleday,1838c.
[224] Doubleday,1838c.
[225] Doubleday,1838a
[226] Doubleday,1838c.
[227] Doubleday,1838,d.
[228] Morrell&Thackray,1981,p.197; Athenaeum,1838,pp.615-6.
[229] Johnston,1838,p.21.

had derived from a Newcastle colliery; 'the lofty brick chimney… analogous to the *upcast* shaft of a coal mine… A shaft in the Victoria tower… form[ing] the *downcast* pit for the supply of pure air to the new Houses.'[230] The same ventilation shafts that spiked the ground, which had hosted the great occupation of the Town Moor, were now modelled in Westminster, a mockery of political voice in politician's breath.

The journalist Doubleday reported in detail in *The Northern Liberator* on the proceedings of the gentlemen of science, observing the dissent within the British Association for the Advancement of Science between the 'scientific commoner' and aristocratic layman, that culminated in Babbage's furious resignation, partly because of confusion about his nomination for president, mainly because he felt it was insufficiently engaged with practical sciences. Doubleday identified in this fracas the Chartist struggle of inequality of labour and representation.[231] Doubleday listened too to Bombay Engineer Thomas Best Jervis, then on leave in England, who had at this point successfully represented himself to the metropolitan community as the next Surveyor General of India. Addressing the Section for Geology and Geography, hosted in the same music hall where the Radical Reformers had met two months earlier, Jervis argued for the reduction of Geography under the headings of 'Physical, Statistical, and Political'. To do so would develop Geography as the 'Sister Science' to Astronomy and as such a fundamentally '*progressive science'*. Astronomy was presented as the pattern survey science and the exemplary instrument of reform. Geography's potential, Jervis argued, was wasted until it could be restructured on truer principles. To speak of '[t]he reduction of Geography' treated the discipline as a reservoir of quantitative data that awaited rendering. To be like Astronomy, a powerful tool of reform, Jervis argued that geographical science had to first be itself reformed; and for this to happen required the understanding of geography as the stuff of statistical analysis.[232]

Jervis was one of the founding members of the 1837 Admiralty Compass Committee set out in the introduction to this thesis as important to an understanding of the magnetic campaign. The reform he referred to stood first and foremost for the reform of magnetic compasses, his comments setting out the utilitarian promises of the incipient British chapter of the magnetic campaign. Above all the professed intention to reform the surveyor's magnetic compass as an instrument of statistical science is critical. Fundamentally a science of population and governance within a fiscal state, the explosion in the use and authority of statistical techniques in the period 1820 to 1840 was motivated by fear of civic unrest, and the belief

[230] Sopwith,1843,p.68.
[231] Doubleday,1838e; Hyman,1982,p.156.
[232] Jervis,1838,pp.3-6.

that science would provide a solution.[233] The Statistical Section was the focal point of the Newcastle British Association meeting. It was at this meeting that the eminent geologist, Whig reformer and Cambridge professor Adam Sedgwick, proselytiser for Fourier's theory of central heat, gave closing remarks highlighting the statistical analyses of the ignorance, pestilence, and poor ventilation of Newcastle rope, iron, and glass workers.[234] What Jervis was proposing in arguing for the reform of Geography under the headings of 'Physical, Statistical, and Political' was to make the magnetic compass and survey an instrument of population control. The ultimate success of the magnetic lobby did not simply take place in the context of Newcastle protest, it was significantly a consequence of precisely those acute concerns, and what a global physics of metal might offer the governance of a city built on coal and on the brink of revolution. Far from a convenient accoutrement in this, that might be substituted for by any other survey instrument, the compass was integral and indispensable. The compass performed the fundamental commutation of land and labour into quantity that fed the statistical juggernaut, whether on tithe surveys, Caribbean plantations, or the global distribution of Cornish mines. In the magnetic needle converged the optimisation of labour extraction, with the hardware of British maritime power, and the natural history of the new central industrial material: iron.

Conclusion

This chapter has traced the construction of the global in a peculiar, brittle Cornish copper. In the early decades of the nineteenth century, those paths once gilt in copper would be wrought again in a new kind of iron. To understand this the following chapter must return to the British West Indies, which early in the eighteenth century became the largest global market for wrought iron.[235] This chapter set out how the copper and surveyor's compass of the Cornish system laid down the labour extraction of Jamaican plantations. The following chapter considers how Jamaican iron framed the emergence of physics in Britain, and what such framing meant for this new discipline and its emphasis on the survey.

[233] Wise&Smith,1989a,p.285.
[234] Doubleday,1838e; Doubleday,1838f.
[235] Goucher,1993,p.204.

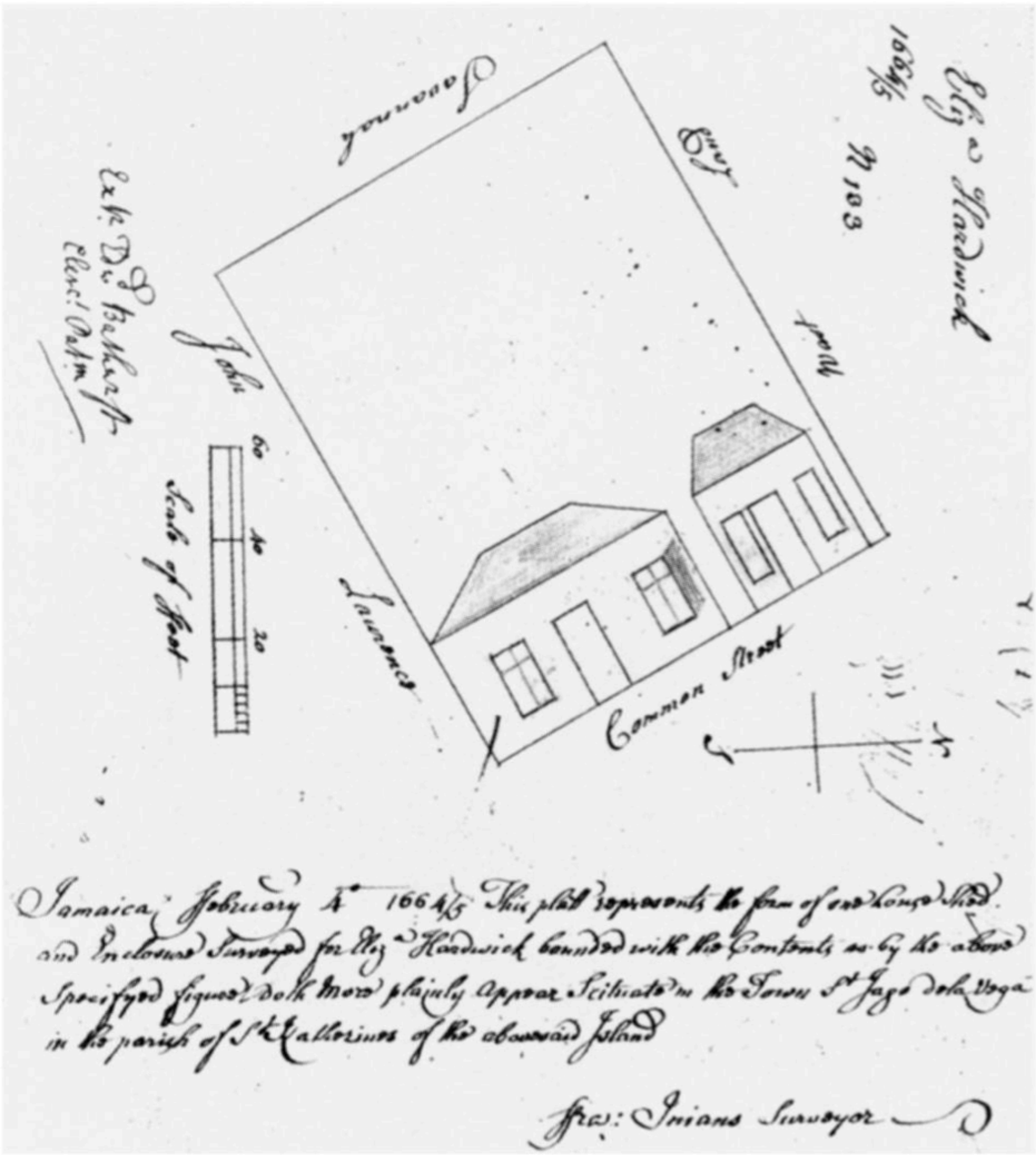

Figure 1.3: Elizabeth Hardwick's property, Spanish Town, February 4, 1664/5, Francis Inians, surveyor. Jamaica Archives 1B/11/2/f. 31.

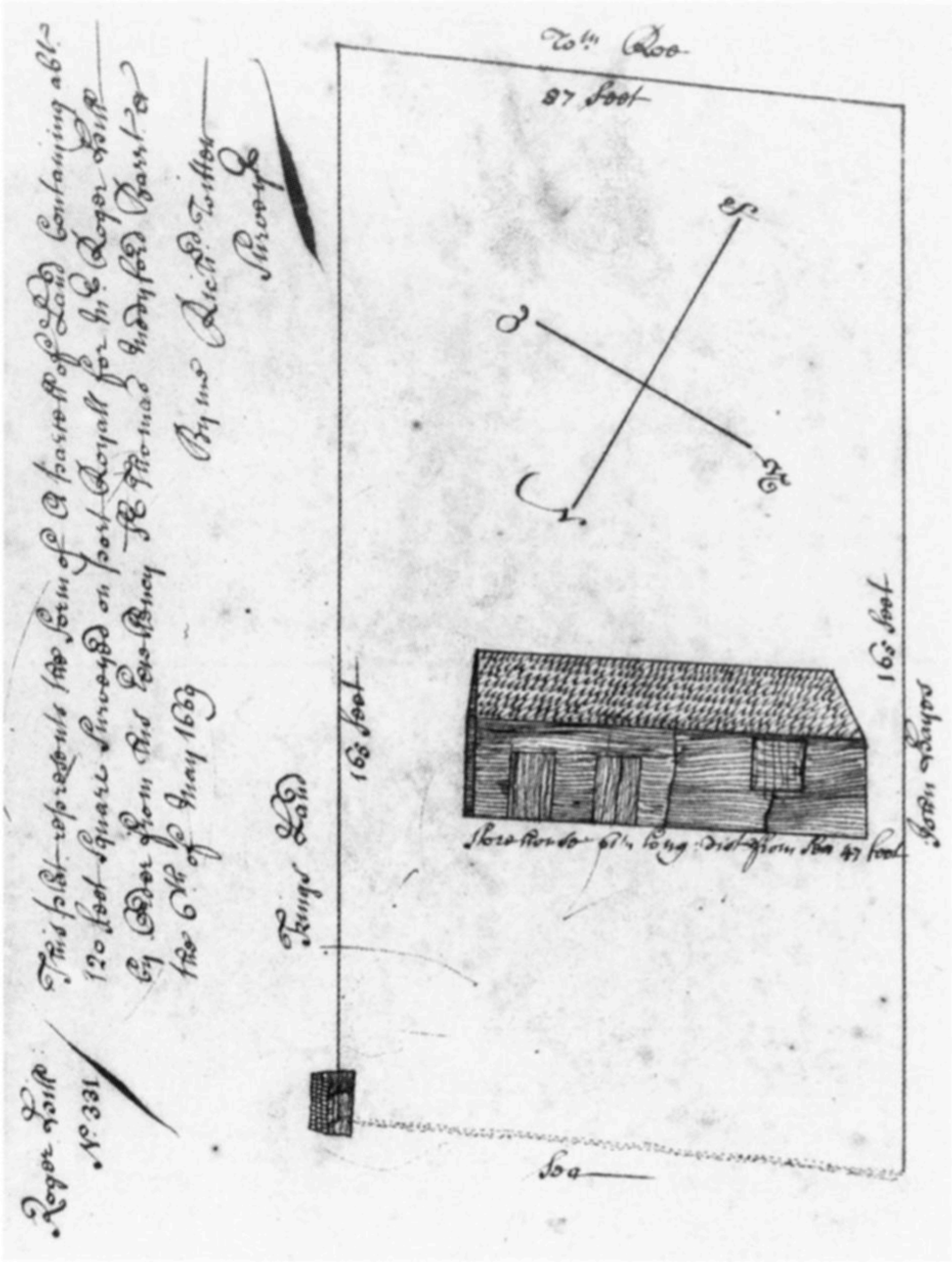

Figure 1.4: "Storehouse" Port Royal, May 1669, Richard Writer, surveyor, Jamaica Archives1B/11/2/28, fol. 62.

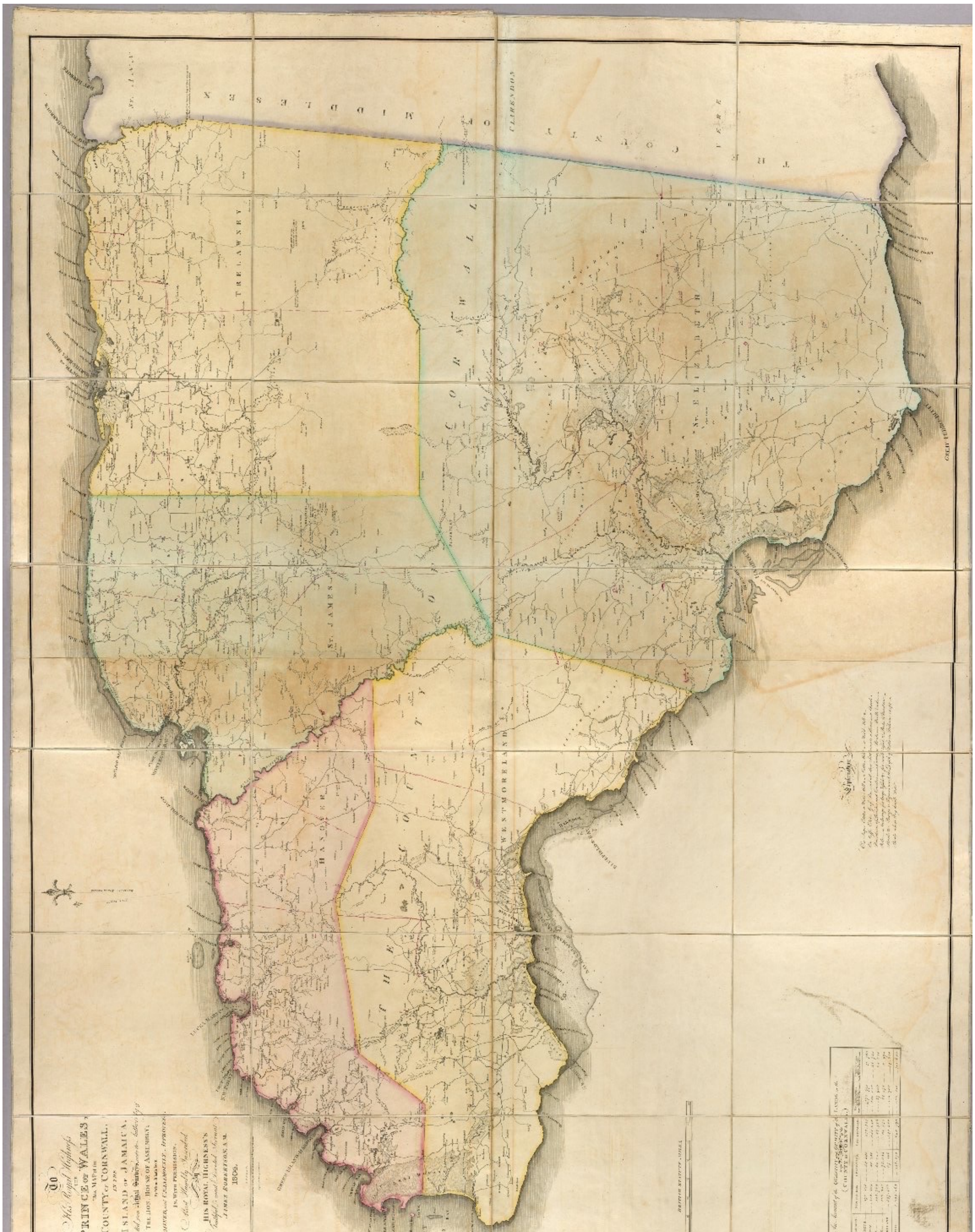

Figure 1.5: Robertson, James, 1804, *To His Royal Highness the Prince of Wales, this map of the County of Cornwall, in the island of Jamaica, constructed from actual surveys under the authority of the Hon. House of Assembly; by whom it hath been examined, and unanimously approved*, London: James Robertson.

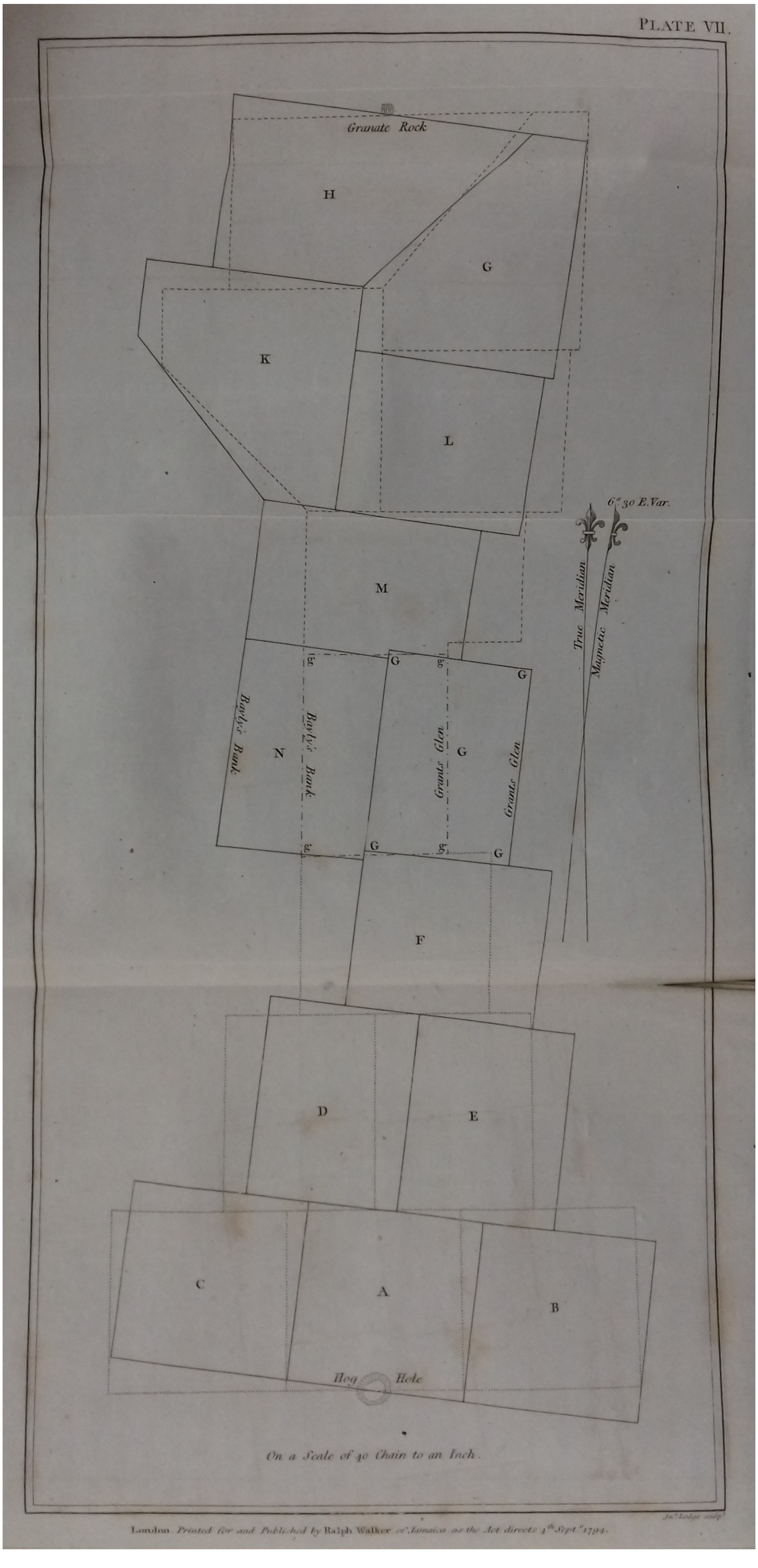

Figure 1.6: Walker, Ralph, 1794, *A treatise on magnetism: with a description and explanation of a meridional and azimuth compass*, London: R. Hindmarsh, Plate VII.

Chapter two: The debtor's progress

The political and scientific revolutions of the late eighteenth and early nineteenth centuries mark a very particular conjuncture that saw a new kind of integration in Britain between the forces of empire, war, economy, science and industry: new alignment and alliance in their respective identities and ambitions.[236] As early as the seventeenth century, the economic authorities Sir Josiah Child and Sir Thomas Dalby declared the Caribbean the most precious group of colonies ever recorded. Barbados alone, Child asserted, was worth more to England than all the American colonies combined.[237] By 1775, the British West Indian plantations were valued at £50 million (£71.7 billion in 2010) and only three years later they were estimated to be worth £70 million (£97.9 billion in 2010).[238] The enchained uprisings of the black Atlantic, the Maroon wars, and the formation of the Haitian Republic were no less salient or significant than the revolutions of Paris and Boston.

This chapter documents a technological and theoretical debt to the Atlantic diaspora and its West African roots that would shape the emergence of physics as a discipline in nineteenth century Britain, as it did the development of British technocratic capitalism. This physics was marked both by the reception and appraisal of a mathematically characterised experimental tradition known as *la physique* that came to the fore in post-revolution France,[239] and the rise of a new dominant class of practitioners, disciples of the Woolwich Military Academy.[240] Of *la physique*, it was the torsion studies of Charles Augustin de Coulomb, colonial engineer and *Polytechnicien* that would come to be the ubiquitous reference of the magnetic campaign.[241] The Woolwich School's elaboration of these researches was peculiarly marked by the application of Coulomb's torsion principles to industrial materials, notably wood and iron. While that application is central to chapter three, this chapter is concerned with what Woolwich was galvanised to see in Coulomb.

To understand this encounter between traditions, this chapter argues it is first necessary to understand the long history of European exchange with West Africa, one of, if not the, most linguistically and culturally diverse regions in the world. Across this vast region, diversity was expressed not least in the distinct rituals and practice of ironworking, and its

[236] Bayly,1989,p.1-15.
[237] Beckles,2013,p.91.
[238] Williams,1944,p.53; Beckles,2013,p.91.
[239] Crosland&Smith,1978,p.2.
[240] Miller,1986,pp.107-34; Gooding,1989,pp.183-223
[241] Dörries,1994,pp.123-4.

concomitant cosmologies, between different groups.[242] Yet overarching this linguistic and cultural diversity was a shared concept of the social role of ironworking.[243] It is tracing the successive syncretisation of this concept with the new traditions from Jamaica and Martinique to Woolwich and Paris that binds this chapter: a chain of ideas, linked in iron, ways of seeing and of being seen.

§1: Baltic iron and West African skill

In the mid-seventeenth century several hundred years of trade between West Africa and Europe underwent a devastating transformation. Since at least the fourteenth century European merchants had coveted an array of West African manufactures, alongside an increasing rapacity for the region's gold. In the 1650s, this European appetite shifted suddenly and decisively to *nkoli*, to be transported and forced to labour as enslaved people in the New World.[244] Originally the Western Bantu term for pawns, under the pressure of European demand for plantation systems that depended both on the forced labour of *nkoli* and on the skills they possessed, most notoriously in crop subsistence,[245] *nkoli* came to mean prisoners of war.[246] With this dramatic change in demand from African products to African people came a swift decline in the use of consumer goods and African currencies for exchange.[247] Where cowrie and manila currencies had once bought Europeans West African gold, in exchange for *nkoli*, West African traders demanded large tapered bars of iron.[248] Together with the seasonality of this trade, the particular insistence on iron made for an especial reliance on the accumulation and speculation of capital, and so on banking systems.[249] To eighteenth century British observers, not least the Royal African Company clerk Francis Moore, whose participant account of the Company's human trade first mobilised famous abolitionist Thomas Clarkson,[250] the direct equivalence drawn by African traders between the bar-weight and the value placed on *nkoli* lives was of particular note.[251]

For European traders, this insistence on iron as the appropriate exchange for *nkoli* presented a significant challenge. The great diversity of West African iron production was not only well

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[242] Mann&Dalby,2018,index map.
[243] Vansina,2006,p.329.
[244] Inikori,2011,p.654
[245] Carney,2001,pp.281-310.
[246] Vansina,1990,p.155.
[247] Inikori,2011,p.666.
[248] Inikori,2011,p.664,p.667,Table:25.4,p.671; Green,2019,pp.359-61; Curtin,1975,p.241; Goucher,2013,p.181; Goucher,2014,p.109.
[249] Evans&Rydén,2018,p.54.
[250] Clarkson,1786,p.41,ft.
[251] Moore,1738,p.45,p.58; Goucher,1981,p.181.

established but also exceptionally advanced. Through slow charcoal-based smelting, West African metallurgists produced an extremely high quality iron, while currents of hot air induced by their high furnaces and particular arrangement of °-*kélwa*,[252] (*tuyères*), dramatically lowered the otherwise prohibitive fuel cost of the process.[253] An equivalent hot blast effect,[254] described as the single most important advance in fuel efficiency and one of the greatest achievements of the industrial revolution,[255] would not be achieved in European production until the early decades of the nineteenth century. The skill of African smiths working on this quality iron was similarly virtuoso, from highly ornamental work to the precision dimensions of the forged bars which European imports were required to replicate.[256] The unparalleled cultural and linguistic diversity of eighteenth-century West Africa was expressed not least in the distinct cosmologies of different groups.[257] Such heterogeneity makes it particularly striking that, while gods, meaning, and practice, as evident in iron making, differed between groups, there existed a singular correspondence in the ontology of iron.

This is not a phrase used casually. Across the extraordinary diversity of West African languages the classification of iron is exquisitely finely graded, distinguishing very minutely, for example, between first, second, or third cycles within a single stage of production such as blooming.[258] This is in marked contrast to the notoriously loose European terminology, words such as 'wrought' or 'puddled', which created confusion for eighteenth and nineteenth century metallurgists as much as they do for industrial and economic historians to this day. Crucially, the West African lexicons for such fine classificatory gradations differ between cultural groups. There is no single unifying concept of iron. Throughout all the great diversity of West African languages, however, use of the proto-Bantu stem **-túd-,* referring to the hammering forging action of the smith, is ubiquitous.[259] This human action in generating iron is the overarching concept, rather than a static material category. The ubiquity of this hammering concept across West African linguistic groups is further accompanied by a common cultural understanding: that iron manufacture was always inherently the negotiation of movement between human and spiritual worlds. Generating and maintaining the exquisite balance required for smelting and for forging was also the skill of restoring balance to disorder in society. In this way the material itself was imbued with the collective

252 Vansina,2006,pp.340-3.
253 Goucher,1993,pp.202-2.
254 Goucher,1981,pp.180-1.
255 Landes,1969,p.92.
256 Goucher,1981,pp.185-6.
257 Mann&Dalby,2018,index map.
258 Vansina,2006,p.323.
259 Vansina,2006,p.329.

memory and experience of a group. Iron tools – whether weapons or agricultural implements - were themselves the wrong, the restorative justice, and the balance between the two.[260] In the *nkisi n'kondi* power figures of the Kongo peoples, iron pegs are driven into the wooden body of the figure to resolve social transgressions in the material itself (Figure 2.1). In the perfect artistry of the Edo craftsmen the demi-god status of Benin rulers was materialised with eyes inlaid with iron (Figure 2.2).

Figure 2.1: Nkisi N'Kondi, Kongo peoples, Yombe group, 19th C, 2008.30.,The Met.

260 Goucher,2014,p.108.

Figure 2.2: Bronze bust, Edo, Benin City, early 16th Century, Af1897,1011.1, British Museum.

Foundational to the sociology of scientific knowledge is the Durkheimian principle that to inhabit a system of classifications is what it is to belong to a cultural group. Across this region of extraordinary diversity, closely reflected in the distinct ferrous lexicons, West African iron working was not a shared category, but rather a shared concept of resolving these transgressions of being. To drive iron pegs into the *nkisi n'kondi* figure was an ontological intervention (Figure 2.1); pegs which, in their squared edges and tapered shape, resemble scale models of the iron bars demanded of Europeans by African traders,[261] in exchange for people as property. The emphasis on bar iron as the exchange good for *nkoli* was not just that iron was the currency of human exchange,[262] but that iron was the exchange for the transgression.[263]

By contrast to the iron of virtuoso African smiths, among the European powers seeking *nkoli* labour to develop New World plantations, only France is thought to have been self-sufficient in ferrous metal of sufficient quality for the African market,[264] and notably, even this was still inferior to the African iron. While Britain had a substantial iron industry, its poor quality output was frangible, granular, and quickly worn out, inadequate for its own dockyards, let alone for the discerning African trade. It would not be until the very end of the eighteenth century and the innovations attributed to the hero of industrial revolution hagiographies, financier turned Navy yard ironmaster Henry Cort,[265] that the poor quality British iron was remanufactured into an elastic, fibrous material which might compete with foreign products. For industrial historians, Cort's name remains as synonymous with British technological triumphalism as those of steam engine entrepreneurs, Boulton & Watt.[266] Developed at the very end of the eighteenth century to render scrap metal workable, his combined process enabled the relentless and seemingly inexhaustible global export of cheap British iron in the nineteenth century. Prior to this development, however, dockyards and enslavers, whether British, Portuguese, or Dutch, relied on 'voyage iron' imported from the Baltic.[267]

Expunged of all its carbon, this 'voyage iron' was a malleable material, easily deformed and unable to sustain a cutting edge. To this the high carbon West African iron makes a sharp contrast, its quality described as 'an intentional steel'.[268] Metal comparable to the ferrous material ubiquitous in West Africa was an expensive and prestige commodity in European

[261] Goucher,1981,p.185.
[262] Goucher,2013,p.181.
[263] Sahlins,1988,pp.1-51.
[264] Evans&Rydén,2018,p.51.
[265] Dickinson,1940,p.42; Smiles,1864,pp.148-69.
[266] Allen,2009,p.243.
[267] Evans,Jackson&Rydén,2002,p.645; Evans&Rydén,2018,pp.51-52.
[268] Goucher,1981,p.181.

manufacture. Wealthy young men adorned themselves with oversized steel buttons to dazzle intended mates,[269] such displays of fetish and conspicuous consumption being central rituals in the European capitalist cosmology (Figure 2.3). In order to make cutting implements that would maintain an edge, European manufacturers would weld a wafer thin layer of the costly material on a body of cheap malleable iron. Such composite construction was not a feature of West African manufacture before or after the onset of the trade in African people for Baltic iron. In the single trading year 1707-1708, the Royal African Company alone committed itself to shipping a minimum of 1000 tons of iron to the West African Coast, a tiny per cent of the vast quantities of iron introduced by all European trade through the eighteenth century. Yet of this tide of inferior iron only a negligible proportion went directly into the manufacture of unsatisfactory tools, quickly worn out and discarded.[270] Where the steel-like West African iron was worked by cycling between beating and quenching, and beating and annealing, African smiths treated this European material as effectively raw and unprocessed, to be transformed by reheating over a long time with charcoal, re-introducing carbon to the surface of the metal, to give it a steel-like skin.[271]

Figure 2.3: Humprey, W., *Steel Buttons/Coup de Bouton*, April 1777, J, 5.37, British Museum.

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[269] Evans&Withey,2012,pp.546-7.
[270] Evans&Rydén,2018,p.60,p.66.
[271] Goucher,1981,p.187

The reliance on Baltic iron, made to the highly specified dimensions demanded by African traders, whose particular requirements changed with the changing value placed on *nkoli* in a trading season,[272] had significant implications for the financial mechanics of the transatlantic trade. Such commissions required a major outlay of capital well in advance of the high-risk return. In short, and as the great Trinidadian historian Eric Williams seminally demonstrated for enslavement in general,[273] Baltic iron for the African market meant banking. In the immediate wake of the South Sea Company bubble collapse in late 1720, bars of voyage iron went from over a third of all the commodities carried to the Bight of Biafra from Britain, to none; with textiles deployed in an attempt to plug the gap.[274] Following the bubble collapse, joint-stock companies were outlawed in England,[275] yet the capitalism of enslavement and its transatlantic trade continued to demand high capital investment.

Chapter one described the peculiar structure of the Cornish financial sector where interdependent industries, linked in metal, formed co-operatives to act as venture capital firms. The risk of their investment was secured by ensuring each link in the chain of supply, production, and demand was represented in the friendly and familial make-up of shareholders' apparently distinct interests.[276] A mining industrialist might agree to invest heavily in the engine-building enterprise of close friends in exchange for the contract to supply the metal, and preferential terms on the cutting-edge engines, not only for his own mines, but for the plantations of his investment partners, and his family's latest shipping venture between the two. Or so was the case for the Fox family of Cornwall and their close friends, Boulton & Watt.[277] Enslavement capitalism was almost uniquely associated with the massive, fluid assets necessary for high-risk, high-return speculations. For an enslaver heiress and spinster looking to invest in a portfolio of such schemes, she could go a long way to secure returns by, for example, also laying out the substantial sums required to establish the career of an illegitimate relative from the family's West Indies estates as a financier to the Admiralty, the biggest commissioners of manufacturing contracts in Britain. With him well established in Navy finances, she might then be persuaded to invest significant capital in the experimental scheme of said relative to transform Admiralty scrap into iron of a tradeable, workable quality, and so secure substantial returns on the contract she helped him purchase

[272] Evans&Rydén,2018,pp.52-5.
[273] Williams,1944,pp.98-102.
[274] Inikori,2011,p.667,Table:25.4; Green,2019,pp.88-91,pp.359-62.
[275] Brunt,2006,p.82.
[276] Brunt,2006,74-102; Ince,2001,p.14,p.20.
[277] Ince,2001,p.29-30

to supply ironwork back to the Navy. Or so has been argued from the probate of Jane Cort of Lancaster, and her famous cousin Henry Cort.[278]

§2: Old into New

Through the period of the Atlantic trade, the famously 'wooden walls' of maritime Britain were increasingly held together with iron. Knees – the angular brackets supporting the framework of ship - were wrought for new builds, and retrospectively fitted in the maintenance of existing vessels.[279] Iron hoops stayed the casks, and great iron nails, well over a foot long, held in place the copper sheathing widely in use by the British navy, and ubiquitous among vessels of all European nations engaged in the human traffic.[280] Naval artillery pieces were made almost exclusively of cast iron,[281] while blocks of slag and voyage iron served not only as ballast, but also as a crucial reservoir of the much sought after resource. The Caribbean had no indigenous traditions of ferrous metallurgy, but ships needed metal and skill for their maintenance and repair, while enslavement capitalism had an insatiable hunger for iron.[282]

Early in the eighteenth century the British West Indies became the largest global market for wrought iron, yet even this flood of imported iron was not enough; still this amoral economy that rendered African people into European commodities demanded more. Iron was not just the currency by which African lives were bonded, and the shackles, chains, weapons and torture that held them in bondage, it was the agricultural implements and machinery of plantation production, from hoes and cutlasses,[283] to the great iron rollers which crushed the sugar cane.[284] Indeed, the concentration of iron capital on sugar estates far exceeded even that of other plantations such as coffee, tobacco or cotton, and was only matched by the intensity of human labour. Where coffee or indigo could be profitably grown with fewer than a dozen hands, the cultivation of sugar saw hundreds bound to a single estate,[285] more cutlasses, more chains, more crushing iron rollers. This intimate articulation of iron and sugar in the extraction of human labour pressed, above all, in Jamaica, where after over a decade of outright war, in two successive treaties of 1739 and 1740, Maroons had successfully forced the British to recognise their freedom and self-governance. The Trelawny

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[278] Greenwood,n.d.
[279] Stammers,2001,p.115.
[280] Solar&Rönnbäck,2015,p.825.
[281] Gille,1980b,p.406.
[282] Goucher,2013,p.182,p.185.
[283] Goucher,1993,pp.203-4; Goucher,2013,p.180.
[284] Daniels&Daniels,1988,p.495.
[285] Dubois&Garrigus,2017,pp.4-5;p.9; Sheridan,1989,p.68

family had come to power in 1738, and now the absolute and explicit dependency of the sugar industry on black skill and expertise saw Jamaican enslavers look to their close West Country connections to overcome the labour resistance peculiarly present on the island.[286] As mentioned in chapter one, from as early as 1768 these enslavers sought to grind sugarcane using innovative steam-engine designs, among them an adaptation whereby the sugarcane boiler house itself, fuelled by the relentless cycle of *bagasse*, heated the engine's boiler.[287] In these same years Jamaican enslavers began to promote a vision of the plantation 'as a well-constructed machine',[288] looking to mechanical innovations to crush what iron shackles could not,[289] innovations that depended on skilled maintenance and repair.[290]

With demand way beyond even what the vast imports could supply, foundries were established throughout the Caribbean in every town harbour and plantation,[291] to take the rusted scrap from dockyards - ballast, hoops, nails, and knees - and render them again. Sometimes through long slow smelting with charcoal,[292] sometimes through cycles of forging,[293] sometimes both together, applying exceptional skill to the most recalcitrant materials, the virtuoso metallurgists of these foundries made a workable material, cast new cannon,[294] repaired and maintained the maritime machine, and, above all, fed the iron hunger of the New World plantations.[295]

Where documentary records exist, names such as the Akan 'Quashie' and 'Quarco' reveal the African and Afro-Caribbean identity of these virtuoso metallurgists.[296] Just as has been found for the production of sugar, the skill and the science of plantation production was that of the enslaved.[297] According to John Reeder, a Devonshire coppersmith whose lucrative foundry, 'Reeder's Pen', was established just west of Morant Bay, Jamaica, in 1772, his foundrymen – enslaved Africans, Maroons, and free Africans - were 'perfect in every branch of iron manufacture' from 'casting and turning' to 'wrought iron'. Such rich documentary records as exist for Reeder's Pen are rare for New World foundries in the long eighteenth century.[298] The

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286 Sheridan,1989,pp.68-9.
287 Satchell,1995,pp.224-5.
288 Martin,1765,pp.36-7.
289 Sheridan,1989,pp.59-70.
290 Satchell,1995,p.227.
291 Goucher,1993,p.204.
292 Goucher,2013,p.182,pp.184-5,p.187,pp.191-2
293 Goucher,1993,p.208,p.212; Goucher,2013,pp.186-7,p.191.
294 Goucher,2013,pp.182-3.
295 Goucher,1993,pp.203-4,p.206; Goucher,2013,pp.183-7.
296 Goucher,2013,p.189.
297 Sheridan,1989,pp.68-9; Singerman,2017,pp.42-7.
298 Goucher,1993,p.203,pp.205-6.

most substantial resources for the historian of Caribbean ironworking are its archaeology, its ritual, and its resistance. Metallographic analyses of iron ballast, cannons, and anchors show the tell-tale physical traces of the metallurgical skills specific to African and diaspora smiths. Centuries of modern Caribbean culture, from its carnival,[299] to its literary movements and critical theories,[300] attest to the continuity and elaboration of the particular ontology of iron described in section one: the balance between human and spiritual worlds, transgression and restorative justice, subjugation and resistance. Such concepts and knowledge systems were ineluctably linked to ritual and practice in African iron working.[301]

Reeder's reference to Maroons working in his foundry was a reflection of Maroonage as a central and defining feature of the colonial Atlantic world, and in particular the dominant force in its culture of iron working.[302] Central to the Maroon triumph over the British in Jamaica was their independent ironworks and the iron weaponry they forged through the remanufacture of old agricultural implements and scrap. In these works chains and shackles became *afana*, the Akan for cutlass, a word now remembered as too dangerous to speak by the present-day Kumina community, a Jamaican culture derived from BaKongo *nkoli*. Precisely because iron was an instrument in the movement between human and spirit worlds, to this day the utterance of *afana* risks drawing the attention of violent and vengeful spirits from the terrible transgression of human bondage.[303] As part of the British *entente* the Maroons agreed to provide military support in the event of invasion by a rival colonial power and, notoriously, to assist in the capture and return of any future runaways and the suppression of revolts. The treaties, as with other Maroon accords, were ritually sealed using iron knives.[304] From the metallurgical skill through which they forged their resistance, to the ambivalent role they then played in the subjugation of others, the Maroons were the embodiment of iron culture, both resolution and transgression.

The dependence on iron, and the strength and reputation of Maroon ironworking culture, saw smiths throughout the Caribbean accorded high political and social status. Winkel Village, Guyana, was a particular centre of ironworking and, when the British seized the territory from the Dutch in 1803, Maroon and free African smiths used this status and indispensability to strike for better wages, while enslaved African smiths used it to force the

[299] Goucher,2013,p.182,p.188,pp.191-2.
[300] Hardwick,2017,p.70; De Groof&Gyssels,2015,p.114.
[301] Goucher,1993,p.203; Goucher&Agorsah,2011,p.152; Goucher,2013,pp.187-188,pp.189-92; Goucher,2014,p.123.
[302] Goucher&Agorsah, 2011,p.145.
[303] Goucher,2013,pp.190-1,
[304] Goucher&Agorsah,2011,p.152.

British to recognise their freedom. Here too the colonial contradictions fulfilled the ontology of iron, for every freedom hard won by iron yet another was violated or taken away by it. Terrified, above all, of uprisings and resistance by the enslaved, and fearing, in particular, the ability of iron technology to empower those who possessed it, the British government made it illegal for an enslaved African to be found carrying anything made of metal.[305] As with carrying iron, the cultivation of sugar cane for subsistence was strictly forbidden to enslaved Africans. In defiance of the prohibition Maroons grew the cane around 'Seal Grounds', specifically using the sugar to demarcate sacred areas favoured by spirits.[306] Sugar thus shared with iron the materialisation of subjugation and resistance, and the role as a tool in the movement between human and spiritual worlds. Where the production of coffee or indigo depended on the labour of a dozen hands, Reeder's foundry was like a sugar plantation, in relying on hundreds of African craftsmen, 276 to be precise. And, as with a sugar plantation, it was equipped with a rolling mill.[307] While fundamentally the same in form such mills historically served different functions. The crushing action of the sugar mill transformed the cane into a different material of significant value: cane into grain. By contrast the metal mill made uniform – by flattening and slitting – the iron sheet passed through it.[308] But in the Atlantic world of the African diaspora such European classificatory conventions were challenged. Sugar and iron shared much overlapping conceptual space, and the poor quality scrap and ballast, so far removed from the intentional steel of African metallurgical tradition, required total transformation.[309]

Since 1750 the British government had expressed and acted upon significant concern at the self-sufficiency of its colonies in iron production and finishing to the exclusion of its domestic manufacture and exports. In 1782, citing fear of invasion and capture by French and Spanish forces, the government forced Reeder's spectacularly lucrative foundry to close and be entirely dismantled.[310] The given concern was a loaded statement. France and Spain both made increasing use of African troops through the eighteenth century, not only for their conquests in the Caribbean, but also to antagonize British settlements on the North American mainland. In this way such French and Spanish forays became a by-word for the British planters' more fundamental fear of African rebellion and retribution in the diaspora. While the rival colonial powers contributed to the onset of the war between Britain and its thirteen colonies, it was the uprising of enslaved Africans in the New World, directly in the wake of

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[305] Goucher,2013,p.191.
[306] Gibson,2016-; Gibson,2019.
[307] Goucher,2013,p.183.
[308] Daniels&Daniels,1988,p.495.
[309] Douglas,1984.
[310] Goucher,2013,pp.183-4.

the Somerset Case that legally distinguished civil rights in England from its colonial possessions, which precipitated the revolt against British control of North America. With the American war in its seventh year, and fuelling further insurrection in the Caribbean, British wariness at French and Spanish intentions was precisely their terror at the prospect of African uprising, free, enslaved, or Maroon.[311] Explicit concern that Reeder's Pen might fall into French or Spanish hands was implicit admission of fear at the valuable and strategically critical asset being seized in a revolt.

Reeder received compensation from the Jamaican House of Assembly, but his ongoing attempts to petition the British government suggest the components of his foundry together with the skill and expertise of its African craftsmen were absorbed into the transatlantic machine of British maritime power and Admiralty dockyards.[312] The same year Reeder's Pen was dismantled, in 1782, Navy pay agent turned ironmaster, Henry Cort, was contracted by the Navy Board to supply ships' ironwork; and, further, encouraged by the Admiralty to attempt the conversion of ships' cast iron ballast into more valuable wrought iron. Cort had initially entered the iron industry in 1775, after taking on the Portsmouth works belonging to one his debtors. In 1780, struggling to make the works a financial success, Cort invested huge sums to erect a rolling mill in order to make mast hoops for an Admiralty contract. His losses were substantial, amounting to nearly £10,000. In 1781, chasing yet further investment, Cort entered into partnership with Samuel Jellicoe, son of Portsmouth Navy Pay Agent, Adam Jellicoe. This partnership and the familial connections that came with it coincided with a new contract whereby Cort began to receive from the Admiralty 'extraordinarily large quantities of old iron hoops' and 'not an opportunity of working them in any ordinary way without incurring a great loss'. Since extant records of Cort's activities are sparse, the retrospective patent and compensation claims of the former financier and his family have provided historians with much of their information. According to these compensation claims, Cort, inundated with scrap, undertook experiments costing an estimated £20,000. It was only in December of 1782, at the very end of the year, and with much capital laid out, he was able to declare that he had 'found out some grand secret in the making of Iron', while visiting 'brother projector' James Watt, hankering after the latest Boulton & Watt engine. It was this 'grand secret' that was the basis of Cort's Admiralty contract.[313]

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[311] Horne,2014.
[312] Fuller,[1788],**NA**/CO/137/87/43
[313] Dickinson,1940,pp.32-4.

The 'grand secret' discovered by Cort, for which he was and continues to be lionised as a hero of the industrial revolution,[314] was founded on two principles. First the financier turned ironmaster, beneficiary and executor to the will of his enslaver heiress cousin, and with further family 'now in the West Indies',[315] proposed 'Cast iron is to be sunk down in the finery into half blooms and shingled'. In the precisely timed presence of charcoal, the iron would be carburized, endowed with a steel-like skin. In the absence of such reducing conditions it would be further decarburized. Such a process, putting what was considered to be a finished product back through fining and so treating cast iron as crude raw material, was exceptional in the European tradition of ferrous metallurgy. However, it was precisely the response of West African metallurgists, faced with voyage iron so inferior to their own product as to be almost unrecognisable, precisely the knowledge and techniques John Reeder had described as 'perfect' in every respect. Cort's second claim to innovation was to cut or fold old mast hoops and bundle them into fagots, to undergo cycles of heating and beating, before being fed, hot from forging, through 'the rollers of common rolling or slitting mill whereby the cinder is squeezed out and the metal compressed into a fibrous and tough state'. Such fagoting, heating and beating were commonplace in European manufacture, and in particular in dockyards. Where Cort's second claim to innovation lay, was in the striking application of the rolling mill. In the then state of European metallurgy, rolling mills were fed with smooth sheets of newly made iron, already prepared by hammering. Here again Cort treated the scrap as raw material, passing bundles of iron sticks through the rollers as if they were sugar cane, transforming the individual pieces into a single mass with a grain that gave it a fibrous tensile strength.[316] This was not the British tradition of manufacture, where, as previously noted, the costs of working up old material could not compete against the ready availability to buy new cheap. This was the production of the colonial Caribbean with its insatiable hunger for iron that depended on African skill to transform old scraps.

The success and uptake of Cort's process was immediate. Politician and vocal proponent of enslavement, John Baker Holroyd declared 'our knowledge of the Iron trade seems hitherto to have been in its infancy', and, in direct reference to the loss of the American war and newly founded United States of America, described Cort's process as being 'more advantageous to Britain than Thirteen Colonies'. Holroyd was explicit on what he saw to be the nature of this advantage: the former colonies were to become markets for British manufactures, above all Cort's iron.[317] Just three years on from Holroyd's assessment, in 1788, Cort's financial partner

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[314] Dickinson,1940,p.42; Smiles,1864,pp.148-69; Allen,2009,p.243.
[315] Greenwood,n.d.
[316] Dickinson,1940,pp.32-4.
[317] Cort,1787,appendix,p.13.

Adam Jellicoe died suddenly, and their partnership was discovered to be founded on £39,676 of embezzled Navy funds. The following year the Navy Board advertised its new bar iron contracts, stipulating that only iron manufactured according to Cort's patents would be considered, and at the same time moved to recover the embezzled funds, seizing the property and goods of the banker-cum-ironmaster. The theft was a drop in the ocean compared to the peculation of thirty-four million pounds by first Viscount Melville, Henry Dundas, Treasurer of the Navy, discovered in 1803, with much of it spent gambling on the Stock Exchange;[318] but it was more than sufficient to bankrupt Cort. Friends helped him pay debts and secure a small pension, and in their efforts launched the myth of 'industrial martyrdom', but he remained an undischarged bankrupt until his death, 3 May 1800. In 1802, two years after his death, and with at least two of his sons already located there, Cort's widow and children acquired plots of land on the Courentyne Coast of Berbice,[319] otherwise known as Winkel, where, as already mentioned, the high status and indispensability of the African smiths had enabled them to strike for better wages and win their freedom from European enslavement.

§3: ***physique d'outre-mer***

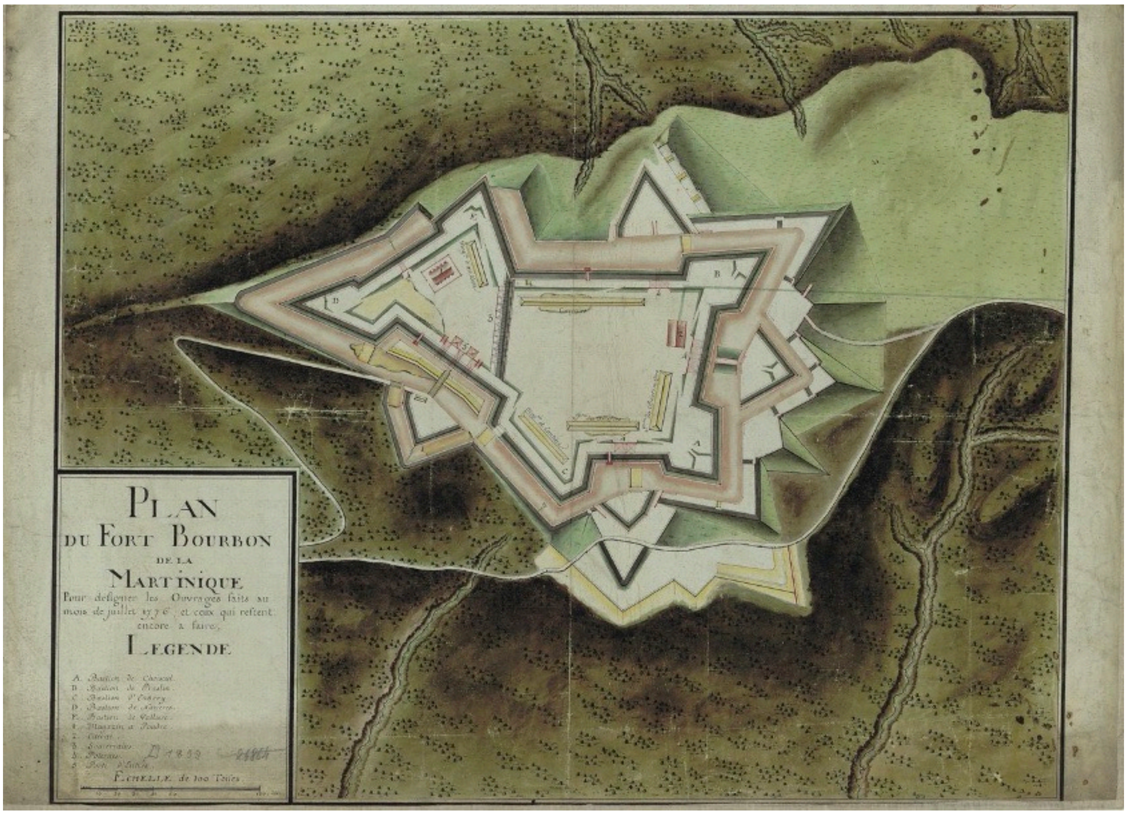

Figure 2.4: *Plan du fort Bourbon de la Martinique, pour désigner les ouvrages faits au mois de juillet 1776 et ceux qui restent encore à faire*, GED-1859, Bibliothèque nationale de France.

[318] Dickinson,1940,pp.41-2.
[319] Alston,n.d.

On 29 April 1781, *Lieutenant général des armées navales* François Joseph Paul, comte de Grasse broke a seventeen-line British blockade of Martinique but ignored the opportunity to pursue the scattered fleet. For de Grasse and for France there was a much bigger prize in sight. Martinique was just the first in a chain of French and Spanish Antillean ports: hubs of the human trade, where de Grasse's convoy would call in the weeks that followed, 'recruiting' and arming tens of thousands of Africans in preparation to invade Jamaica.[320] Detailed secret intelligence of de Grasse's operations and orders, including the African militias, reached London in August via Lord Shelburne, a powerful proponent of American free trade in opposition government, and one of his principal agents, Jeremy Bentham.[321] In April the following year, a major naval battle at the Îles des Saintes forced France to abandon its planned invasion of Jamaica, too late for the incumbent British government, badly damaged by Grasse's 1781 victories in America and the Caribbean. In March the opposition took power and in July Shelburne became prime minister. In December, despite the collapse of the planned conquest of Jamaica, still the spectre of the secret intelligence that had described armed Africans in 6,000-strong 'militias of colour' remained, and Reeder's foundry was dismantled.

Before this intelligence had reached London in August 1781, however, news of the Martinique victory, the vast *enrôlement forcé* it enabled, and the coveted prize this *enrôlement* seemed to promise, already circulated among the veterans of the French colonial service. In these same weeks, in July 1781, Charles Augustin de Coulomb wrote to his superiors in the Corps royal du génie, applying both for promotion and a medal for his service, emphasizing in particular his time in Martinique, and providing the supporting testimony of an old Martinique comrade. In the application he presented his imminent election to the Académie des Sciences as rationale for permanent transfer to Paris, and again raised his specific colonial credentials. It was his time in Martinique, Coulomb argued, that had placed him 'in the situation of discovering how much all theories, founded upon hypotheses or carried out in miniature in a *cabinet de physique*, were insufficient guides in practice.'[322] The 1781 application and Académie election would prove the turning point in his life and career, but Coulomb himself identified Martinique as the seminal moment in his intellectual development. To understand what he saw in Martinique, and how he deployed that moment to frame how his superiors should see him, it is first necessary to consider the tradition Coulomb carried with him to the Îles du Vent.

[320] Lewis,1945,p.229
[321] Bentham,28/08/1781 in Christie,2017,pp.65-6.
[322] Gillmor,1971,p.40,p.23.

In 1760 Coulomb had entered Mézières, the outstanding technical school in Europe, to train for the Corps du génie. That same year Abbé Jean-Antoine Nollet began to teach a new course, with practical demonstration, based on his recently published six-volume work, *Leçons de physique expérimentale*.[323] For this *ouvrage, Académicien* René Antoine Ferchault de Réaumur was Nollet's friend, patron, judge and editor.[324] The first volume drew heavily on Réaumur*'s* 1722 *L'Art de convertir le fer forgé en acier* and specifically his study of the property of '*corps*' in materials.[325] '[O]rdinarily used to describe the ability of quenched steel to resist the force that wants to break it,' Réaumur noted that for 'the artisan who is little accustomed to connect clear concepts and well-defined meanings' body had a different meaning. It indicated not giving way to either fracture or flexion. Body for the artisan was resistance to any imposed action. For Réaumur, to bend was part of not breaking. Steel beaten to a fine-grain structure possessed great body, and for Réaumur, the way in which the relative body of two steels was to be compared and assessed was by breaking them.[326]

Réaumur assumed the structure revealed by fracture was indicative of a smaller invisible structure.[327] In this he followed millennia of metalworkers, whose art had been to read this fracture surface as a sign of both the composition and the process of its manufacture.[328] For Réaumur, while heat caused excitement, beating and mechanical violence produced an orderly structure. The greater the order, the better the quality of steel formed. Fracture structure was both indicative of the particular labour history embodied in the metal, and determinant of the peculiar properties that metal exhibited. It explained hardness, softness and strength, even the surface colour-changes of the metal during heating and quenching were explained through the arrangement of particles and fibres. He extended the same principles of fracture and process by which he characterized steel to other materials, such that anything with body might be read in the mould of metal.[329] All this Nollet carried into his *Leçons,*[330] and Coulomb with him to Martinique.

Just recently graduated and only on his second posting, Coulomb joined the island's colonial structure of some 450 sugar mills, 18-19 million coffee trees, and an average import of 3,500 enslaved people, each year, to a population that nonetheless declined, the 'rate of net natural

[323] Gillmor,1971,p.15.
[324] Nollet,2008; Fouchy,1748.
[325] Nollet,1743,pp.131-145.
[326] Réaumur,1956,pp.181-2,p.193. Réaumur,1722,pp.266-7,p.277.
[327] Smith,1960,p.106.
[328] Smith,1956,p.xxix.
[329] Bycroft,2013,pp.33-39.
[330] Nollet,1743,pp.131-145.

decrease' was so high.[331] *The Colonial Magazine and Commercial-maritime Journal* described the demographic for 1770 as 'whites 11,588; free blacks, 2,525; slaves 71,142' with a total population of 85,254.[332] Such figures do not take into account the role of Martinique as the central redistribution point from where Africans, trafficked by French and British merchants, were sold into French plantations.[333] It was the monstrous significance of Martinique's marinas that underlay the importance of de Grasse's victory for raising an army, and saw the revolution that would sweep the French Caribbean begin there in 1789. Enslaved Africans took up *afana*, and assembled on the docks with the support of free Africans and Martinique's Maroons. The letters from the revolutionaries were marked by their absolute cohesion, declaring

> the entire Nation of Black Slaves united together has a single wish, a single desire for independence, and all the slaves with a unanimous voice send out only one cry, one clamour to reclaim the liberty they have gained through centuries of suffering and ignominious servitude.

This revolution, noted Governor Charles Joseph Hyacinthe de Houx de Vioménil, had been a long time coming.[334]

In Martinique, Coulomb was 'responsible during eight years… for the construction of Fort Bourbon (Figure 2.4) and for a workgang of 1200 men'. Assembled in spite of severe labour shortages, these men were enslaved Africans.[335] During this time, overseeing this vast forced labour he was 'almost always alone' and yet always watched, under the gaze of 1200 pairs of eyes, the salience of the power relations, and the ever-present threat of an uprising. Overseeing this labour alongside the rupture of materials under stress led Coulomb to refine Réaumur's concept of 'body'. The *Ancien Régime Académicien* had understood resistance to fracture and the capacity to bend as a single concept. So too had the *ouvriers* he observed and interviewed, though the composition of the concept differed, referring instead to a combined property of resistance to fracture and flexure. Within the intellectual tradition of West African metallurgy developed in the Atlantic diaspora, the single material embodied, through working and the negotiation of transgressions, the agonistic tension of multiple distinct and often opposing concepts. Iron was the material of oppression and of retribution, the concepts were separate, but simultaneously sustained in the single form. Watching and acutely aware of being watched, the tension of his position, in total power and yet overwhelmingly overpowered, Coulomb divided Réaumur's concept of 'body' into cohesion between

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[331] Curtin,1972,p.80.
[332] Martin,1840,p.317.
[333] Stein,1979,p.109.
[334] Dubois&Garrigus,2017,p.12,pp.51-5.
[335] Coulomb,1781 in Gillmor,1971,pp.22-3.

molecules, and elasticity within them: distinct concepts expressed within the single material form.[336] Far from observing passive subjects as objects or material resources, Coulomb came to his division because he himself was altered by the concepts he encountered, as he was permanently altered by the exposure of his post that destroyed his health for the rest of his life. Coulomb himself claimed he found his calling in contrasting oversight of the labour of enslaved Africans with the state of theoretical physics. Writing to his superiors in 1781, as de Grasse assembled an army, starting from Martinique, Coulomb recalled his time at the *entrepôt* of *la traite* and identified it as the moment he 'devoted [him]self to every form of research that could be applied to the enterprises that engineering officers undertake'.[337]

In June 1772, Coulomb returned to France, his health and his thinking permanently altered.[338] Four years on, while posted in La Hogue, near Cherbourg, Coulomb composed a memoir for an Académie des Sciences competition to find 'the Best Method of Making Magnetic Needles'. The Académie's challenge sought to harness magnetic science to navigation reform and Coulomb's response was to turn the torsion balance into a magnetic compass. Taking the effect of torsion in a thread of silk or hair as negligible with respect to the magnetic force moving the compass needle it suspended, he studied twist in relation to the thread's dimensions and elasticity. In doing so he showed that the force of torsion was proportional to the angle through which the thread was twisted, such that twist might measure magnetism to unprecedented degrees of precision. Not only would this research become the basis of Coulomb's celebrated law of torsion, it would transform the science of magnetism.[339]

His balance won acclaim, and was taken up at the Paris Observatory in 1780 as its instrument of magnetic observation. But Coulomb remained concerned at the difficulty of assuming with confidence the homogeneity and standard dimensions of organic fibres along their full length; while making the exquisitely sensitive compass robust enough to operate became a source of constant struggle. After initial concerns over gusts of air and vibrations from passing carts that led Coulomb to move the instrument into the cloistered Observatory basement, Coulomb came to identify the instrument's erratic behaviour with the electricity of observers' bodies. Control over space quickly became control over bodies as Coulomb issued instructions for the observers to linger in the basement before making their measurements so that their static charge could dissipate into the dank surroundings. Despite such measures, still bodies continued to confound results and Coulomb reluctantly proposed to substitute silk with

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[336] Gillmor,1971,p.23,p.151,pp.157-61.
[337] Coulomb,1781 in Gillmor,1971,p.23.
[338] Gillmor,1971,p.25.
[339] Dörries,1994,p.123; Gillmor,1971,pp.140-6.

metal, motivated by the belief that the properties of metal made it less susceptible to the influence of the human body. Faced with these challenges: acute concern to bring the behaviour of materials, disrupted by unruly bodies, in line with his own law of force, Coulomb looked back to the formative experience of his career, when he first came to essential principles of his division of the property of body: his time in Martinique overseeing the construction of a garrison by enslaved Africans.[340]

§4: the Woolwich inequitable building society

Under the Napoleonic *régime,* Coulomb's work and that of *la physique* generally became comprehensively organized into a coherent system of thought. Physics would only emerge in Britain as a discipline in its own right in the wake of the Napoleonic Wars with the reception and appraisal of this research tradition. Even then it would lack the close coherence of its continental antecedents as different institutions and groups interpreted la physique in the light of their own individual traditions.[341] How the French colonial engineer would be read in the 1810s would matter for the development of electromagnetic research in the 1820s, the concern of chapter three, as it would for the launch of the 1838 magnetic campaign detailed in the thesis introduction and chapter six. To understand this form of reading and of disciplinary reorganisation, the military and political setting of the age of Atlantic Revolution, and its specific embodiment in the disciplinary systems of the Royal Military Academy at Woolwich, need to be understood in some detail.

The late-eighteenth century saw government spending on military and naval ordnance increase on a scale unprecedented in British history.[342] Prior to 1799 the state's capacity to flexibly increase the military budget during periods of conflict relied on loans from London financiers:[343] the agents of Cornish corporations described in chapter one with vested interests in West Indies plantations. Together with the powerful presence of enslavers, their shared interests dominated parliament.[344] In 1798, having lost four million pounds and 100,000 men in a failed attempt to seize the newly formed Republic of Haiti from the revolutionary government of Toussaint L'Ouverture, and with British enslavers and their investors gripped by rising fear of enslaved uprisings, government policy shifted decisively. The enslavers' fears and their desire for military support enabled the Tory party to redistribute political power, where once in debt to enslavement capitalism, now the

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[340] Gillmor,1971,pp.146-50,pp.22-3,p.151,pp.157-61; Heering,1994,p.54.
[341] Crosland&Smith,1978,pp.1-61.
[342] O'Brien,2011,p.11; O'Brien,1988,Table:2.
[343] O'Brien,1988,p.2.
[344] Jaggard,1999,p.11,pp.21-22; Beckles,2013,pp.131-142.

exchequer took a share. From 1799 the state raised revenue for emergency military spending by indirect tax on luxuries such as coffee, tea, sugar, rum, tobacco, wine and spirits.[345] Between 1800 and 1815, the revenues appropriated to military spending increased from 12.9 per cent to over 22 per cent of Britain's national income.[346] Chapter four considers the development and expansion of a revenue-base for the standing military and how the purported 'abolition' of 1807 enabled British monopoly and nationalisation of the human trade. Here, however, the significance is with respect to the massive development of ordnance in mainland Britain, specifically Portsmouth and Woolwich, which saw the optimisation of labour extraction in different forms to that of the British Caribbean, but notably the same kind of iron.

In 1806 the Military Academy long associated with the gun-proofing centre of Woolwich Warren relocated to Woolwich Common. When George III saw the building site, teeming with a workforce some 2,000 strong, he dubbed it 'an Arsenal'.[347] The reference was canonical, pointing to the famous Venetian arsenal, the pivot of state power that was Galileo's exemplary field of investigation for the physical sciences.[348] In this period the historic complex of shipyards and armouries clustered around Woolwich was rebuilt in suites of cutting-edge machinery powered by coal and steam.[349] Originally designed for Portsmouth dockyard in the early 1800s, these machines were unprecedented in being made entirely of iron.[350] By the late-1820s, Woolwich had become the Navy's steam manufactory and centre of technological innovations.[351] Through a concatenation of successive reforms, the Woolwich Academy mathematics curriculum instrumentalised this power. To understand how, it is first necessary to return to the Newcastle Town Moor, a centre of the overseas coal trade where black Atlantic uprisings inspired radical politics,[352] and the rights of man were marked in base metal.

Chapter one gave some account of the dispute over the Newcastle Town Moor that irrupted in 1770, and further described industrialist Matthew Boulton's later eighteenth century innovations in the design of copper currency, concurrent with radical book-seller Thomas Spence's mobilisation of trade tokens following his campaign to prevent its enclosure. For over a century prior to the dispute over common land, copper tokens had been a central part

[345] O'Brien,1988,p.2; pp.6-7,p.23.
[346] O'Brien,2011,p.11; O'Brien,1988,Table:2.
[347] Woolwich,1870,p.280; Guillery,2012,p.32.
[348] Renn&Valleriani,2001,pp.481-503.
[349] Guillery,2012,p.427.
[350] Russell,2014,p.197.
[351] Guillery,2012,p.101.
[352] Cazzola,2017,p.5.

of the labour culture of mining towns such as Newcastle. Known as 'People's tokens' these copper discs were struck with a device denoting the issuer and names, places and rhymes often phonetically spelt.[353] Between 1772 and 1774, the same years that required Spence to raise significant coin for legal action to be brought regarding the Moor, this informal tender began to be formally suppressed, with Boulton appointed to recall and render it down. In this contest of representation, the 'People's token' was disqualified. The experience cast the die for Spence's politics, that 'Property in Land is Every One's Right',[354] and his action, coining not only radical tokens but also phonetic script.[355] In this work Newcastle copper-engraver and seal-cutter Ralph Beilby and his assistant Thomas Bewick were Spence's friends and close allies,[356] with Bewick recalling how he 'cut the letters' for Spence's phonetic dictionary and Beilby 'struck them on matrices for casting'.[357]

The son of a colliery viewer on a Newcastle peer's estate, by the early 1770s Charles Hutton was founder and master of a successful writing and mathematical school and already an established author on bookkeeping. While principally known for accounting works, Hutton had just published *Treatise on Mensuration*, his first work on the mathematical methods of surveying, when the dispute over the Town Moor broke. That same year he was employed as a surveyor to draw an accurate map of the city.[358] It was following directly on this experience that he sought out the Newcastle copper-cutters, Bewick and Beilby, and commissioned them to apply their metal-cutting skill to the peculiarities of wood.[359] The commission resulted in a second edition of *Treatise on Mensuration*, innovatively illustrated with elevations carved by Bewick. In the same years and in the same town as Spence sought to turn coin into land, Hutton solicited the same radicals to turn land into coin. In the midst of this, in May 1773, after several days' intense examination, the appointments committee of the Woolwich Royal Military Academy 'unanimously recommended [Hutton] as peculiarly qualified to fill and adorn the situation [of First Professor of Mathematics at Woolwich]'.[360] From the first Hutton engineered his publications as the fulcrum of power in labour relations.

Hutton's liberally illustrated texts proved lucrative. By 1786, working from the Academy site known as 'the Warren', he had accumulated an extensive portfolio and won the contract to

[353] McKivor,n.d.
[354] Spence,1775a
[355] Spence,1775b; Beal,2016.
[356] Downey,2016,p.5,para.19.
[357] Bewick,1862,p.73.
[358] Johnson,1989b,p.198.
[359] Hutton,1822,p.321.
[360] Gregory,1823,p.207

produce longitude tables for the eponymous Board.[361] With the significant capital these publications provided, Hutton purchased land on Woolwich Common, employed brick-makers, directed the manufacture of his own bricks, and planned and erected a series of genteel houses. New to brickmaking, he immediately updated his teaching and publications with an account of 'Bricklayers [sic] Work' that assumed the use of bricks of standard dimensions.[362] The first patent for a brickmaking machine coincided with the founding of the Academy in 1741, with a surge in such patents in the late-eighteenth century, harnessing the craft to steam power. Brickmaking by hand was skilled but highly situated, without commensurable professional standards. It was argued that the advantage of the machine over the handcraft was precisely the production of standard bricks.[363] The particular loamy clay of Woolwich Common lent itself to mechanised brickmaking.[364] But Hutton's publications and their assumed standard dimensions, made these brickmaking machines, already exported globally, indispensible to those civil and military engineers who referred to the practical guidance of the Woolwich textbook.[365] Just as Hutton's longitude tables facilitated the global extension of British maritime power; his brickmaking tables determined the extension of its technocratic capitalism.

Following the French declaration of the First Republic in September 1792, the Master-General of the Ordnance sought a way in which indoctrination into Woolwich tradition could be bought alongside commissions, to expedite the qualification of new Artillery officers. Hutton took advantage of this concern to win support for his proposal to produce a digest of 'all the mathematical branches and books now in use in the Academy'. What purported to formalise the existing curriculum became an opportunity for Hutton to overhaul the syllabus, and define it in his own terms.[366] Three years prior to the publication of this *Course of Mathematics* in 1798, he brought out his voluminous 1795-6 *Mathematical and Philosophical Dictionary*, explicitly a reference text for the *Course*. The first editions of Hutton's *Dictionary* and *Course* combined original Woolwich research in gunnery and ballistics with what were principally compilations of published articles extracted verbatim from the Royal Society's *Philosophical Transactions* and Ephraim Chambers' *Cyclopaedia*. This latter was itself a compilation of treatises, for which achievement Chambers had been appointed a member of the Académie Royale in 1729.[367] By the 1741 fourth edition, Chambers' *Cyclopaedia* was

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[361] Minutes,[1780-1801],**CUL**/RGO/14/6/pp.6-7;16;29.
[362] Hutton,1786,pp.161-3.
[363] Watt,1990,p.403,p.247.
[364] Dickinson,1843,p.155.
[365] Watt,1990.pp.163-171.
[366] Woolwich,1895,p.32,p.34,p.46.
[367] Jacob,1992,p.1037.

composed of *Histoire* and *Mémoires de l'Académie Royale des Sciences*, in line with his ambition that the work should perform the function of the institution itself.[368] In 1746 radical writer and philosophe Denis Diderot was passed a commission to translate this fourth edition into French, under the title *Encyclopédie, ou Dictionnaire Universel des sciences, des arts, et des métiers.*[369] With a keen eye to integrating the Royal Society's *Philosophical Transactions*, Diderot arranged his translation of Chambers' *Cyclopaedia* as an intervention to reorganise the Académie Royale.[370] On its publication in November 1750 the first volume of the *Encyclopédie* was immediately damned as dangerous iconoclasm. By 1765, with the publication of the last of the sixteen volumes of text, it was a work of international renown.[371]

Across the Atlantic, Hutton's Course quickly came to be seen as a route to superior French mathematics where French language education or access to translations was lacking.[372] In 1801, five weeks after Thomas Jefferson became president of the United States, his Secretary of War Henry Dearborn ordered the newly founded West Point Military Academy to adopt Hutton's *Course*, then on the third edition, as its textbook.[373] Shortly afterwards, a major brickworks was established there.[374] In 1809, after nearly fifteen years of circulating the content of the Royal Society's *Philosophical Transactions* within his *Dictionary* and later *Course*, Hutton brought out an edited and abridged edition that saw the work made familiar under his name now crediting the original authors under his editorial. Characteristically of Hutton, he won his wars before his combatants even entered the field.

In Woolwich Academy, where power relations were defined by examination and punishment as public spectacle, both violence and order were performed as theatre.[375] In the same days as Hutton wrote and gained approval to compile the course, the Master-General of the Ordnance ordered Hutton's overseer, Lieutenant-Governor of the Academy Benjamin Stehelin, to publicly read out the written reprimand he had received for allowing 'a spirit of insubordination, little short of mutiny, [to break] out in the Company of Gentlemen Cadets', so severe it threatened to 'entirely ruin the Institution'.[376] While Hutton began to formalise the Woolwich experience in text, the violent insurrection of cadets escalated. In 1794 Stehelin was stood down, replaced by the commanding royal engineer for the southern military

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[368] Chambers,1753,'iron'; Yeo,2001,p.121
[369] Lough,1989,p.13.
[370] Lough,1952,pp.291-2.
[371] Lough,1989,pp.37-8.
[372] Rickey&Shell-Gellasch,2010a.
[373] Rickey&Shell-Gellasch,2010b.
[374] Scarlett,Rahn&Scott,2006,pp.28-46.
[375] Werrett,2015,pp.87-98
[376] Woolwich,1895,p.34.

district, lieutenant-colonel William Twiss, a close friend of the Benthams: Jeremy, Lord Shelburne's agent mentioned in section three, and his younger brother, Samuel.[377]

Formerly manager to the Krichev estate in White Russia, Samuel Bentham was then in England preoccupied with promoting his Panopticon. This 'inspection house' principle was designed to instrumentalise the inspector's gaze, not only to construct those under observation, but also the inspector himself, and so abstract the external power as natural law. These ideas were significantly informed by the contingencies of Bentham's role in Russia. His immediate obstacle was not the well-disciplined Russian peasantry. Rather it was overcoming the linguistic and cultural barriers posed by the diverse assemblage of ethnicities and religions in his employ,[378] and above all keeping in check their English supervisors, described to him as "a Newcastle election mob" and "no better than hirelings from that rabble town".[379] In addition to these immediate challenges was the power play of his own supervisor, Prince Grigorii Potemkin, seeking to secure his high favour with Catherine II despite intrigues against him at court.[380] Catherine was herself a great admirer of the *Encyclopédie*, understood as the production of law-like order to strengthen the apparently natural rule of law: the redistribution of power to consolidate overarching power. This interpretation she explained to Diderot in person, seven years after she bought his library in 1765,[381] saying, 'While you write on unfeeling paper, I write on human skin, which is sensitive to the slightest touch'.[382] Under pressure from Potemkin, Bentham was tasked with displaying to Catherine her cyclopaedia in human skin. His interpretation of this challenge was to draw on the inherent dramaturgy of Russian aristocratic tradition, to produce an ideal factory built on the principles of a theatre. The mysteries of arts and manufactures would be revealed by turning the peasantry into spectacle, and, through architecture and staging in relation to spectacle, subversive supervisors and plotting princes would recognise their roles and perform in orderly fashion as apparently self-acting machines.[383] Now in England Bentham sought to promote his architecture of power as a scheme for prison design.[384]

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377 Bentham,1849,p.298
378 Werrett,2008,pp.50-4.
379 Debraw:Bentham,1786, in Werrett,2008,p.52.
380 Werrett,2008,p.55.
381 Lough,1989,pp.37-8.
382 Zaretsky,2017.
383 Werrett,2008,pp.59-61.
384 Bentham,1849,p.298.

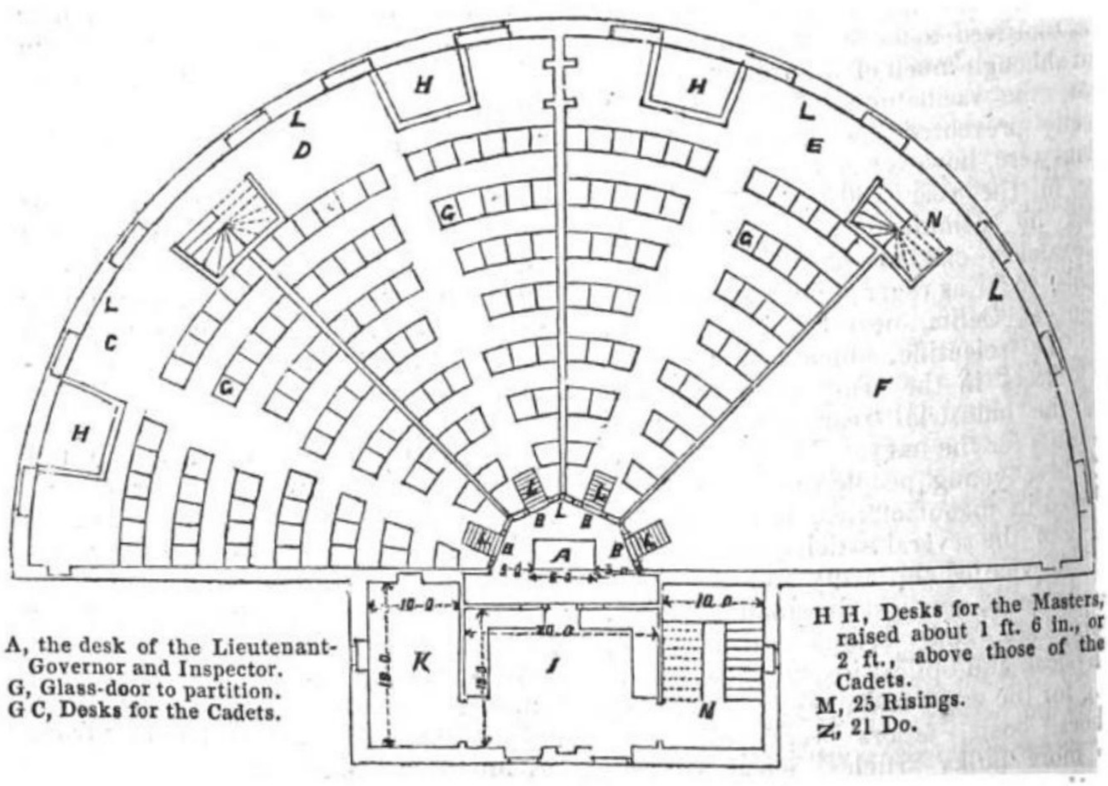

Figure 2.5: Bentham, Maria, 1849, 'The application of the Panopticon principle to a school… for the gentlemen cadets at Woolwich', *Mechanics Magazine*, Vol. L, Saturday March 31, p.296, Fig. 3.

Twiss, the newly appointed Lieutenant-governor of Woolwich was at this point considering plans to rebuild the Academy, whilst overseeing Hutton's reconstruction of Woolwich training in print, and dealing with the on-going and mounting insurrection of cadets. In the midst of these challenges he was 'struck with the power given by [Bentham's] principle, of overlooking by a headmaster, at once the pupils and the several masters under his control.' In 1796, as Hutton's *Dictionary* went to press, he 'requested his friend, Sir Samuel to devise a plan for the intended school' (Figure 2.5).[385] That same year, the Admiralty appointed Bentham inspector-general of naval works. This was a direct intervention in the workings of the Navy Board, responsible for running navy yards and under whose corrupt management the yards had become notorious centres of resistance by skilled labour; giving birth and berth to the term 'strike'.[386] Such fraught relations between echelons of power recalled Bentham's experience in Russia but further introduced new and significant challenges: where aristocratic Russian tradition fetishized the gaze in its political theatre,[387] in the dockyards the expression of power was wooden.[388]

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[385] Bentham,1849,pp.297-8.
[386] Schaffer,2004,p.89.
[387] Werrett,2008,pp.59-61.
[388] Linebaugh,1993,pp.371-401.

Since the sixteenth century, the British state had argued that the requirement to protect the supply of timber to navy yards necessitated close regulation of the circulation and consumption of wood, in particular for furnace-based industries such as iron and glass. Through this argument for regulation the state then used timber as a focus of social control, in particular over intellectual property, and the free movement of workers.[389] By the early decades of the seventeenth century, wood as the expression of tensions in the labour system was made explicit in the prescriptive rights of dockyard workers. Within the dockyard, the right to appropriate a certain amount of wood came to be read into the chips themselves; fragments of wood came to embody skill, power and resistance among dockyard labourers.[390] This tradition developed alongside increasing timber shortages in Britain, made acute by the American War of Independence and the Continental blockade that disrupted the staple Baltic trade. By 1796, it had become a trope that the pilfering of wood chips crippled naval administration.

Faced with the new challenges of this tradition, and in conversation with factory owners and industrialists, Bentham extended Catherine's ruling ambition for total visibility and total oversight into the accounts and bookkeeping of the dockyards: what the Admiralty needed, he argued, was an 'eye' in every yard.[391] The encyclopaedic vision for educational reform such as that underway in Woolwich under Hutton and Twiss, provided a salient model for tacit skill and hidden processes to be broken up and reconstituted as discrete, orderly, and visible units of production.[392] This principle then underpinned Bentham's design of an innovative new approach to mechanisation, in collaboration with engineer and inventor *émigré* Marc Isambard Brunel, just recently come from New York where he had redesigned and supervised the construction of the arsenal and cannon foundry; and cutting-edge machine tool innovator Henry Maudslay, who grew up working in the Woolwich forges and foundry before training with the celebrated locksmith Joseph Bramah.[393] The crucial Portsmouth navy yard was the focus of these reforms. In Portsmouth, Bentham's preoccupation with the supply of timber would become a frightening obsession[394] that total control over the bodies of dockyard workers would only come with the substitution of wood by ferrous metal.[395] In Portsmouth, Bentham exposed and ordered skilled and secret trades in encyclopaedic terms through a

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[389] Godfrey,1975,pp.65-74,p.94,pp.47-50.
[390] Linebaugh,1993,pp.371-401
[391] Ashworth,1998,pp.63-79.
[392] Picon,1992,pp.143-4
[393] Cooper,1984,p.195,p.202; Ashworth,1998,p.68,pp.70-1,pp.73-8.
[394] Ashworth,1998,p.67,p.72.
[395] Linebaugh,1993,p.398; Ashworth,1998,p.66,p.78.

theatre of innovative ironwork driven by steam, and from this model sought to extend these systems to Woolwich, not a significant site for shipbuilding but the yard most directly under the Admiralty's gaze.

Encountering block after block in the Navy Board's resistance to Admiralty interference and the dockyard labour aristocracy's resistance to overseers,[396] Bentham struggled to carry out his plans for Woolwich. In 1802 he was successful in introducing steam-driven bucket dredging, but his subsequent scheme for a mechanized ropery failed to get approval, as did a design for a steam-powered saw mill.[397] The steam dredging system has been considered the last of Bentham's plans to be realised in Woolwich before his post was abolished in 1807. Historians have judged that even the innovative principles behind his mechanization in Portsmouth, while a notable tourist attraction, 'were not generalized.'[398] So too his design for a new military Academy, the Panopticon of military education under Twiss's enthusiastic patronage and alongside Hutton's educational reforms, appeared, at least superficially, to have been forgotten.[399]

Two years on from when Twiss was so struck by the principle of the panoptic headmaster, Hutton, Bentham's fellow Smeatonian and celebrated author of bookkeeping guides, produced his *Course*, the Woolwich training ordered along rational principles and made public. To understand the *Course* terminology, students had to purchase his voluminous and expensive 1795-6 *Dictionary*, the building blocks of the *Encyclopédie*, here, as in Catherine's library, put in the service of consolidating power. Just as he had done with Bewick and Beilby in Newcastle two decades before, Hutton appropriated the instruments of radical philosophy in the materialisation of political theatre, to place his work at the fulcrum of power. In 1806, the year before Hutton stepped down, the Academy relocated from the Warren to Woolwich Common, buying Hutton's land, houses, bricks and all, and using the plans of his favoured former pupil, William Mudge, now surveyor to the Ordnance, to agree on a price.[400]The most striking feature of the architecture of the newly built Academy was the design of the central and largest block as an imposing look-out tower or gatehouse, in theatrical Tudor-Gothic style with 'great scenographic impact' and at odds with the 'entirely classical' barracks on the other side of the common. The 'massiveness' of this central watchtower, which housed the inspector and his clerk, was further emphasised by four large ogee-topped octagonal corner

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[396] Ashworth,1998,pp.70-1
[397] Guillery,2012,pp.98-9.
[398] Cooper,1984,p.225,pp.182-3.
[399] Bentham,1849,p.298.
[400] Vindex,1820,p.516.

towers.[401] Here successive First Professors oversaw public examinations from a table so exposed (Figure 2.6), according to Hutton's client and successor the mathematician Olinthus Gregory, that it made them sick and drove Hutton to retire within the year.[402]

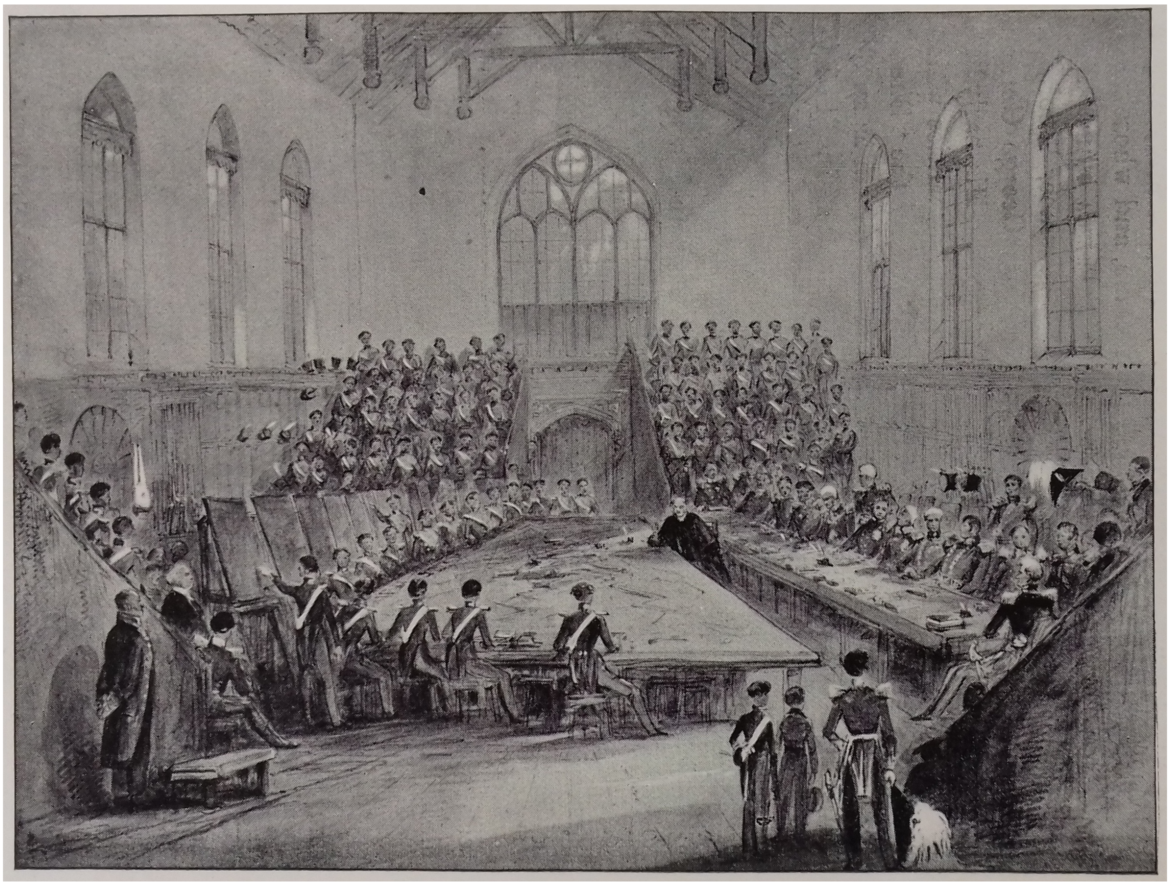

Figure 2.6: As in Bentham's plan (Figure 2.5) the space is organised as a semi-circular amphitheatre where the cadet's raised desks are divided into four radial parts around the focal point of the examiner's desk, which is exposed from all sides.
'A public examination about 1820 (from a painting at "The Shop")', in Guggisberg, Frederick Gordon, 1900, *"The Shop;" the story of the Royal Military Academy*, Woolwich: Royal Military Academy, p.83.

Twiss was not only lieutenant-governor of the Military Academy, but also commanding royal engineer for the southern military district. Under his tenure and continuing after his retirement in 1809, Bentham's plans that were blocked in Woolwich docks were taken up in the military arsenal of the same Woolwich complex. In 1804 a steam-driven pump was used to reclaim land. The following year saw the Royal Carriage Factory introduce a Bramah steam engine and iron wood-planing machine, adding two reverberatory furnaces and a large compass saw for circular cutting in 1807, and a further small steam engine and boiler in 1809. Between 1811 and 1812 the iron sawmill Bentham and Brunel had designed and

401 Guillery,2012,pp.423-5.
402 Gregory:Drummond,[02/01/1835],**Sandhurst**/WO/150/13/44.

planned for Portsmouth dockyard was finally realized in the arsenal Carriage department. Before 1810 structural iron was exceptional in warehouses, but the sawmill drove logs through four great cast-iron column frames.[403] In 1814, seven years on from the ignominious abolition of Bentham's role as inspector of naval works, Woolwich dockyard followed the Arsenal on a dramatic scale with the construction of a monumental John Rennie steam-powered anchor forge. Hailed as the first machine-driven facility of its kind in England, the forge was housed in one of the very earliest iron-framed buildings (Figure 2.7), where the integrity of the frame depended on a new kind of iron capable of extraordinary tensile strength. Under this canopy of iron, two Boulton & Watt engines powered two forge hammers for anchors, a drilling and boring machine, and a lathe, as well as blowing forty-two fires. In 1815, a further Boulton & Watt was introduced as a second forge engine.[404] In 1818, in the model of the *chinoiserie* iron bridges that decorated Catherine's imperial garden, Tsarskoe Selo, from 1788,[405] the Woolwich forge was used to remake John Nash's Pagoda Bridge, St James's Park, in iron.[406]

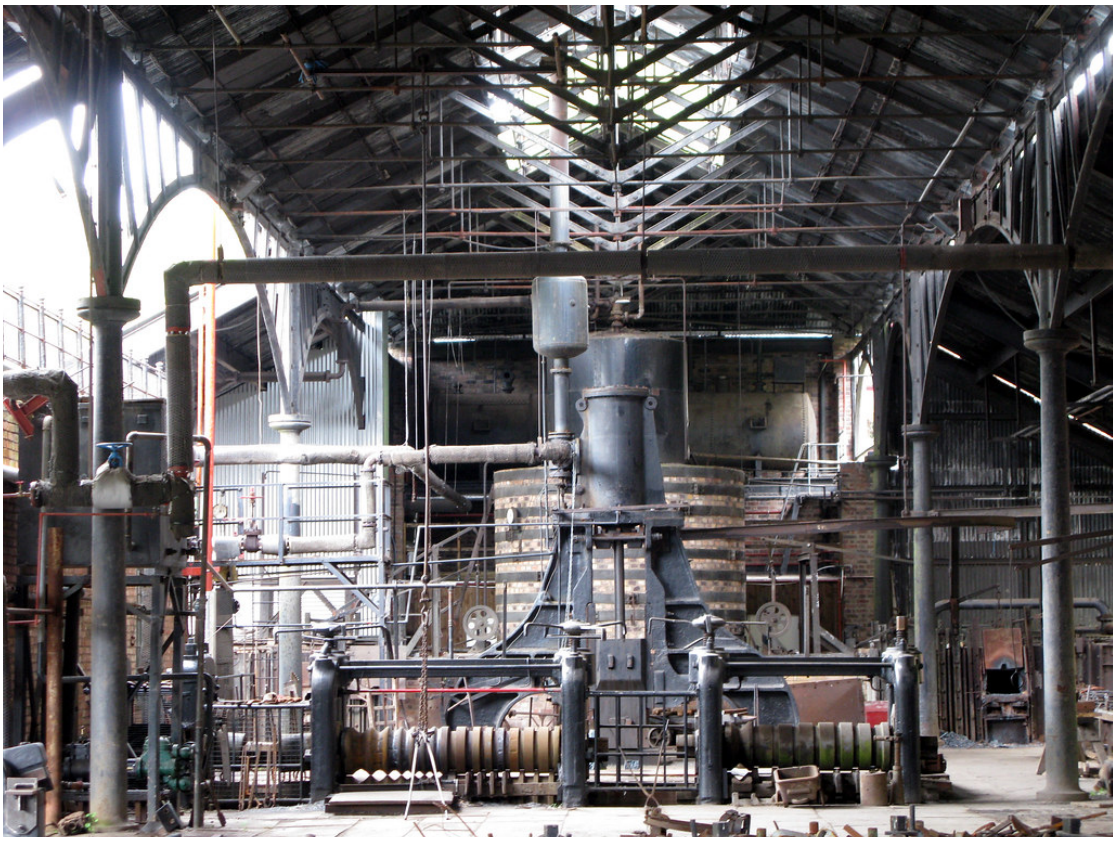

Figure 2.7a: Woolwich's 1814 iron framed building, extant at the Blists Hill site of the Ironbridge Gorge Museum in Shropshire where it now houses James Nasmyth's monumental steam hammer.

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[403] Guillery,2012,pp.150-7.
[404] Guillery,2012,p.99.
[405] James,1987,p.157.
[406] Guillery,2012,p.99.

Figure 2.7b: The 1814 iron frame in its original Woolwich setting. The frame was taken down in 1973-4 and re-erected at the Blists Hill site of the Ironbridge Gorge Museum, as shown in **Figure 2.7a**

Despite no longer invigilating in person following his retirement in 1807, still Hutton maintained incorporeal oversight by continuing to control the editorship of the *Course.* Then already on its fifth edition, each new imprint was revised and updated with Woolwich data and Woolwich experiments as new iron and new machines were built into the rapidly expanding site. By 1811, it was on its sixth British edition and with this latest revision Hutton introduced a third volume. While the title page still only credited Hutton, a review from the year of publication attributed seven of the fourteen chapters to Gregory. In particular chapter eleven, 'on the maximum effects of machines in motion,' was 'obviously Dr Gregory's', it was so clearly derived from his 1806 *Treatise of Mechanics*,[407] a natural history of machines that drew on Gregory's interviews with steam-engine builders,[408] and which described the engines in Maudslay's workshop.[409] The review attributed the 'Promiscuous Exercises' of Volume III to Hutton, but Problem 40, 'To ascertain the Strength of Various Substances', was straight Gregory, carried over directly from proposition 190 of his 'Strength and Stress of Materials' chapter in *Mechanics*.[410] In 1812, the new Volume III, with tables of data on Woolwich ironwork and Gregory's natural history of machines, was incorporated into a second New York edition of the *Course* for use at West Point. Five years later the West Point brickworks became an iron foundry.[411] In 1815, Gregory's *Mechanics* was updated to carry technical accounts of Bentham's Portsmouth machinery, and the mechanisation of Woolwich, crediting Bentham.[412] In 1821, the updated *Mechanics* was added to the West Point course list.[413]

That year Hutton's friends commissioned a commemorative marble bust of their mathematical patron. Prominent among the disciples was Britain's Lord Chancellor, 1st Earl of Eldon, who had learnt his bookkeeping from Hutton back in Newcastle. Hutton was so delighted with the result that he 'immediately' gave directions for a die to be cut and a medal struck off for every subscriber, his profile on the obverse and, on the reverse, the emblems of his 'philosophical works': ballistics and the density of the earth. The medals were delivered on 27 January 1823, the day of his death.[414] That year two obituaries of Hutton were produced in dialogue with one another. One, by John Bruce, Vice President of the Newcastle Schoolmasters Association and committee member of the Newcastle Literary and

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[407] Review,1811,pp.964-5.
[408] Gregory,1809,pp.207-8.
[409] Gregory,1806b,p.474.
[410] Gregory,1806a,p.121; Hutton,1811,p.345.
[411] Scarlett,Rahn&Scott,2006,pp.28-46.
[412] Gregory,1815b,pp.129-31,p.350.
[413] Rickey&Shell-Gellasch,2010c.
[414] Gregory,1823,pp.223-4.

Philosophical Society; the other by Gregory. Bruce's account transformed the relative affluence of an estate-manager's household into humble origins and religious awakening as pit boy and the son of a Newcastle collier.[415] In precisely the moment that the Newcastle society figure composed his eulogy, the coal extraction industry was mobilised to fight for its case over and against the well-established waterpower.[416] Coal would cost industrialists more than water for the same power output well into the 1870s. Further, the giant waterwheels of the 1820s out-performed the most powerful steam engines of the day. Even in the mid-1840s, the largest and most powerful engines then in existence only just exceeded the average maximum of waterwheels in general use.[417] Yet for all the comparatively greater cost and lesser power of coal-fuelled steam, after the 1830s waterpower was widely regarded as obsolete.[418] Where coal was preferred, it was not for reasons of physical power or economy but for social control, to optimise labour extraction.[419] This steam proselytism was of a piece with Gregory's ardent support for the anti-enslavement campaign. The labour extraction achieved under steam and the financial bonds that had long linked plantation production with machine-building and metal extraction industries would enable all three to profit on abolition.[420] This was the position from which Bruce and Gregory harnessed their respective accounts, uniting Newcastle coal and practical mathematics in the scientific evangelism of steam cosmology.[421] In this battle over power, the Academy's publications on Woolwich engines, and Gregory's in particular, provided force.[422]

Conclusion

The great cyclopean engines of Woolwich were Bentham's principle at work, generalized in the iron theatre of late-Georgian architecture. In his analysis in *Surveiller et Punir*, Michel Foucault used this Benthamite panopticon philosophy together with prison and factory architecture to describe the apparatus of institutional discipline, where *surveiller* 'makes the individual'. Oversight not only constructs those under observation, but also the guard himself. For Foucault, 'by this very fact, the external power may throw off its physical weight; it tends to the non-corporeal'; and through the fetish of power 'establish[es] a direct proportion between 'surplus power' and 'surplus production'.[423]Foucault's analysis was

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415 Bruce,1823,pp.5-6.
416 Malm,2014, pp.55-77.
417 Malm,2016a,pp.91-3.
418 Malm,2014,p.56.
419 Malm,2016a,pp.121-193.
420 James,2001,pp.41-4; Williams,1944,pp.98-106.
421 Bruce,1823; Gregory,1823,pp.201-227
422 Gregory,1806b,pp.190-4
423 Foucault,1991,p170,p.203,p.206.

famously indebted to Marx's exposition of capitalist labour extraction, for which earlier nineteenth-century Britain was the archetype, and specifically its discussion of surplus power, surplus production, and the role of steam in the generation of surplus value. In Volume One of *Capital,* Marx introduced the process by which the products of labour are transformed into commodities as, '[i]n the same way the light from an object is perceived by us not as the subjective excitation of our optic nerve, but as the objective form of something outside the eye itself'. In the tradition of the capitalist cosmology, there exists 'a definite social relation between men, that assumes, in their eyes, the fantastic form of a relation between things.' From this Marx insists we must 'have recourse' not to the illusion of the fetish, but rather the power relations themselves, not commodities but 'their guardians'.[424] The English translation of the verb loses the sense of the original German '*umsehn*',[425] better retained in the French version *'tourner nos regards*'.[426] *Umsehn* and *regard* make eloquent the coherence of Marx's visionary analysis of the production of commodities with the fetish at work in the sight of Bentham's 'eye',[427] the totality of the textual overview,[428] the 'cyclopean engine', and the '*regard'* that carries Foucault's characterisation of the panoptic gaze of institutional discipline.[429] The significance here is in the specifics of the links.

Foucault quoted the eighteenth century *avocat-general* Joseph Michel Antoine Servan, writing in 1767:

> a stupid despot may constrain his slaves with iron chains; but a true politician binds them even more strongly by the chain of their own ideas; it is a stable point of reason that he secures the end of the chain; this link is all the stronger in that we not know of what it is made and we believe it to be our own work; despair and time eat away the bonds of iron and steel, but they are powerless against the habitual union of ideas, they can only tighten it still more; and on the soft fibres of the brain is founded the unshakable base of the soundest of Empires.[430]

The endless cycle of remanufacture in the ferrous culture of the Caribbean, saw black skill render scrap into valuable metal. This was an unwearying iron. In 1765, in the same years as Servan wrote down his ideation of iron, Antiguan enslaver Samuel Martin's *Essay upon Plantership,* originally printed for and in the British West Indies, was republished for sale in

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[424] Marx,1954,p.77,p.88.
[425] Marx,1872a,p.62.
[426] Marx,1872b,p.34.
[427] Ashworth,1998,p.67, p.72.
[428] Picon,1992,pp.143-4
[429] Foucault,1975.
[430] Foucault,1991, pp.102-3.

London. In this as in the earlier Caribbean editions, Martin looked out on the endless cycle of bodies and ironwork and envisioned the perfect plantation as 'a well-constructed machine', frictionless.[431] Chapter one introduced Ralph Walker, the Jamaican enslaver and machine designer whose boundary instrument was taken up by the Admiralty as the reference compass. Due to the proficiency restriction on his compass described in chapter one, Walker spent much time in Portsmouth docks at precisely the point Bentham began his tenure as inspector in 1796. By February that year, Walker was already paying new attention to the 'deviation' of the compass in the proximity of iron.[432] In April he proposed a 'strikingly innovative' design for the rebuilding of West India docks, to be made of iron, with iron floors and iron arches in a perimeter wall eighteen foot high. On the strength of the proposal, his fellow West India merchants appointed him engineer, so that in the same moment as the head of Woolwich Academy consulted with Bentham over how to build autodidact discipline into architecture, Bentham's Portsmouth colleague began to rebuild the metropole in the disciplinary material of its colonies.[433] From Jamaica to Woolwich, Martinique to Paris and the dockyard to the textbook, disciples of the capitalist cosmology saw this unwearying iron, dreamed of Servan's chains that would not break, and built machines.

On his retirement in 1838, the then First Professor of Mathematics at Woolwich, Olinthus Gregory, noted to the Master-General of the Ordnance:

> More than nine-tenths of the Officers of the Royal Artillery and of the Royal engineers whose names now stand in the Ordnance Department of the Army List have been under my actual instruction in the Mathematical Sciences and their practical applications…[434]

The significance of such an assertion for the administration and practice of the physical sciences in 1830s Britain, its army and its navies, both merchant and marine, and its colonial outposts, is hard to overstate.[435] Within a year Gregory's note might have legitimately claimed that more than nine-tenths of those now charged with the administration and practice of British science, imperial rule, and industry standards, were trained by the Woolwich school. Historians have attended to the British-led magnetic campaign as an exemplary episode in the emergence of modern science,[436] an analytical way of knowing, born in the wake of the French Revolution, that saw the machinery of the military state mobilised in the systematic extension of discipline and quantification on an unprecedented

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[431] Martin,1765,p.2,p.36.
[432] May,1987,p.161.
[433] Hobhouse,1994,pp.248-68.
[434] Gregory:Vivian,[15/3/1838],**Sandhurst**/WO/150/19/13.
[435] Miller,1986,pp.107-34; Gooding,1989,pp.183-223
[436] Cawood,1979,p.493.

scale.[437] Within Britain, this way of knowing has been identified with the rise of a new dominant class of practitioners, significantly made up of servicemen, and the mathematics professors of the Royal Military Academy at Woolwich who disciplined them.[438] Alongside and integrated with the study of terrestrial magnetism, pendulum studies have been identified as pivotal to the development of the physics which emerged in Britain in this period.[439] As such, it is worth noting that for Woolwich initiates, their first and formative close encounter with a pendulum was neither geodesic nor horological but theatrical and ballistic. Pendulums in Woolwich culture disciplined the marching body,[440] and were themselves proxy bodies for trials of gunnery. Together with the research materials introduced into Woolwich, the military seminary's own original research tradition was that of ballistics. In this tradition, a pendulum bob, made of iron or wood, was taken as a proxy for the *corps*: both as the individual human body and the collective military unit. The fracture and fibres of this wooden or iron pendulum bob were then scrutinised to understand the penetration and force of the gunshot into the *corps*.[441] Wood, metal and bodies were defined in breaking. The tradition of the scientific servicemen who would dominate geodetic and magnetic research, zealously swinging pendulums throughout the furthest reaches of the empire, was defined by a material concept of discipline and violence.

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[437] Kuhn,1976,pp.27-31; Cunningham,1988,pp.385-9; Cunningham&Williams,1993,pp.417-29.
[438] Miller,1986,107-34; Gooding,1989,183-223.
[439] Miller,1986,pp.119-127.
[440] Werrett,2015,p.90.
[441] Johnson,1989b,p.217.

Chapter three: The physics of twist, 'what a field for buying power'!

Figure 3.1: 'The Sunday Stone', OUMNH-PAL-T.00152, Oxford University Museum of Natural History.

> the black and white marks being observed… were found accurately to correspond with the entries therein; namely, small streaks, alternately black and white, represented a week; for during the day the men were working, and during the night, they were at rest. Then came a white layer as large as a black and white one put together. This was Sunday – during which there being no work, the water was clean for forty-eight hours. By the by there appeared a forty-eight hour mark in the middle of one week. The books tell the tale: this was the day when a cock fight took place…

Buckland, Francis, 1853, 'Oxford Fossils' in Dickens (ed), *Household Words*, Saturday, October 29, 188, 193-216, 209-10, p.210.

In 1637, the French philosopher and Dutch-army mercenary René Descartes composed from his Netherlands residence a metaphysical metaphor that would come to frame the agenda of modern philosophy and physical science. He invited his reader to 'Take, for example, this piece of wax', so fresh it still possesses 'the sweetness of the honey' and 'the odour of the flowers'. Admiring this body, its colour, figure, and size, place the wax near the fire and observe how the taste exhales, the smell evaporates, the colour changes, and its figure is destroyed. Everything about it has changed, and yet it is still wax. One might, Descartes went on, take from this that 'the wax is known by the act of sight, and not by the intuition of the mind alone were it not for the analogous instance of human beings passing on in the street below…'

> I do not fail to say that I see the men themselves, just as I say that I see the wax; and yet what do I see from the window beyond hats and cloaks that might cover artificial machines, whose motions might be determined by springs?

Judgment alone tells him these mechanical visions are but men. This knowledge cannot come through the senses, argued Descartes, and on this premise set out the founding act of dualism that fundamentally separated human reasoning from the organizing principles of matter.[442] Sensory experience was to be expelled from the reality physics pretended to describe, and, having bounded this physical world, so too were all authorities but reason.[443] Two centuries on, museums had become the bastions of claims to rational, ordered and authoritative knowledge of the world. As such it is significant that, in 1853, prominent attractions of the Clarendon Museum in Oxford included 'a huge sack of fossil cement' imprinted with a cast of the back of the enslaved Roman who last carried it, and the red bones of a woman from an ancient grave whose stain was thought to have been acquired in life from selling 'ruddle' for a living.[444] These were artefacts of the mid-nineteenth century fascination with man's stamp on nature,[445] as if Descartes's deformed and odourless lump of wax were itself on display.

Among these exhibits, under a glass case, was a calcareous deposit, taken from one of the drainage pipes that received the boiling waters off the steam engines of a Tyneside colliery, gifted by a T.W. Biggs Esq. to William Buckland, the famous geologist and canon, and from Buckland to the Clarendon (Figure 3.1). It was striped alternately black and white, Buckland noted, because, as the colliers worked, coal dust turned the hard water black and with it the chalky deposition in the pipes. When work stopped, water ran chalk without coal, and the deposition formed white. That year Francis Trevelyan Buckland, Household Cavalry surgeon, and William Buckland's son, contributed an article on the abovementioned 'Oxford Fossils' to Charles Dickens's publication *Household Words*. In this he observed the comparison of the layers in the stone against the clerk's daybook reported by the Clarendon (Figure 3.1). The striations revealed the raw material of the natural world transformed by the organisation of labour and, as on the day that a cock fight broke the factory rhythm, its subversion.[446] These stones and bones attracted mid-nineteenth century audiences precisely because they read and understood them simultaneously as natural forms and reports of powerful systems of labour extraction. Two centuries on, the Cartesian division was assumed, but its significance was situated, as it had been for Descartes's intended readers.

Since antiquity, philosophy had attended to and exploited the malleability of wax, while the place of wax in the intellectual hierarchy of philosophical materials was further sustained by its role in sealing documents. But by the time Descartes wrote from the home of the *Vereenigde Oostindische Compagnie*, the sealing wax on his desk had ceased to be wax. Where medieval European seals had been made of beeswax and larch resin, contact with the Asian

[442] Descartes,1912,pp.90-3.
[443] Toulmin,1992; Dear,2006.
[444] Buckland,1853,p.209.
[445] Bulstrode,2016,pp.1-25.
[446] Thompson,1967,p.56-97.

market, early in the sixteenth century, introduced shellac, the resinous secretion of the female lac beetle, in its place. With a little turpentine, imported lac could be restored to its fresh plastic state. Far from smelling of flowers, it was used by industries both to block stain and odour. When Descartes narrated deforming the wax and rendering it odourless, he performed what the *Vereenigde Oostindische Compagnie* had already done. His argument to know the world through the mind was an argument to know the world as the product of trade. In the same year as he composed this wax argument, Descartes published an account of a machine he had designed that promised to make lenses without hands: a self-regulating lathe. His two-decade-old concern to attain a hyperbolic lens had, for the last eight years, been dominated by the conviction that the prohibitive labour of grinding such a lens would only be overcome by automation.[447] His mechanical visions of men as automata in hats and cloaks with their motions determined by springs, was the world he sought to create.[448] His metaphor was a method to make it happen, not a description of the world but a means to an end: rule by reason alone and see the dense tangle of human activity in the street woven in mechanical terms.

This chapter is concerned with such metaphors and machines for the development of electromagnetic research in Woolwich, and its legacy in the early articulations of field theory; a development indebted to a central concept of 'twist'. Unlike silk, made from long continuous fibres, cotton thread was composed of short links. To create thread from cotton wool, the wool ball had first to be dressed, and then divided by carding into short lengths laid parallel by the rollers of the drawing frame (Figure 3.2), which performed mechanically the action of the finger and thumb. These parallel lengths were then twisted together under tension to form a chain, where the short twisted links conferred the strength, elasticity, and cohesion to be woven. Even the finest single thread of cotton was a mechanical assemblage of these fibre springs, and the carding and spinning industry were devoted to producing this mechanical assemblage, because, in its strength, elasticity and cohesion, twist was the indispensible basis of the cotton weaving industry. To understand the significance of twist for Woolwich electromagnetism this chapter begins, as Descartes did, with the East Indies trade and mechanization, and develops, as the Sunday stone did, with the manifestations of the steam cosmology.

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[447] Burnett,2005.
[448] Schaffer,2009b,p.167.

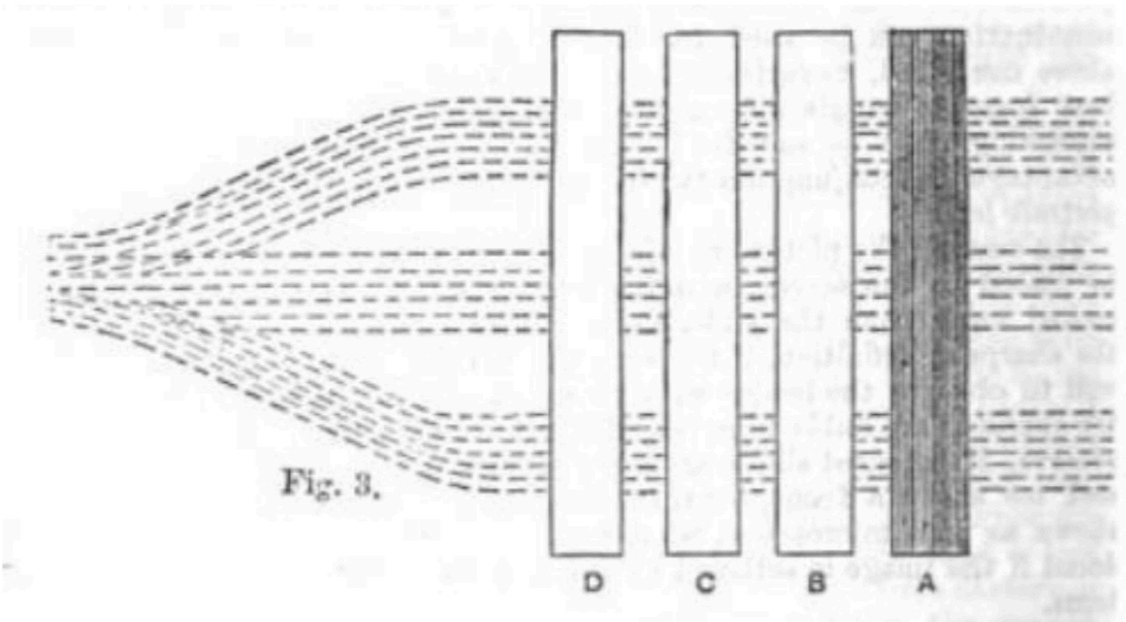

Figure 3.2: Diagram of a drawing frame, showing the short staple lengths of cotton being drawn through rollers in preparation for spinning. Robertson, J., 1844, Cotton-spinning-III: Combing machine-Drawing-frame, *The technical educator, an encyclopaedia*, Vol. III, London: Cassell & Company Ltd., pp.335-336. Fig.3.

§1: man or machine and the fetish in the tweyne

> Mrs Mann raised her hands in astonishment; but added, after a moment's reflection, "how comes he to have any name at all, then?"
> The beadle drew himself up with great pride, and said, "I inwented it."
> "You, Mr. Bumble!"
> "I, Mrs. Mann, We name our foundlings in alphabetical order. The last was a S, - Swubble, I named him. This was a T, - Twist I named *him*..."
>
> *The Adventures of Oliver Twist,* 1837

Through the early modern period, India had dominated the world's market of cotton textiles. During the eighteenth century, British manufacturers, in particular those engaged in the highly mechanised art of calico printing, deconstructed the Indian hand-loom and spinning wheel to flood the European market with cheap machine-spun twist. By the end of the Napoleonic wars, machine spinning in Britain could outcompete the finest Indian twist within its own domestic market,[449] so that British manufactures 'inundated the very mother country of cotton with cottons'.[450] The substitution of Indian spun cotton by British twist took place under significant protections.[451] Indeed, for over a century, between 1666 and 1774, cotton twist had been the focus of intense, centralised legislation throughout Europe, prompted by the threat of Asian textile imports. This legislation would prove crucial to shaping the

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[449] Broadberry&Gupta,2009,p.279,p.285; Chapman&Chassagne,1981,pp.37-40.
[450] Marx,1853b.
[451] Berg,2004,pp.99-104; Ashworth,2017,pp.165-8.

subsequent development of the textile industry.[452] Through the eighteenth century, in keeping with technological developments in Britain, the focus of such protections shifted first from imports of goods, to the export of artisans, and then again, to machines. Two acts, passed in 1719 and 1750, prohibited the emigration of skilled artisans from leaving Britain; while, between 1750 and 1785, a number of restrictions were enacted against the export of machinery. The initial legislation on artisan freedom focused on restricting the movement of textiles workers. By contrast, the subsequent restrictions prohibited the export of tools and machinery used in the cotton, woollen, and silk textile industries, as well as the tools used in the manufacture of iron and steel. Of the latter restrictions, those referring to textiles machinery were set out in far greater detail than any other manufacturing equipment.[453] Textile machinery then provided the pattern for other machines,[454] as textiles and engineering industries developed through close integration of innovations.[455]

In late-eighteenth and earlier nineteenth century Britain, labour generally employed in the manufacture of consumer goods was significantly transferred to the manufacture of machines: producers' goods to be sold to commodity manufacturers in Britain and overseas. By the 1820s, this shift had given rise to a ferocious policy debate. If the means of production were human, it was argued, the movement of skilled machine builders must be restricted, as they had been since the 1719 and 1750 acts. If, however, the machine was the basis of manufacture, then to sell and export the machine was to give away the source of British power.[456] The question of whether the locus of skill and ingenious innovation resided in the artisan or the machine, not only challenged the nature of man and machine, but also of property, specifically what historians have called 'the property of skill', whereby a worker recognises his craft in its final form, even when alienated by the exchange.[457] The ferocity was further amplified by significant coverage in the popular press.[458]

As mentioned in chapter one, Charles Dickens began his career as a journalist in the 1820s, as machine export polemics reached breaking point, submitting material for Thomas Hansard's official report of all parliamentary debates and to Whig paper *The Times*. Bitter recollection of eighteenth-century tensions over twist was explicit in such debates, as it was in the minutes of the 1824 Select Committee that reviewed the prohibitions on the export of artisans and

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452 O'Brien,Griffiths&Hunt,1991,395-423.
453 Jeremy,1977,p.2; Berg,1982,p.205.
454 Parliament,1841b,p.4.
455 Berg,1982,p.218.
456 Berg,1982,pp.203-225.
457 Rule,1985,p.22; Rule,1987,p.107.
458 Berg,1982,p.42.

machinery and led to the repeal of restrictions on artisan movements. Indeed, twist was still the central tension in 1841, when a second Select Committee saw the restrictions on machine exports lifted.[459] For Dickens, reporting on this intensity of feeling became a resource not only for creative composition but also the regulatory battles of his own profession. The etymology of 'text' is fibrous, from the Medieval Latin *textus*, a 'tissue of a literary work': literally 'that which is woven, web, texture' and the participial stem of *texĕre,* to weave. The link was material. Dickens and his contemporaries drew directly on debates over the classification of machinery and the ownership of mechanical invention to articulate attacks against new forms of intellectual property. In particular, they fought against publishers' treatment of the serialised novel as a mechanical product, defined by the division of its production: the mechanism and not the labour of the author expended therein.[460] In this complex and tense debate on the relation between man, machine, and means of production, precedent was crucial and the precedent of choice, in Parliament and in the press, was cotton twist.[461]

In August 1834, Dickens was relieved from his precarious freelance work by appointment to the reporting staff of *The Morning Chronicle*, the principal platform of the machine export debates.[462] Here, he rapidly developed a reputation as the paper's foremost special correspondent with a particular emphasis on politics. Yet, in the same year as his appointment, and the relief that represented, he found himself thrown into intellectual property disputes, his work pirated and reproduced without permission. His very first story, 'A Dinner at Poplar Walk', only published in December 1833, he discovered in 1834 stolen and reproduced in a magazine named *Thief*.[463] In the textiles industry, when queries arose as to the legality of an export, legal interpretation followed whether its action corresponded to the 'dressing', in which case the machine might be exempt from the prohibition on the export of machinery, or whether it divided the substance. '[A]ny machine which once takes the very first movement to the dividing of this substance', the basis of twist, 'the prohibition has been strictly enforced, and no license ever given.'[464] The serialisation of a text, 'that which is woven, web, texture,' was mechanical division, and as Dickens found to his cost in 1834, serials made 'the tissue of a literary work', vulnerable to theft.

[459] Berg,1982,p.205.
[460] Pettitt,2004,pp.36-83.
[461] Berg,1982,pp.207,p.212,p.219.
[462] Berg,1982,pp.207,p.212,p.219.
[463] Pettitt,2004,p.81,ft.186.
[464] Parliament,1841b,p.4.

In autumn 1836, Dickens's sketches began to take off in popularity, and by October he felt sufficiently confident of living on the proceeds that he resigned his post at *The Morning Chronicle*. The following year he fought for a new copyright agreement with his publisher and revised his *Pickwick Papers*. The new edition was to be dedicated to law-maker and politician Thomas Noon Talfourd for his work on copyright reform: 'inestimable services… to the literature of the country'. In the midst of this, in 1837, Dickens published his latest serial, *The Adventures of Oliver Twist*. In the famous novel, an orphan, named 'Twist' by the overseers of the factory workhouse where he was born, was set to work picking oakum, the tortuous and punishing labour of unwinding old ships' rope. After a notorious porridge incident, it was decided he should be exported, 'shipp[ed] off… in some small trading vessel bound to a good unhealthy port'. A value of five pounds was placed on his life, to be awarded to anyone who would take him, so that, like his material namesake, he might be exported and sold for less than it cost to make him. Before this could happen, however, the workhouse beadle, Mr Bumble, 'drew Oliver along' and sold him to a man with 'in a suit of threadbare black,' 'dark cotton stockings' and an 'elastic' step.[465] When Oliver ran away, picked up by thieves, just as Dickens's first story was pirated by the *Thief*, he existed on a knife-edge of illegality until his long-since alienated kin, scrutinising him closely to assess whether he had a nature that belonged to criminals, recognised him as their own: the property of skill in manufacture.[466] *Morning Chronicle* reportage and the intellectual property battles that dogged his literary career were far from Dickens's only sources, nonetheless they are a reminder of what was salient. 'Oliver Twist' was both boy and mechanical assemblage of springs. The tension of the narrative lay in whether Oliver or Twist would be found to be his true nature. Two centuries on, Descartes's mechanical vision was realised. In considering the means of production and the property of skill, it was no longer clear whether one looked at man or machine.[467]

§2: the staple of production

> By his perfect finery the worst pig iron is made bar of the most valuable kind, and fit for every purpose… it breaks most tough & fibrous. You will understand the value of this discovery; the land of coal and iron stone will be the land of bar iron, what a field for buying power at your shop! I think you say that the slit mill gave origin to the cotton mill, now the cotton mill may give a lesson to its parent and learn Britain to spin iron for all the World.[468]
>
> James Hutton to Matthew Boulton, 24 May 1784

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[465] Dickens,1866,p.23
[466] Rule,1985p.22; Rule,1987,p.107.
[467] Schaffer,2009b,p.167.
[468] Hutton:Boulton,[24/05/1784],**BL**/MFM/Mic.A.19787/172/306.

Figure 3.3: 'No.4: A portion of a bar of Fibrous Iron which was placed on the top of a Tilt hammer working at the rate of 355 strikes per minute & which after being exposed to this species of concussion for 24 hours at last broke off quite short like a piece of glass' c.1840, WHITMSC0178, Whitby Museum.

Chapter two described the production of a new kind of iron, the iron of the epigraph to this section: fibrous, elastic and with an extraordinary tensile strength, rapidly incorporated into the workshops of London's cutting-edge machine builders and above all, Woolwich. London-based free traders, fighting for repeal of the prohibition on machine exports, used observations on this revolution in machine-making, and in particular metal-cutting tools, to claim that the locus of skill and innovation resided in the machine and not the mechanic. By contrast machine-manufacturers from Manchester, where the division of labour had reached unprecedented levels, argued that machine construction was impossible without a whole suite of ingenious artisans specialised in different processes.[469] Such debates prompted a peculiar self-reflexive awareness among manufacturers as to the mechanism of growth in machine and machine-tool manufacture.[470] Just as the dependence of machine-building industry on a skilled workforce became explicit and evident, that same dependency became intolerable as the principle obstacle to cost reduction. Debates that had, since seventeenth

[469] Jeremy,1977,p.21.
[470] Parliament,1824; Parliament,1841b.

century, focused on protecting the means of production in textile industry, paid increasing attention to the place of British iron; and the constant innovation that characterised machine-building, in maintaining leadership of the international machine-building trade.[471] Of the 1824 Select Committee findings, two are particularly central here. First, that artisan movement was necessary for machine export, continued regardless of restrictions, and might be better regulated if legalized.[472] Second, that French machine building, the principal concern of the inquiry, relied absolutely on the peculiar qualities of the new English iron.[473]

Henry Maudslay's extraordinary innovations that saw Woolwich rebuilt in cutting-edge iron machinery only became possible with the changing tolerances of the new metal.[474] His iron machines and workshop drew pilgrims from all over the world. Among them, the *polytechnicien* Pierre Charles François Dupin, in Britain in 1816 on the first of five tours to observe the 'mechanical and geometric processes employed for raw material to become an industrial product'.[475] Dupin was explicit: he went to Maudslay's for the metal.[476] From Maudslay's Southwark workshop, Dupin went straight to the establishments of East India Company hydrographer, Joseph Huddart; and former Naval Captain, Samuel Brown, both makers of ships' cordage. The analysis of British cordage was a particular preoccupation for the *polytechnicien*, who used the 'beautiful results' of his civil engineering predecessor, Henri-Louis Duhamel du Monceau, to compare the strength of ropes differently spun, twisted and sealed.[477] Duhamel's treatment of ropemaking, published first as *Traité de la fabrique des manœuvres pour les vaisseaux, ou l'art de la corderie perfectionné* in 1747, led directly to the realisation of the Académie Royale's long overdue *Descriptions des arts et métiers*.[478] Since his successful overhaul of rope manufacture in Marseilles and Brest, Duhamel's work on cordage had been an archetype of the rationalisation of labour. As his title indicated, Duhamel proposed to control the movement of ships through controlling the production of rope. In Huddart's works, Dupin was struck by how the rope was twisted and sealed by the action of steam. It was Brown's works, however, which particularly preoccupied the *polytechnicien*. Here, the cables were made from iron, '*d'une extrême légèreté et d'une grande économie*'. A central concern of Duhamel's work was the *dépérir* or rotting of hemp and timber. Dupin saw the chains in the same organic terms, Brown's iron chains' greatest advantage being that

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[471] Parliament,1824,p.33,pp.112-3; Babbage in Barlow,1836,pp.77-82.
[472] Parliament,1824,p.23.
[473] Parliament,1824,pp.112-3.
[474] Cooper,1984,p.197; Thom,2010,p.55.
[475] Dupin,1816, in Bradley&Perrin,1991,p.50.
[476] Dupin,1818,p.13.
[477] Dupin,1818,pp.329-333.
[478] Gillispie,1980,p.340.

when the iron rotted (*dépérir*), individual links could be replaced.[479] Chapter two described the remanufacture of scrap that produced a kind of inexhaustible unwearying iron that was the materialisation of Servan's conceptual chains. In Brown's words, his chains 'may be rendered almost imperishable… for every bolt [rod] may be taken out and renewed.'[480]

From his first patent in 1808, Brown sustained a telling preoccupation in the development of his iron cables: namely that elasticity was conferred by the twist. Even in the face of contrary evidence, Brown was convinced that the performance of chain cables, which he specified 'to be made of short twisted links', depended on this twisting.[481] In 1812, the Admiralty had begun to systematically substitute its hemp cordage with Brown's chain.[482] Iron begat iron as the cables, deployed in the same ways their hemp counterpart had once been, destroyed wooden fixtures, which in turn were first armoured and then ultimately replaced by new designs in iron.[483] Between Brown's, Maudslay's, and Woolwich works, London became a centre of iron into ship-building. By 1816, Brown's method was refined so that rods, called bolts, went straight from the furnace to the rolling mill and then to a mandrel that wound a spiral of iron so that each revolution produced a link of the required length.[484] Using steam, Brown wound iron like cotton onto a spindle. That year a disastrous test performance forced Brown's hand. After nearly a decade of persisting with twisted links, his principal contract, the Admiralty, prohibited any further commission of twisted links for their vessels. His belief in twist had survived the rapid emergence of competition up until then because, since 1812, Brown had thrown himself into finding the best iron. The failure of his twist was balanced with his successful realisation that fibrous iron conferred elasticity better than the form.[485]In 1817, on a second visit to Britain, Dupin was able to fulfill his particular aim of viewing the launch of a British warship. The launch used chain in place of rope and Dupin noted his amazement at the substitution of hemp fibres for iron, 'an innovation as happy as economical.' He was struck, in particular, by the great advancements attained through large-scale comparative experiments on the strength of wrought and unwrought hemp and iron.[486] The experiments to which he referred were a significant collaboration between Peter Barlow and Brown.

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[479] Dupin,1818,pp.13-4.
[480] Brown,1822,p.26.
[481] Lenox,1860,p.161; Turner,2012,p.237,p.241; Harland,2013,p.75.
[482] Harland,2013,p.75.
[483] Harland,2013,p.77.
[484] Turner,2012,p.241.
[485] Lenox,1860,p.161; Turner,2012,p.237,p.241; Harland,2013,p.75.
[486] Dupin,1818,p.53.

§3: the instrument of capital

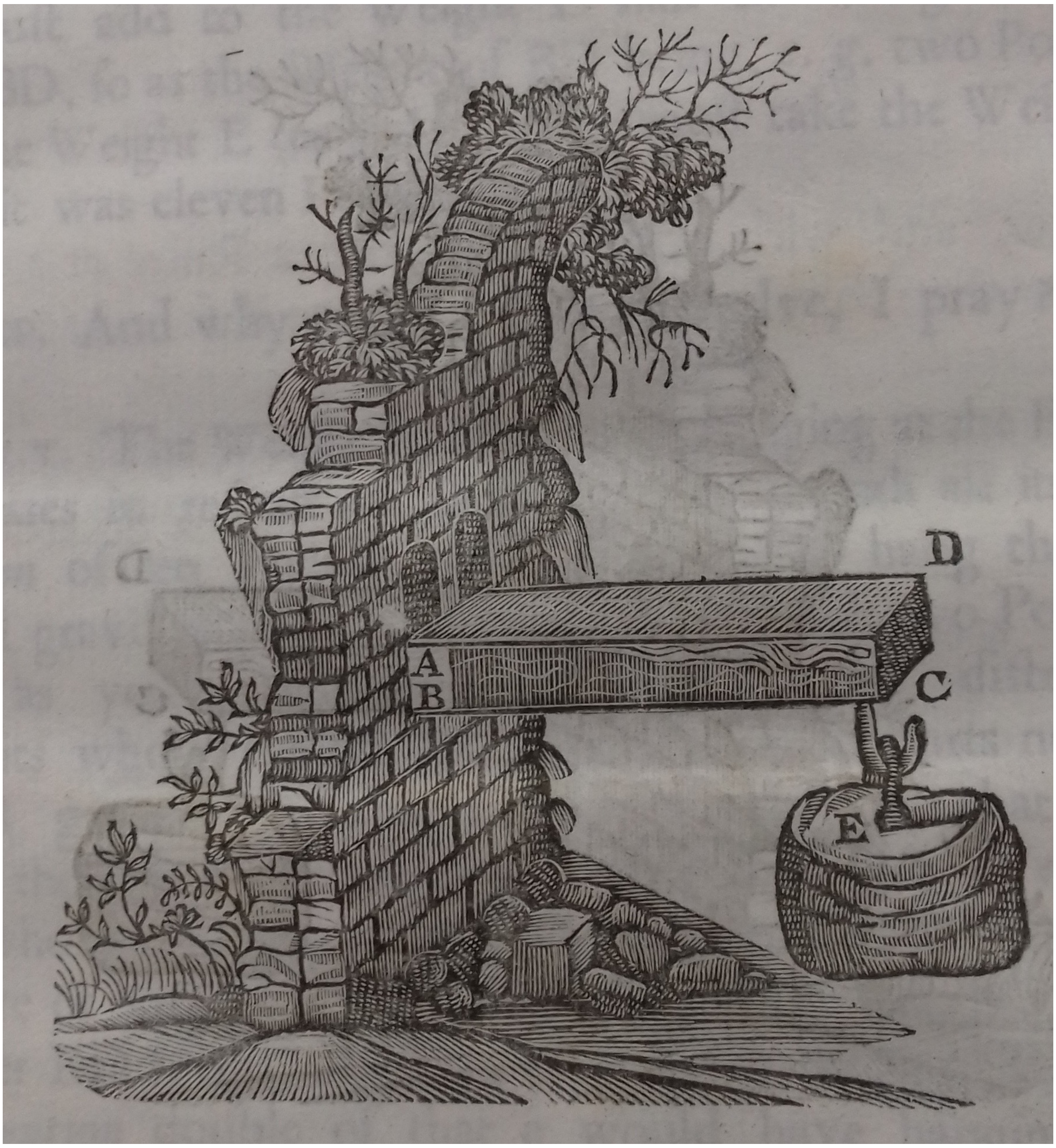

Figure 3.4: Galileo's cantilever model, Galilei, Galileo, 1730, *Mathematical Discourses concerning Two New Sciences relating to Mechanicks and Local Motion… done into English from the Italian by Thomas Weston*, London: J. Hooke, pp.169-70.

In 1814, Woolwich mathematics master Peter Barlow followed his patron Charles Hutton in giving an account of the strength of materials that paraphrased Galileo's introduction to the *Two New Sciences*, where timber was represented as a fibrous material that resisted fracture through the cohesion of fibres against the weight of the body (Figure 3.4).[487] In the lineage of

[487] Galileo,1974; Barlow,1814.

Arsenal engineers, each sought to understand the structural limitations on the size of animals and machines through the interaction of fibres, as these material bodies resisted the principles of scaling. Where Barlow's account departed from Galileo, and from Hutton, was in following seventeenth-century French physicist and priest, Edme Mariotte, who argued that 'fibres are to be considered as so many little bent springs, which never exert their whole force, till stretched to a certain point, and never break till entirely unbent.' As Barlow moved between machines, animals and materials, considering their resistance to scaling, he understood all three as composed of fibres where every fibre was a spring. For Barlow, springs denoted both the motive force of autonomous machines, and the means of quantifying the strength of men or animals. They were not just analogous but mutually constituted. For further information, he referred the reader to the new Volume III of Hutton's *Course*, which, as chapter two described, carried the data of materials tested in Woolwich dockyard and arsenal.[488] Barlow set out these terms in 1814. Within a year he materialised this framing into an extraordinary experimental formulation that saw timber as a kind of machine for measuring force, schematised its behaviour, and then substituted it with iron, as a more perfect illustration of the schema.

In December of 1816, William Mudge, Hutton's former pupil who had surveyed the Woolwich site on behalf of the Ordnance and now held the position of lieutenant-governor of the Royal Military Academy, wrote to the Secretary of the Master General of the Ordnance, to report the faculty's concern at recent research coming out of the École Polytechnique. This research, Mudge noted, had prompted the Woolwich mathematicians to scrutinise the subject with the 'utmost care and attention… we have within the last twelve months devoted much time to the purpose; two of our Mathematical-Masters, Dr. Gregory partially, and Mr Barlow principally, with my superintendence...' The former Ordnance Surveyor noted that while some of the most celebrated mathematicians had written on the strength and stress of timber, none of their work was any use to the civil or military architect. Now recent research at the École Polytechnique looked as though it might be, and necessitated swift action. 'Aware of the singular importance of the subject to the scientific world at large, and to the Ordnance in particular', Mudge argued it was essential this work be published 'at the expense of Government'.[489]

The cause for concern was a paper by Dupin, 'Expériences sur la flexibilité, la force et l'élasticité des bois, avec des application aux constructions en général, et spécialement à la construction des vaisseaux', based on experiments made at the arsenal in Corfu in 1811 while

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488 Barlow,1814,'Automaton';'Dynamometer'.
489 Mudge,1816 in Woolwich,1895,p.75.

the island was in French possession. The paper had been published twice in 1815, first, in abbreviated form within premier mathematics journal *Annales de Mathématiques Pures et Appliquées;*[490] then again in full, with all the tables of data, this time in the *Journal de l' École Polytechnique,* a scientific publication popular with British magazines of industry and arts. It was this second version the Woolwich mathematics masters encountered.[491] Mudge's letter followed Dupin's visit to Woolwich earlier that same year. The *polytechnicien* had come to Woolwich straight from witnessing Brown's chains and Maudslay's works, noting in his journal, '[w]e are winning on the theoretical side' but 'our rivals are winning out in the practical field and in the wisdom of their economy.'[492]

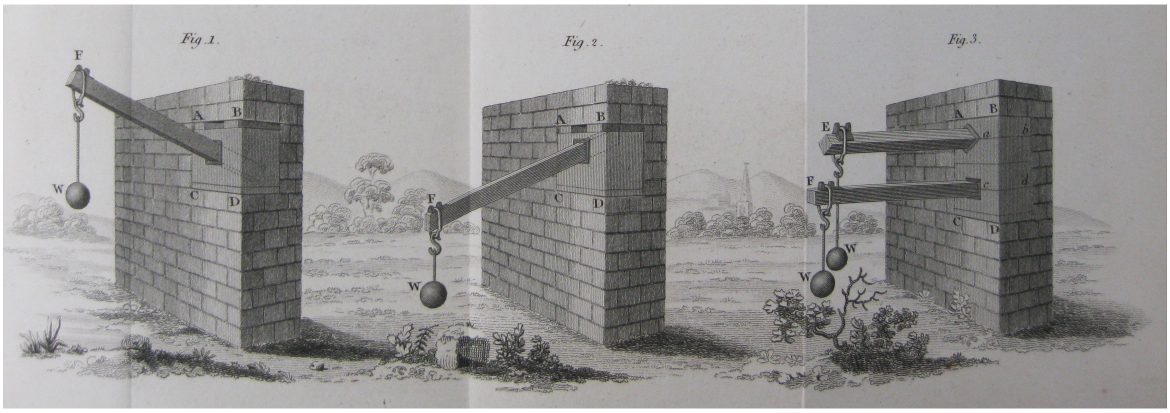

Figure 3.5: (to compare with Figure 3.4) artist's interpretation of the experimental set up, Barlow, Peter, 1817, *An essay on the strength and stress of timber founded upon experiments performed at the Royal Military Academy on specimens selected from the Royal Arsenal and His Majesty's Dockyard, Woolwich... with an appendix on the strength of iron*, London: J. Taylor, Plate 17, Figs 1-3.

On publication Barlow would criticise the artist who illustrated his timber research for the abstracted representation that recalled Galileo's famous cantilever experiment (Figure 3.5), and noted that it was 'proper to inform the reader... that the walls in which the blocks were fixed were not less than 40 feet high, although in the plate they are represented as if they were not above 6 feet[.]' No 40 foot walls were erected for this purpose, when Dupin came to Woolwich he saw the cantilevers of Barlow's timber experiments built into the existing structure of the Academy itself. Where Barlow did consider the artist to have done justice to the experience was in his 'very correct representation' of the timber fracture (Figure 3.6).[493] Since Mariotte's identification of timber fibres as springs, the mathematical characterisation of the strength of materials had been preoccupied with determining the neutral line, where

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[490] Dupin,1814-1815,pp.33-49.
[491] Dupin,1815,pp.137-211.
[492] Dupin,1816 in Bradley&Perrin,1991,p.50.
[493] Barlow,1817,p.158.

fibres were neither compressed nor extended, forming an axis about which movement occurs. For Barlow, 'the principal desideratum for establishing a correct theory' was to identify this neutral axis. However, unlike his celebrated antecedents, Barlow found this line 'unequivocally' in the form of the fracture itself. To characterise timber strength in terms of torsion was no more than a continuation of standard rules Coulomb had established that made an abstract conceptual analogy between the torsion thread and the timber beam. Barlow's work differed from this and almost all those who had gone before, in that his experiments displaced analogy with a direct material relation: he didn't just extend torsion theory to timber, he read timber as if it were a torsion thread, as if it were twist.

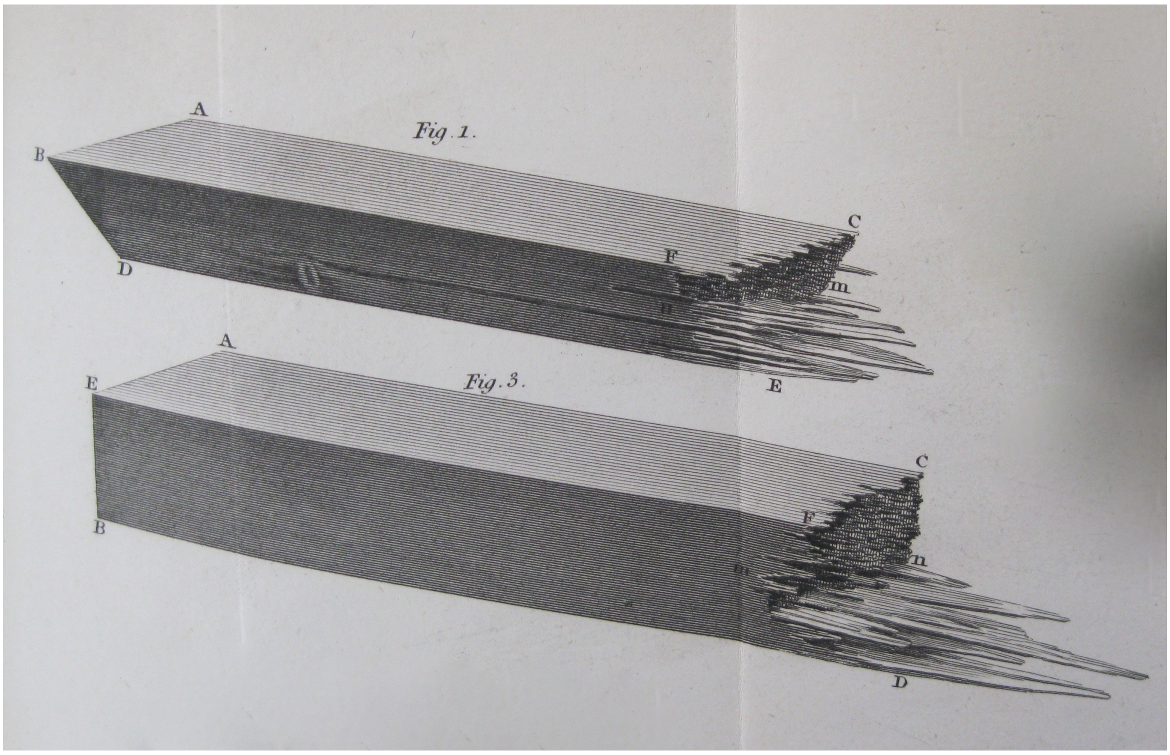

Figure 3.6: timber fracture, Barlow, Peter, 1817, *An essay on the strength and stress of timber*... London: J. Taylor, Plate III, Figs 1 and 3.

Mr Benjamin Couch, 'Timber and Store Receiver', described by the Woolwich mathematician as master mast-maker at Plymouth dockyard, was a principal source of observations and experience for Barlow. Couch himself was undisguised in his contempt toward gentlemen who sought to teach practical men what was already known, 'not only to all respectable dealers in oak timber, but also to woodmen, coopers, farmer's servants, in short to the most illiterate persons in the neighbourhood of Tophill.' His unpublished manuscript, carrying decades of data and detailed observations of timber, was considered so valuable it was purchased by the Botanical Branch of the British Museum alongside '805 specimens of

Woods' in May 1840, the year Couch died, and the acquisition noted in that year's Parliamentary Papers. In it, Couch described his experiments:

> [conducted] by merely keeping his eyes open to certain instruments, and noticing the effects of certain agents upon them; these instruments have been prepared for his observation without any trouble or expense to himself, but which has cost the owners £1000 each. In watching the operation of these instruments duty and pleasure have been blended. The instruments referred to are lower masts; for 15 years, during the war, the writer [has] surveyed in place the lower masts of H.M. Ships that have arrived in the Port of Plymouth[.][494]

For Couch it was not only his extensive experience that assured the significance of his research, it was that his instruments were valuable capital, crucial means in the generation of further capital through war and trade, and that they registered their instrumentation through their progressive destruction in use.

Barlow noted that, '[t]he instruments [of modern mathematical analysis] have been too delicate to operate successfully upon the materials to which they have been applied;'[495] before going on to propose reading the fracture surface of timbers (Figure 3.6) to characterize the distribution of compression and extension to the fibres. Having observed that 'the impression of the fibres were very distinctly marked on the wedges; strongest at the top, and gradually weakening towards the bottom where they could scarcely be distinguished,' he concluded '[t]he most certain index to be found [of the centre of tension] is the *crush*', revealed 'after fracture', when the timber, progressively marked, was finally broken in two.[496] He tested the same piece, over and over, until its destruction, combining the logic of proof by exhaustion with Couch's observation of capital, then schematized the distribution of destruction in diagrams (Figure 3.7).[497]

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[494] Couch,[n.d.],**NHM**/MSS COU/EX174717.
[495] Barlow,1817.p.58.
[496] Barlow,1817,p.164.
[497] Barlow,1817,p.93.

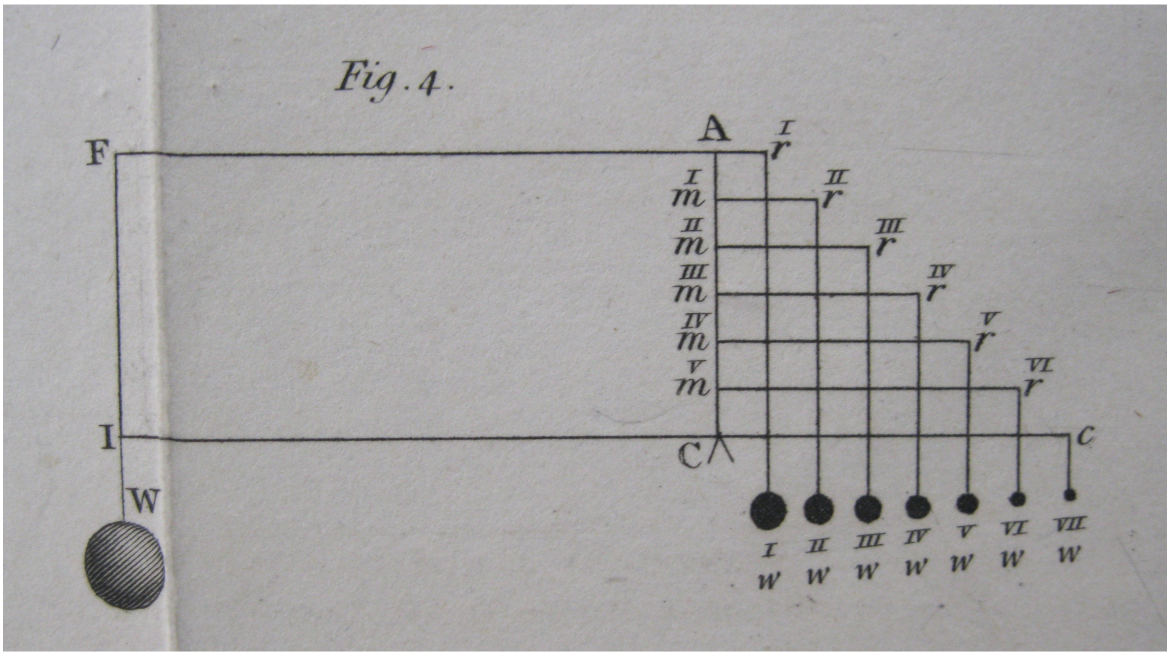

Figure 3.7: schematic of timber fracture, Barlow, Peter, 1817, *An essay on the strength and stress of timber...* London: J. Taylor, Plate I, Fig.4.

Barlow's researches were published in 1817 under the title *Essay on the strength and stress of timber* and carrying a significant appendix: Brown's extensive and unprecedented survey of the quality, property and optimal form of different kinds or origins of iron, published for the first time. Further, the Woolwich mathematician extended his schema to Brown's findings. Brown's iron became the natural progression in a hierarchy of technological development from wood and hemp to iron that Woolwich had long sought to construct in its publications as in its architecture and mechanical innovations. In 1826, Gregory incorporated parts of Barlow's *Essay,* then on its third edition, into a fourth edition of his *Mechanics.* The following year he carried the Barlow material from *Mechanics* into a fourth edition of Volume III of Hutton's *Course,* now on its ninth edition overall. Barlow's work on timber was used to revise and extend Problem 40 of the 'Promiscuous Exercises' of Volume III, and add a whole new section 'on the flexibility, strength and rupture of timber'. The text now carried new material, tables of new data and reports of contemporary experiments from Royal Society fellows, through expert instrument makers, to canal engineers; not only on timber, but also iron and brass.

Reporting on his several tours of the Woolwich dockyards and Academy, Dupin described the faculty of the military seminary as being 'like the Polytechnic school at Paris, although with less *éclat* and extent'.[498] It was a view that would be echoed in decades to come by the late-nineteenth century Cambridge mathematician and historian of mathematics, Isaac

[498] Dupin,1820,p.462

Todhunter, who dismissed the Woolwich mathematicians, saying of Gregory's works, '[n]othing shews more clearly the depth to which English mechanical knowledge had sunk at the commencement of this century';[499] while Barlow was

> another striking example of that want of clear thinking, of scientific accuracy and of knowledge of the work accomplished abroad, which renders the perusal of the English text-books on practical mechanics published in the first half of this century such a dispiriting if not hopeless, task to the historian of theory.[500]

Gregory himself appeared to invite Dupin's and Todhunter's criticism in the three editions of *Mechanics* published prior to Barlow's *Essay*, noting 'no materials whatever accord less with the theory than timber of all kinds'.[501] Yet the work which Todhunter condemned developed with a keen eye to that on the Continent, while its extent made Barlow an international name, and rapidly became an indispensible reference for engineers, with translations into German, Spanish, French, Arabic, Urdu, Marathi, Gujarati, together with many American editions. Over two decades on, British colonial officials still sought sources of wood that conformed, such as Indian 'Saul':

> The general appearance of its fracture beautifully illustrates Mr. Barlow's theory of the axis of motion, or rotation being centrically situated; the upper or compressed fibres being smooth as though cut with a sharp knife; those in a state of tension, so fine and intimately blended, as to resemble those of hemp rope, when violently torn asunder.[502]

Barlow's research claimed to have developed an 'instrument' so robust it could rationalise timber, and further could extend this rationalisation to the characterization of Brown's iron, as a system for knowing all iron. Instruments are reified theorems:[503] rather than a want of ambition or accuracy, the significance of Barlow's instrument was like Descartes's *Method*, in describing the salient ambitions of capital, and in offering a means to make the world it described.

A good example is provided by the Scottish timber merchant John Rae, remembered for his highly influential system to quantitatively measure the future impact of fixed capital. In this system, capital for Rae was made up of men, materials, machines, and processes that he termed 'instruments'. Each instrument could affect the future, but in doing so was subject to 'exhaustion', at the point at which it was transformed into new materials.[504] Educated at

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[499] Todhunter,1886,p.88.
[500] Todhunter,1886,p.105.
[501] Gregory,1806a,p.121; Gregory,1815a,p.124;
[502] Phipps,1840,p.45
[503] Bachelard,1984,p.13.
[504] Berg,1982,p.122.

Edinburgh University, Rae had entered the timber trade in 1820 following the bankruptcy of his father's shipbuilding business. In 1822, he emigrated, and spent the next decade travelling extensively through Upper Canada investigating its economic prospects while British military engineers supervised the construction of the Rideau Canal, applying Barlow's principles to investigate the potential of Canadian timbers. In 1832, he moved again, to Boston, during the unionisation of the Boston Journeymen Bootmakers' Society, notorious because it highlighted the surprising application of English Combination Laws, developed specifically to combat virulent London spinners and weavers' unions,[505] to American labour law.[506] Two years later, the timber merchant published a highly influential classification scheme for capital with a telling quantification of the 'instruments' of capital by 'exhaustion'. For Barlow's contemporaries, his work read like political economy.

§4: the axis of the instrument

> … the timber now imported for Dock Yards and public buildings may be advantageously dispensed with and iron substituted that the Govt. may use advantageously large quantities for floor plates in public buildings, that public rail roads may be formed; and that probably with encouragement foreign markets may be obtained.[507]
>
> Lord Liverpool, 1817

The publication of Barlow's instrument coincided with the announcement of Lord Liverpool's new economic policy, quoted in the epigraph to this section. Here the Prime Minister enacted what Woolwich had already performed: the reconstitution of state power in iron. Now Woolwich was established as the core of the new iron economy, in the spring of 1819 Mudge turned to Barlow, fresh from the *Essay*'s success, and encouraged him to consider local attraction. In April that year, following this conversation, Barlow sat in his lodgings at the Academy and drew the figure of an enormous compass on a platform. In the centre of the design, he placed a compass along the magnetic meridian; on the divisions of the figure, at different distances from the central compass, he arranged shells and howitzers from fourteen to ninety-six pounds in weight. Raising and lowering the compass he observed the deviation of the needle with respect to the quantity and direction of iron. Further, he noted a point of no action: a plane where the masses of iron had no effect on the compass. He saw the very neutral line that he had sought in his timber researches, the point of no compression or extension, around which twist occurs.

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505 Gordon,1979,pp.26-38; Prothero,2013,pp.172-82.
506 Tomlins,1993,p.133.
507 Liverpool,1817 in Birch,1967,p.213.

His curiosity piqued, he had a wooden table made with copper fastenings and covered in paper, divided as before, according to the points of the compass. The material layers of ship's sheathing: wood, paper and copper, made into an instrument. In the centre of the table was a circular hole, about ten inches in diameter; a block and pulley passing through its centre allowed a 'ten inch shell [ninety-six pounds of iron,] to be raised and lowered at pleasure'[508] (Figure 3.8). The reversal of the experiment, such that the compass became an immutable and self-acting register of the movement of iron, embodied the same rigging which, as Duhamel had put it, directed the movement of ships as if apparently self-acting machines. Pulley in place, Barlow arranged the compass at the different positions on the paper figure, where the shells had previously been observed. The test, Barlow argued, revealed the plane '*either exactly, or very nearly perpendicular to the direction of the dipping needle.*' The crudest materials of ships' construction made to measure local variation as if the most delicate philosophical device.

[508] Barlow,1820,p.5.

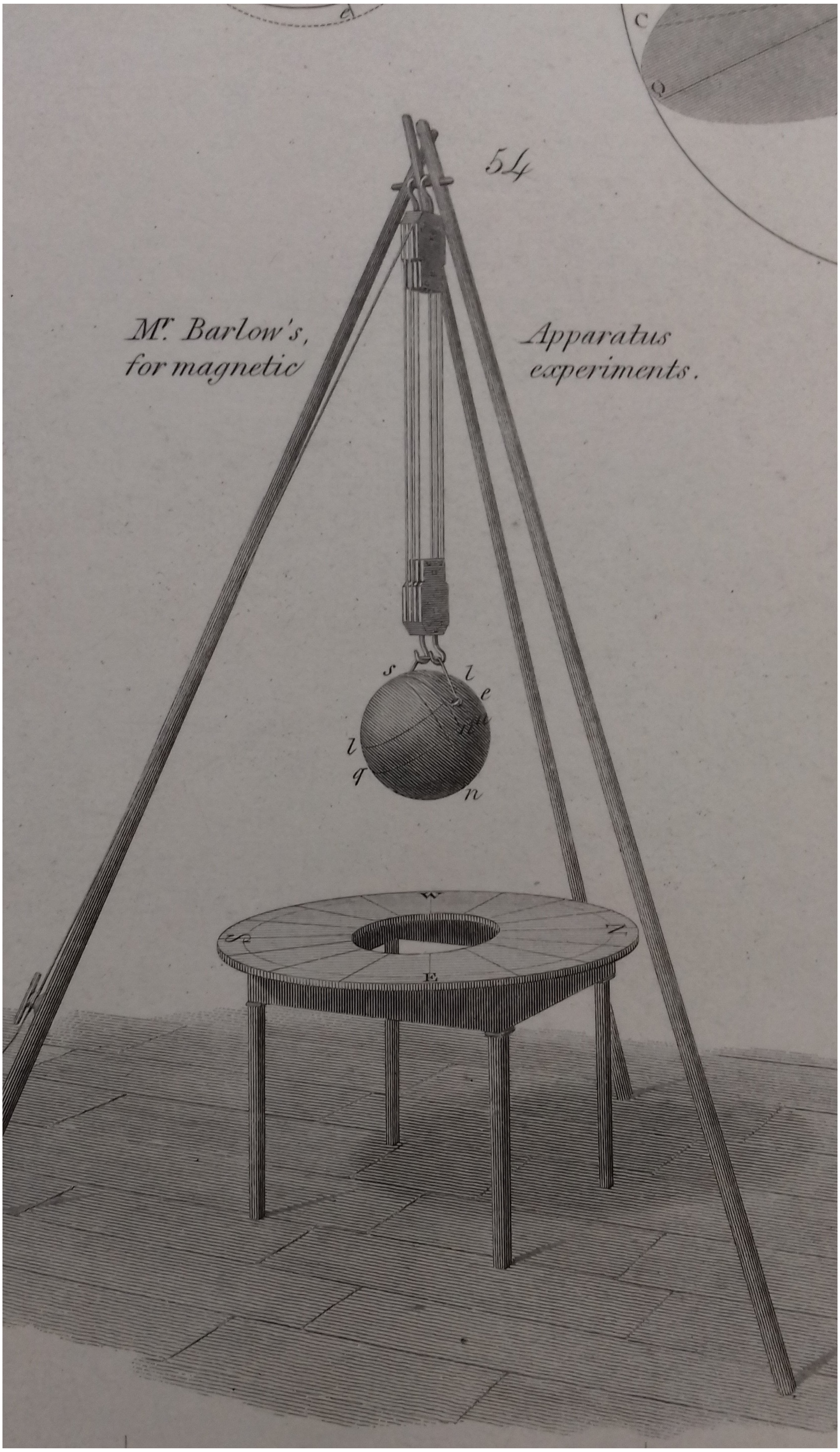

Figure 3.8: 'Mr Barlow's Apparatus for magnetic experiments' (drawn by Barlow) Barlow, Peter, 1829, 'magnetism,' *Encyclopaedia Metropolitana* Vol.I, London: Baldwin and Cradock, 735-845, Plate 6, Fig. 54

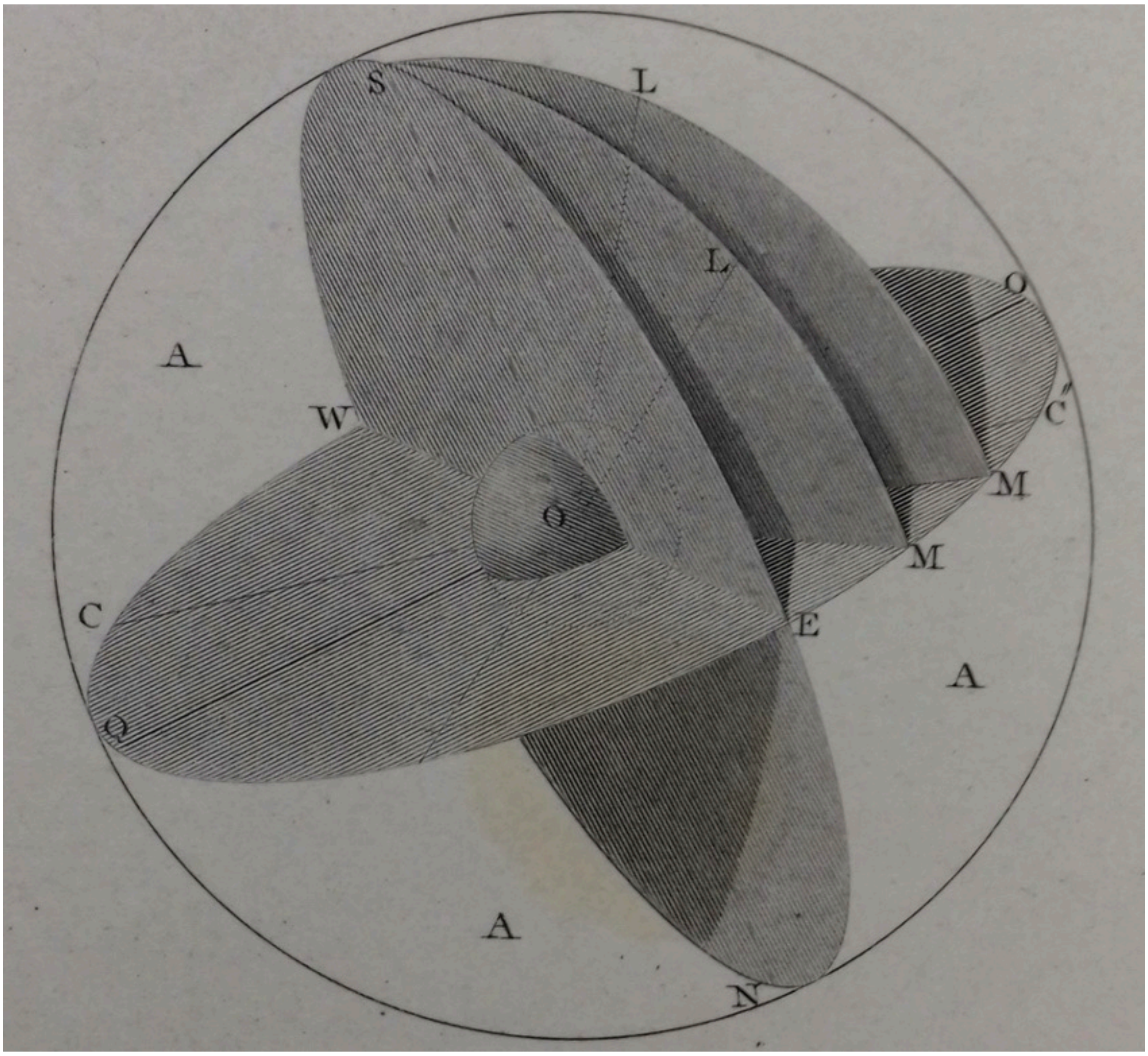

Figure 3.9: (as Figure 0.3) 'First fundamental principle: *In every ball or shell of plane unmagnetized iron there exists a plane of no attraction, or a plane in which the iron produces no disturbance in the needle…*' Barlow, Peter, 1829, *Encyclopaedia Metropolitana* Vol.I, London: Baldwin and Cradock, 735-845, p.775 and Plate 6 Fig. 55.

In the beginning of May, Barlow looked up from the table, beyond his room in the Academy, and saw a way. Woolwich Academy and the Arsenal commanded a complete view of Gallions Reach, down to Barking Creek.[509] Barlow's position at Woolwich not only provided the iron shells, the compass, the wood, copper, paper and pulleys of his design, but also the scope of his vision: from where he sat in his Academy lodgings he looked out on the ships that lay in the river waiting, preparing to hunt for a Northwest passage.[510] In his set up: coppered and papered wood skewered by the same pulley system used on Admiralty vessels that raised and lowered the very iron shells of Admiralty cannon. Barlow made not just a model of the earth, as he claimed, but a ship that could calibrate the dip circle. Mudge saw the significance

[509] Purdy,1838,p.12.
[510] Barlow,1820,p.11.

of Barlow's experiments and gave over the Academy workshop, designated for the construction of models for Barlow's inquiries: more experiments, a bigger table, bigger shells. Here were stored the hundreds of crushed and marked wedges of Barlow's timber experiments. When Mudge had enthusiastically displayed the collection to Dupin on his return to Woolwich in 1817, it must have seemed as much a timber store as a place where representations of the world could be manufactured.[511] In 1819, from this workshop surrounded by broken timbers, Barlow looked out on Admiralty preparations for a second Arctic expedition, and was inspired. He knew that the mission's astronomer, re-appointed from the 1818 polar expedition the previous year, was a former pupil of his: Royal Society protégé Lieutenant Edward Sabine. Further, he knew that on the previous expedition Sabine's attention had been much drawn by the problem of local attraction. Barlow wrote to his student, explaining his model and proposing the Woolwich graduate extend these investigations into the plane of no attraction on the imminent voyage to search for a trade route to India.[512]

§5: the twist and the gilt

> What, then, is truth? A mobile army of metaphors, metonyms, and anthropomorphisms – in short, a sum of human relations which have been enhanced, transposed, and embellished poetically and rhetorically, and which after long use seem firm, canonical, and obligatory to a people: truths are illusions about which one has forgotten that this is what they are; metaphors which are worn out and without sensuous power; coins which have lost their pictures and now matter only as metal, no longer as coins.[513]
>
> Nietzsche,1873

In January of 1820, Barlow submitted a report to the Admiralty on the state of the 150 compasses in their Woolwich dockyard store. These were instruments he declared so defective as to be 'mere lumber', like rotten timber or 'base coin'.[514] This section takes seriously the argument of the epigraph, and finds in both metal and coin, fibre and web, eloquent traces of illusion become truth. The metaphors in these material forms reveal the power of the judgments and classifications made in the nascent development of electromagnetism. Abstract science would achieve a truthful correspondence with one dominant perception of the world, precisely by incorporating the social premise of steam-powered textile capitalism into a system of physical laws.

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[511] Dupin,1825,p.95,note.
[512] Barlow,1820,p.11.
[513] Nietzsche,1982,pp.46-47
[514] Barlow,1837b,p.664.

Chapter one described how illegal tender was recalled and rendered down to make copper hull sheathing to protect timbers from the necrotic effects of the *teredo*. From the late eighteenth century such coppering had been ubiquitous in the human trade where the cost of the sheathing was recovered to profit in a single voyage, with the vast commercial benefit of ten to fifteen fewer captive deaths per voyage, while the outlay on copper sheathing was equivalent to the value placed on two to four enslaved Africans' lives.[515] Since the 1807 abolition of the trade, copper-sheathed transport ships and their human cargo had become Admiralty prizes, a central concern of chapter four. Indentured 'prizes' were found to be cheaper than enslaved Africans in the West Indies, and by the 1820s the interests of capital saw 'benevolent' British enslavers call for abolition of enslavement in the Caribbean, at the same time as lobbying government to cease active suppression of the human trade which fed the British industrial interests in South America, where enslavement remained lucrative.[516] Now, in the second decade of the nineteenth century, Britain no longer re-exported voyage iron into West Africa, as described in chapter two. Instead, it flooded the Bights of Benin and Biafra with textiles and guns.[517] Chapter four considers the 1807 Act in detail; here the concern is the copper and the textiles: to remember quite what the gilt signified, and the thread bound.

Where the testimonies presented to the 1824 Select Committee declared confidence in the new iron to bind the global machinery market to Britain,[518] there was significant anxiety over the export of steam.[519] The decision to lift restrictions on artisan movements but retain, for now, those on machine exports, coincided with a concerted shift to substitute the copper of steam engine boilers for iron,[520] and the publication of Taylor's Humboldt *Selection*, described in chapter one, that sold the newly independent South American states for development under Cornish steam.[521] That year saw the launch of subsidised campaigns to promote the emigration of Cornishmen to South America,[522] to serve as agents of Cornish engineering and overseers of the most brutal and lethal of enslavement systems.

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515 Solar&Rönnbäck,2015,p.825.
516 Williams,1944,pp.154-72
517 Inikori,2011,p.668,Table:25.5.
518 Parliament,1824,p.23,pp.112-3.
519 Parliament,1824,p.126,p.129,p.328
520 Encyclopaedia Britannica,1842,p.676
521 Taylor,1824
522 Payton,2005,pp.106,107; The West Briton,[26/03/1824]; [01/04/1825]; [07/04/1826]; [23/03/1838], **BL**/MFM/M59517-M59545.

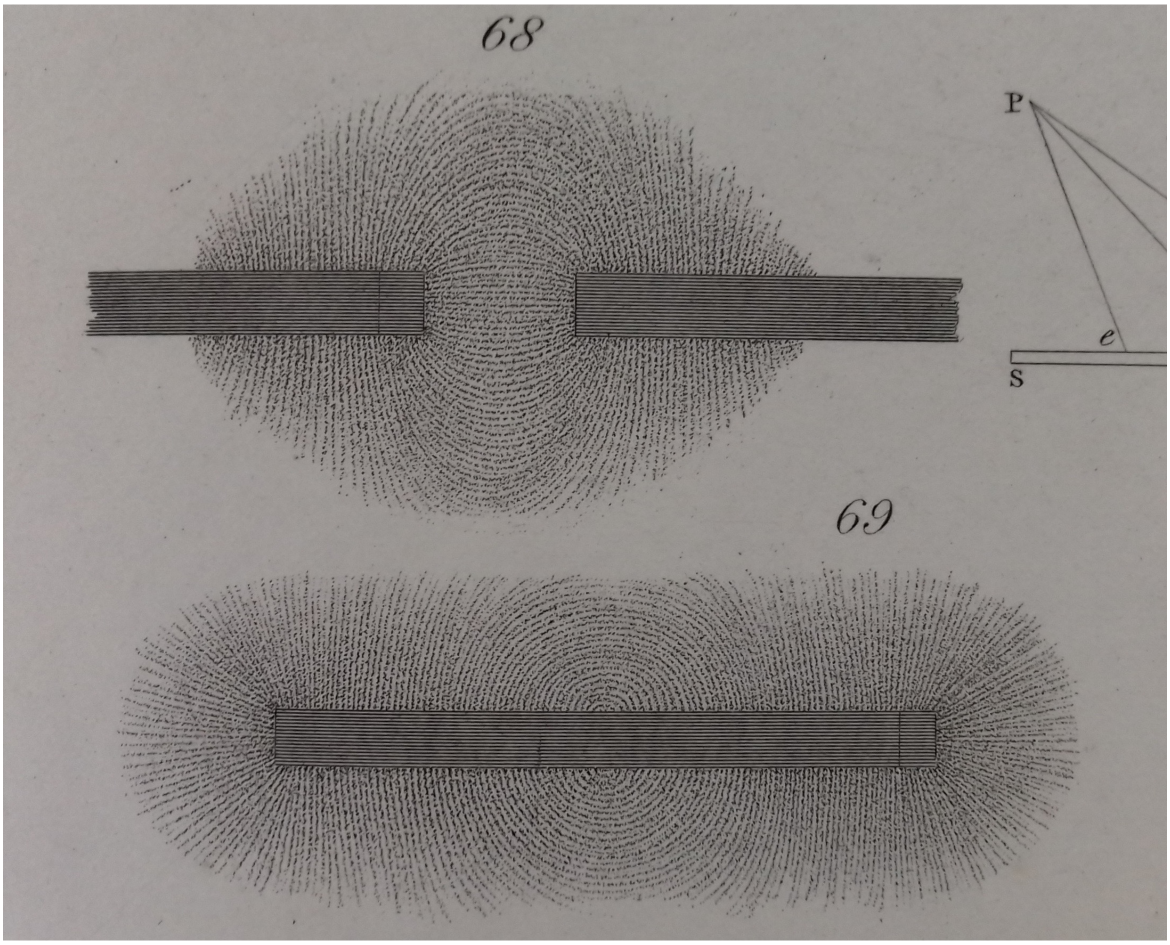

Figure 3.10: (to compare with Figure 3.2) 'iron filings fixed in the pattern into which they arrange themselves around the poles of a magnet' (drawn by Barlow).
Barlow, Peter, 1829, 'magnetism,' *Encyclopaedia Metropolitana* Vol.I, London: Baldwin and Cradock, 735-845, Plate 7, Fig. 68 and Fig. 69.

In the very same months, Barlow performed two significant acts of representation. His first was in his description of the arrangement of iron filings that formed around a magnetised bar. Onto these filings, like the 'short-staple' lengths of carded cotton (Figure 3.2), he drew continuous lines that under the influence of the magnet deviated from an imagined parallel: he saw 'magnetic curves' (Figure 3.10), and fixed these patterns in shellac, just as calico printers did to fix their designs. In the second he took a hollow sphere of wood, and wound in grooves around its surface, copper wire to carry a current (Figure 3.11). When charged this model earth bound in copper would cause a suspended needle to assume the same dip and direction as shipboard instruments 'in the corresponding parts of the earth itself'. For Barlow, it was not only Navy compasses that were dangerously defective, but also all its magnetic charts, where 'no account has even been taken of the local attraction of the ships themselves'.[523] The bold abstractions of Barlow's magnetic science were made possible precisely because, in the construction of his globe, the materials recalled the construction of the global. To illustrate the point, he rotated the globe to three sites and took readings from

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[523] Barlow:Herschel,[16/06/1823],**RS**/MS/10652.286.

each. The first, Ascension, was the crucial victualing station for the West Africa Squadron engaged in suppression of the human trade. The second, London, saw new legislation enacted that same year combine surveillance and regulation of artisan movements with major reform of trading standards as the state attempted to take centralized control over Britain's global trade. The third, Cape Horn, was the gateway to Chilean and Australian mines; again in the same year, 117 merchants of London petitioned for the opening up of the South American market, based on enslaved labour and the human trade.[524]

[524] Williams,1944,p.171.

Figure 3.11: a c.1830 edition of Peter Barlow's 1824 globe, commissioned by Italian physicist Leopoldo Nobili. As with Barlow's the globe is made of wood tightly wound in copper, 413, Museo Galileo

The specific significance of these associations was immediate. In the few years since undertaking observations for Barlow in the Arctic, Sabine had set out to determine the figure of the earth through the combination of pendulum observations at stations in remote latitudes from each other.[525] As chapter six details, this project was of paramount importance to disputes over international trading standards, and the direct basis for the 1824 Weights and Measures Act. For this aim the British Government assigned Sabine to HMS *Pheasant* under the command of another of Barlow's collaborators, Captain Douglas Clavering. *Pheasant* was part of the Africa station patrols, hunting for human traffic. Just the year before Sabine and Clavering set out, she had taken the Portuguese ship *Adelaide* with 232 enslaved on board. The choice and distribution of stations of the 1822 voyage, along the equatorial shores of African and American continents, was determined by the human trade, and in its turn so too was the British claim to the figure of the earth.[526]

Just a few months later, in December 1824, Barlow wrote to Thomas Frederick Colby, his former student and Mudge's successor as superintendent of the Ordnance Survey, speculating that the Earth's rotation might be the cause of its magnetic polarity.[527] The astronomer and secretary to the Royal Society John Herschel had asked for his opinion on a possible relation between magnetism and rotation some two years previously. However, it was only with spinning of his magnetic curves, the assembly of his wooden globe wound in metal fibre, and the salient events of that year, that Barlow began to consider the question in earnest.[528] This interest crystallised into action in the spring of 1825 after hearing of the magnetic rotations produced by astronomer Dominique François Jean Arago, a central protagonist in the international debate over the figure of the earth, whose magnetic research was pointedly textorial.

In 1820, University of Copenhagen Professor of physics and chemistry Hans Christian Ørsted, had shown that a wire carrying an electrical current would affect a magnetised needle. This discovery proved pivotal in redirecting the work of electricians and magnetists across Europe. Within months, Arago won praise from the Académie Royale for showing how, using an electric current, a permanent magnet could be artificially manufactured from an *aiguille à coudre*, a simple sewing needle. Though the Académie's collated memoirs were not published until 1824, Arago's presentation was immediately published as a separate extract in 1820,[529] together with that of groundbreaking work by André-Marie Ampère. Also explicitly inspired

[525] Sabine,1838,p.11.
[526] Sabine,1825,pp.435-6.
[527] Barlow:Colby,[26/12/1824],**RS**/MS/10652.287.
[528] Barlow,1825,p.317.
[529] Arago,1820,p.13.

by Ørsted's discovery, Ampère's paper showed the action of the earth, or terrestrial magnetism, upon electro-magnetic combinations, and, in particular, the mutual action of two galvanic wires upon one another, while in connection with the poles of a battery.[530] In 1821, recently appointed acting superintendent of the house of the Royal Institution, Michael Faraday had reported on these researches as part of a sketch of the progress of electromagnetic research, setting out in detail the Ampère theory of the earth as battery and Arago's manufacture of the sewing needle into magnetic instrument.[531] In the course of writing his report, Faraday identified electro-magnetic rotations.

Four years on, in spring 1825, École Polytechnique professor of chemistry and Sorbonne professor of physics, Joseph Louis Gay-Lussac reported to London scientific society on Arago's discovery that the rotation of a copper disc under one of his remarkable magnetized sewing needles, suspended on a thread of unspun silk, would cause the needle to twist the thread. Despite Faraday's prior findings it was only after hearing Gay-Lussac speak on Arago's latest work, which showed specifically how a sewing needle could be made to act in sympathy with an unconnected rotary body to twist unspun silk, that good friends and close neighbours Barlow, Babbage and Herschel became preoccupied with the question.[532] Writing to Faraday about their experiments in May of 1825, Barlow was explicit on the significance, noting with enthusiasm, 'I have since had Herschel down and I have been *spinning* with him and Babbage in town' [original emphasis][533].

Smooth rotary motion was the basis of almost all manufactures but indispensible, above all, to twist threads into fibres that could be woven. For late-eighteenth and early nineteenth century steam engineers, the generation of frictionless rotary power to give motive force to textiles machinery was an ambition that promised to make heat engines general and applicable throughout Britain's industrial society. Displacing the human body as source of rotary motion to spin a thread offered to collapse the independence and itinerancy of labour, reorganising production under a single factory roof. In the wake of the Napoleonic wars, it was the application of rotary engine power to the British textiles industry that crippled the world-leading South Asian trade in woven stuff.[534] Barlow's December 1824 speculation that the Earth's rotation might be the cause of its magnetic polarity[535] became a formal

[530] Ampère,1820,pp.1-12.
[531] Faraday,1820a,pp.274-8.
[532] Babbage&Herschel,1825,p.467.
[533] Barlow,1825 in James,1991,p.368.
[534] Broadberry&Gupta,2009,p.279,p.285; Chapman&Chassagne,1981,pp.37-40.
[535] Barlow:Colby,[26/12/1824],**RS**/MS/10652.287.

announcement in May 1825 following his '*spinning*' with Babbage and Herschel.[536] Most significant of all, within a month of working together to replicate Arago's rotations, this trio of men specializing in the theoretical mechanics of machines, economies, and celestial objects, decided to reverse the experiment, to see if the magnet could produce the smooth rotary power of an engine needed to power a spinning wheel.

'Money makes the world go round' became a familiar proverb in the mid-nineteenth century,[537] so much so that it was included as a useful phrase in Hindustani-English dictionaries.[538] For the British textile industry the expression was not just figurative. The wealth and power of this global trade was a social economic force that shaped fundamental laws of abstract dynamics. Now the force of the epigraph to section two emerges. Writing to the steam-manufacturer Matthew Boulton, steam cosmologist James Hutton had not exaggerated the impact of spinning cotton to suggest the technology could make a market of the world, or to predict that the new iron would now be deployed in the same groove.[539] Barlow, Babbage and Herschel were neither fanciful nor peculiar in seeing a textiles cosmology in the magnetic power generated by the spinning of the globe. Their experiments remanufactured Arago's work in the figure of the British industrial application of rotary steam to the production of twist.

Only a few months before their '*spinning*', which harnessed the spinning wheel to the rotary engine, an article had featured in the *Mechanic's Magazine*, framed as a response to Dupin's recently published tour of British works, and in particular dockyards. The article reported on a eulogy given by celebrated chemist Humphry Davy, Faraday's former patron, and a Cornishman raised under the Boulton & Watt engine monopoly, at the ceremonial opening of a monument to the late James Watt. In textile terms, Davy expressed his awe at the power of the Watt engine, 'whose giant arm twists the huge cable which is to protect the largest ship of the line, and spin the gossamer-like thread.'[540] Three years on, Babbage paraphrased the Cornish chemist's words in his *Essay on the General Principles which regulate the Application of Machinery, Manufactures and Mechanical Arts.* In this widely reproduced phrasing, the power of the steam engine to bring iron and cotton into equivalence was specified in even more explicit terms: 'It is the same "giant arm which twists the largest cable" that spins from the cotton plant an "almost gossamer thread."'[541] In 1832, he repeated the phrase again in his

[536] Barlow,1825,pp.317-27.
[537] Power,1870,p.451.
[538] Fallon,1876,p.444.
[539] Hutton:Boulton,[24/05/1784],**BL**/MFM/Mic.A.19787/172/306.
[540] Percy,1824,pp.242-4.
[541] Babbage,1827,p.15.

most famous work, *On the Economy,* accompanied with further detail of how he understood the powerful union of steam and cotton twist on labour and a global market,

> The produce of our factories has preceded even our most enterprising travellers. The cotton of India is conveyed by British ships round half our planet, to be woven by British skill in the factories of Lancashire; it is again set in motion by British capital; and, transported to the very plains whereon it grew, it is repurchased by the lord of the soil which gave it birth, at a cheaper price than that at which their coarser machinery enables them to manufacture it themselves.*
>
> *At Calicut, in the East Indies, where the cotton cloth called calico derives its name), the price of labor is *one-seventh* of that in England, yet the market is supplied from British looms.[542]

In 1829, Faraday had been appointed professor of chemistry at Woolwich Academy.[543] In joining the institution he came to share the material and technical resources of his long-standing friend and colleague in electro-magnetic research, Barlow. In this environment and close collaboration, Faraday's work on electromagnetism in the 1830s and 1840s began to articulate the assumptions and interests held implicit in the practices of those around him.[544] In 1832, just a year after identifying electromagnetic induction, Faraday began to adopt Barlow's use of 'curves' and 'lines' as a way of expressing his discovery. This was terminology drawn directly from the silk and wire that made up their shared experimental apparatus, but also from the salience of Britain's global cotton industry, just as Barlow read cotton twist into patterns of iron filings and fixed them with shellac like calico prints. The concepts of force, motion, even of the linkage these forces performed and the system of laws Faraday was developing, were reconstituted with the fetish of the textiles trade. In 1845, Faraday demonstrated that the influence of a magnet could cause even a beam of light to rotate: to twist upon its axis as if it were the thread of a torsion instrument, or the single beam of light were unspun silk and the magnet its spindle. That same year he used the term 'field' for the first time to describe the region of intense magnetic action between poles, and in 1850, as a theoretical concept, defined the field as the space adjacent to an electrical or magnetic power source, strung across with lines of potential force under tension, that came into existence only through the action of the needle. Dickens had attended Faraday's public lectures through the 1840s, and, in December 1850, he wrote to thank the copper wire web-weaving author of

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542 Babbage,1832,p.17.
543 Drummond:Faraday,1829, in James,1991,pp.486-7.
544 Gooding,1989,p.188.

field theory for sharing his lecture notes with a copy of *David Copperfield*, published that year.[545]

Conclusion

On 9 November 1857, James Clerk Maxwell, then professor of natural philosophy at Marischal College, Aberdeen, wrote to a frail and ailing Faraday, recently retired from 23 years service at Woolwich. His letter came after long consideration in response to Faraday's solicitation for his thoughts on a paper titled 'On the Conservation of Force', published in *The London, Edinburgh and Dublin Philosophical Magazine* earlier that year. Maxwell's first academic paper, published in 1846, presented an ingenious mechanical solution to extending the theory of basic conic sections to the characterisation of more complex curves. He did so first by showing that a simple ellipse with the minimum two foci could be drawn using a pin to fix each focus and using a single loop of thread, hooked round each pin, to determine the tracing path of a pencil strained against the fullest extension of the loop under tension. This simple ellipse could then be elaborated to more complex curves by adding more pin-foci, by wrapping more of the loop of thread. In 1806 aged 15 Faraday had worked as a bookbinder's apprentice fixing texts with thread. Four decades on in 1846, while Faraday extended magnetism to optics on the principle of thread, and articulated field theory for the first time, a 15 year old Maxwell used the wrapping and extension of thread to mechanically extend and develop theoretical principles. Now in 1857, aged only 26, Maxwell read in Faraday's articulation the traces of a specific industrial culture, the textile industry, and understood these traces to be true and accurate representation of the combination of social and physical forces governing the world.

Setting out his thoughts, the young physicist credited Faraday with realising 'tension' as more than a metaphor or turn of phrase, but 'as a principle to be actually believed in'. In a clear reference to Barlow's patterns of iron filings around a magnet, and the evident textile derivation of the Woolwich mathematician's interpretation and representation, he went on: '[w]e have had streams of hooks and eyes flying around magnets, and even pictures of them so beset...'. He saw in Barlow's pictures the process of weaving, and could confidently assume others, including Faraday, saw the same. Crucial to this understanding was attraction, or connection, without contact. In his work on knots, Maxwell was explicit: a system of lines where there is '*no linking at all*' and yet which cannot be separated, was 'not a knot or a chain

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545 Dickens:Faraday,[11/12/1850], in James,1999,p.218.

but a web' which must be 'woven'.[546]

Such definitions mattered to Maxwell, who expressed his frustration 'that we do not keep our words for distinct things more distinct'. Accordingly, he was careful to distinguish his terms, defining 'Energy' as 'the power a thing has of doing work arising either from its own motion or from the "tension" subsisting between it and other things.' In its reference to the property of work, motive power, and motive power displaced by certain relations, Maxwell's 'Energy' definition presented a physics of human labour economy: the relations in its organization, and the struggle and resistance as those relations were reorganised with the apparent displacement of the body as prime mover by steam.[547] Nowhere were these principles more embattled than in the textiles trade. The early development of electromagnetism depended on the fiddly and painstaking techniques of wrapping and layering electrical and magnetic components with insulating materials. It is no coincidence that the most fraught labour relations produced the materials upon which electricians and magnetists depended for resistance in their circuits. Nor that Marx's analysis of the relation of the capitalist to the 'human material' of his workforce, 'longing to reduce to a minimum the resistance offered by that repellent yet elastic barrier, man' through the 'apparent lightness of machine work, and by the more pliant and docile character of the women and children employed on it',[548] described the balance and suspension of precision electromagnetic instrumentation. Just as it was for Babbage's engine economy described in chapter one, resistance was a central preoccupation in the generation and articulation of power

Where Maxwell's Energy was a principle of labour, 'Force', 'the tendency of a body to pass from one place to another' that 'depends upon the amount of change of "tension" which that passage would produce', was a principle of exchange. Just as the abstract value of a commodity, external to the commodity and imposed by society, is only manifested when commodities of different qualities are brought into exchange through some common factor, and the commodity itself only exists as commodity when it participates in this exchange, lines of force existed only in potential until a body such as a needle or thread registered this tendency.[549] When Maxwell looked out his window, he saw '*Trade...* in the dense entangled street' as a 'web,' where, as in his work on knots, a system of lines under tension and yet without contact, came into being only through the process of 'weaving'.[550] He saw one realisation of Descartes' vision for knowing the world by the reason of capital extraction:

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[546] Tait:Maxwell,1877 in Harman,2002,p.506.
[547] Marx,1954,pp.354-7.
[548] Marx,1954,p.380.
[549] Marx,1954,p.66.
[550] Maxwell,1853, in Campbell,1882,p.593

British textile capitalism as the laws governing the world. Writing to the ailing Faraday in November 1857, Maxwell reassured him of the seminal *éclat* and extent of his achievements: 'your lines of force can "weave a web across the sky" and lead the stars in their courses… something like a comet, *if lines of force were visible*' (Figure 3.12).[551]

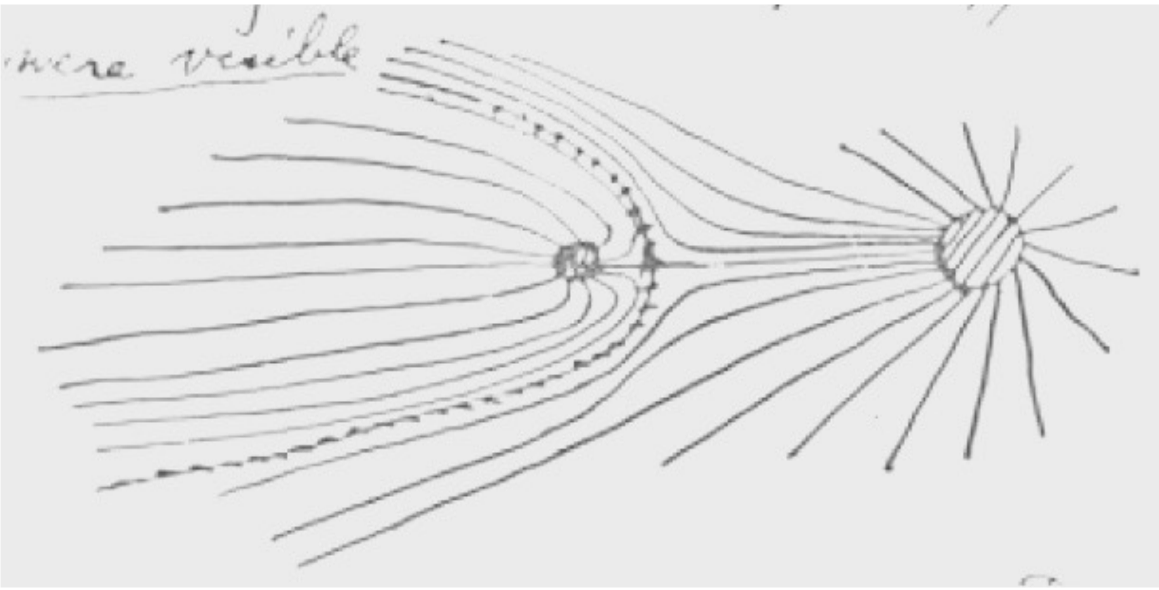

Figure 3.12: 'your lines of force can "weave a web across the sky" and lead the stars in their courses… something like a comet, *if lines of force were visible*' James Clerk Maxwell to Michael Faraday, 9 November 1857 in James, Frank, (ed), 2008, *The Correspondence of Michael Faraday*, 1855-1860, Vol. 5, London: The Institute of Engineering and Technology, pp.301-2.

Nearly two decades on, in 1874, Maxwell was commissioned to write on the atom for a new edition of *Encyclopaedia Britannica*. In his draft, in order to estimate the energy of a corpuscular bombardment, Maxwell bounded the moving system to be estimated with the circumference of a penny coin against the ratio between the diameter of the earth and the penny's thickness, before extending the complexity of the system by considering the penny falling freely.[552] In the published article, as in the 1873 Nietzsche quotation that opened section six, metaphor and illusion had turned to truth, and the final analysis of corpuscular bombardment made no mention of the coin on which it was based.[553] Similarly, discussion of the properties of crystals, such as their structure and division, was understood and developed in the draft in lengthy analogy to cloth, of which this is a brief excerpt:

> …A single thread does not possess the properties we observe in the cloth. The properties of the cloth arise from the arrangement or configuration of the threads.

[551] Maxwell:Faraday,1857 in James,2008,pp.301-3.
[552] Maxwell,1874 in Harman,2002,p.124.
[553] Maxwell,1875,p.46.

> Should we or should we not in the process of dividing and subdividing a crystal arrive at a result analogous to that which we obtain when we have separated a piece of cloth into its component threads...

As with his penny coins, Maxwell's lengthy discussion of cloth presenting the raw material of the universe as a fabric is entirely absent from the finished article, though the point it was to illustrate, on the atom, remains.[554] Coin was to Maxwell currency by which the identity of the invisible force of the corpuscular bombardment was made manifest. Like the commodity form, Maxwell's corpuscles, the fabric of the universe, were only made real when brought into exchange with money. Though coin and cloth were dropped, the final published work closed with an analysis of Herschel's comparison of atoms to 'manufactured articles'. The greatest significance lies in this move by Maxwell. The act of revision makes explicit that for Maxwell the most raw and fundamental material out of which everything was made, could also be the product of manufacture and the scientific tradition that framed that thought.[555] That a body could sustain the contradiction of raw and processed properties, a single thread and an assemblage of springs, a man, or boy, and a machine, was itself a product of the textiles industry and the debates on cotton twist.

[554] Maxwell,1874 in Harman,2002,pp.124-6.
[555] Maxwell,1875,p.49.

Chapter four: Indentured in iron

Figure 4.1: anchor chain, unknown provenance, XXX0042, National Maritime Museum, Greenwich, London.

Maxwell's physics of textile capitalism proposed to model the universe in a penny. The money's form could serve as such a model precisely because it was a microcosm of the universal exchange by which inalienable human properties may be transformed into commodities. To explore this model, to consider the dimensions of the base coin Maxwell used, it is first necessary to be aware of the dimensions of Britain's nineteenth-century global capitalism that he was born into. A transatlantic trade in African lives that was not triangular but quadrilateral; a so-called end to British involvement in this trade that was, in reality, no less than a violently enforced British state monopoly; and the emergence of surveys and centralised state-sanctioned trading standards as the weapon of choice in securing this distinctly British concept of the global.

§1: the quadrilateral trade

Newfoundland and Labrador fisheries were among England's earliest 'plantations' outside of Ireland.[556] Colonisation attempts from the later sixteenth century were well-underway in the

[556] Baker,2015-18.

early seventeenth,[557] coinciding with a shift in the meaning of the word from describing a settlement, to describing a site of intensive production.[558] As such, whaling and the whale fisheries were foundational to the idea of plantation as economy, where the concentration of significant capital was engineered together with an extreme system of labour extraction in order to optimise profit for the enslaver-cum-industrialist; profits which, as early as 1618, lured the East India Company to invest heavily in Greenland fisheries.[559] Yet for all this investment, English whalers floundered. While other Europeans, in particular Hollanders, Hamburghers and 'other fishermen of the Elbe', carried on a highly lucrative trade, English ventures struggled. The principal obstacle lay in longstanding protectionist policies, which specified English trade, and in particular fisheries, should be carried on in English vessels, manned by an English crew. Reinforcing these, the 1651 and 1660 Navigation Acts came as a death-blow for the nation's whaling.[560]

These protections, designed to strangle competition in the colonial trade, in particular with the Dutch, focused on the indigenous origin of ships' construction, equipment, and labour. Yet the possibility of success for a seventeenth century English whaling venture depended entirely upon the international origin of this human and material capital, specifically Basque skill and Baltic iron. Where the Biscayans were thought to be among the earliest people to hunt whales, the English only made their first forays into the lucrative trade with the establishment of the Newfoundland and Labrador fisheries in the late-sixteenth century. Lacking whaling tradition and the highly specialised skills and expertise that came with it, native English harpooners failed to make kills and lost valuable 'fish'. So too with the crucial rendering and packing of whale meat, without which expert coopering and cutting the prize quickly rotted and its value was destroyed.[561]

The demands of the whale hunt were no less specialised, costly, or decisive in the fitting out and maintenance of the vessel. For the ice, whaling vessels required extensive reinforcements with iron, while for the kill itself the performance of the expensive specialised 'fishing utensils' depended acutely on the quality of this metal. Even in the 1820s, with the English trade then well-established, the evangelical whaler and authority on the Greenland fisheries, William Scoresby noted, 'the breaking of a harpoon is of no less value than the value of a whale, which is sometimes estimated at more than a 1000*l* Sterling'.[562] Equally critical were

[557] Pope,2004,pp.1-20.
[558] Minutes,1918,p.354.
[559] Scoresby,1820b,p.101
[560] Elking,1722,pp.43-4
[561] Scoresby,1820b,pp.39-40.
[562] Scoresby,1820b,pp.193-4,pp.224-5.

the integrity of the hoops and rivets of iron in the blocks which hoisted, or the barrels that sealed. By the beginning of the nineteenth century, iron was the medium through which labour relations were negotiated and property claims established in the Greenland fisheries. Indeed, the importance of iron's role in precisely the shift between human and material relations was such that new crew were considered 'not free of the Greenland Sea', but rather enslaved or indentured labour, until shaved with 'a coarse piece of iron-hooping', in a Mayday ritual that marked the beginning of the whaling season.[563]

Crucially, these were not native English products. As chapter two described, for iron to be reliably of the highest quality meant foreign iron. This was Baltic iron and Riga hemp worked by skilled labour of international origin, and if the equipment itself was not cared for and maintained with that indispensible international expertise, the costly investment was lost regardless of the success of the hunt. The Navigation Acts destroyed what little English whaling trade there was, as well as access by British ports to the commodities of the whale plantations. Their impact was so devastating not only because whaling skill was by nature international, but also because these same vessels carried in themselves, as in their holds, the materialisation of that skill in significant imports of Baltic iron.[564] A fully fitted out whale ship was a concentration of huge capital, accumulated at the cost of a vast speculative investment. Whaling, in particular Arctic whaling in the open-water ice floes, was already inherently a high-risk venture. The particular constraints of English protectionism over-determined the failure of its ventures, and with such a concentration of capital and high level of investment, any failure was fatal.

In 1672, in response to this total depredation, Charles II passed 'An Act for the incouragement of the Greeneland and Eastland Trades, and for the better secureing the Plantation Trade'. The Act exempted the British whaling trade from the rigours of the Navigation Acts as they applied to human labour and in particular individuals' indigeneity. With the restrictions on ship construction and equipment still in place, restrictions, above all on iron, still English whaling failed to get afloat. Many subsequent Acts and temporary exemptions were passed before the emergence of an established and lucrative industry in the eighteenth century, when the rise in British machinofacture created an insatiable thirst for oil. But where the 1672 Act appeared to fail in its immediate purported aims, it had a significant legacy. The Act lifted restrictions on labour, while imposing extensive and complex tariffs on labour's products, ensuring close regulation by the Admiralty and excise, whose involvement was to be funded by the very levies imposed. What purported to be deregulation was in fact an

563 Bulstrode,2019a,pp.173-4; Scoresby,1823a,pp.29-63,p.36.
564 Scoresby,1820b,p.225,p.539,p.452.

extreme increase in the intensity and extent of state regulation.[565] In the 1672 Greenland Act lay precedents for the regulatory machinery that would come to dominate the apparently *laissez-faire* free trade policies of Britain's nineteenth-century fiscal-military state,[566] not simply in the statutes it entailed, but the significant way in which they were retrospectively parsed.

The 1764 Sugar Act and 1765 Stamp Act are acknowledged to have played a crucial role in transforming the relationship between the British state and the colonial activities and interests of British industrialists in the West Indies and America. These revenue-raising acts prescribed close regulation and scrutiny by the excise, while generating the funds to support the significant expansion of standing military presence necessary for their enforcement. Thus the acts were critical in bringing the plantation trade under the close control of the British fiscal-military state. Both Sugar and Stamp Acts were specified as acts 'for explaining an act made in the twenty fifth year of the reign of King Charles the Second':[567] the very 1672 Act designed to encourage the Greenland whale fisheries.

The terminology of such law-making mattered, as the Jesuit refugee, Francis Plowden, noted in his 1774 *An Investigation of the Native Rights of British Subjects*, just two years on from the Somerset case mentioned in chapter two, which legally distinguished civil rights in England from its colonial possessions and precipitated the revolt against British control of North America. Plowden had been master of a college in Bruges, however, not yet ordained, following the papal bull to suppress the Society of Jesus he was released from his vows and emigrated to London to train in law. Plowden's decision, seemingly oblivious to the long history of persecution and disenfranchisement of Catholics in England, reflected the contrary condition of Britain with respect to his brethren. The 1774 Quebec Act extended to Quebec Catholics unprecedented powers and freedoms, followed in 1778 by much narrower concessions to British and Irish Catholics, which nonetheless won Jesuits the right to retain ownership of their considerable assets. While European Jesuits were having their property confiscated, Jesuits in Britain, still denied civil rights on the basis of their Catholicism, won further concessions for reasons significantly rooted in the trans-Atlantic trade and driven by Irish politics, in particular after the 1800 Acts of Union.[568] Plowden's *Investigation* was written in response to these events, as was his subsequent 1803 *Historical Review of the State of Ireland* and 1811 *History of Ireland*. His 1774 *Investigation* was prompted not only by a

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[565] Raithby,1823,pp.63-4.
[566] Ashworth,2017,pp.129-44,pp.221-42.
[567] Pickering,1764,pp.33-52,pp.179-205.
[568] Stanbridge,2003,pp.375-404.

marked increase in legislation over British civil rights, but specifically the legislation of the lives of those who were denied them, on plantations at either end of the trans-Atlantic trade, in Ireland and the Newfoundland and Labrador fisheries of the Province of Quebec.

In this, Plowden's principal concern was to educate individuals on the meaning of the crucial yet apparently innocuous legal jargon in which their access to rights were parsed. 'Explaining' in particular, was significant for Plowden. In any act for explaining an act, 'the explaining act and the act explained make but one law, and the new explaining words are taken as the words of the act explained'. Through this process of rewriting history, the original act, here the 1672 Act, was transformed into pre-existing common law, which the explaining act, here the 1764 Sugar Act and 1765 Stamp Act, formalised as statutory law.[569] In this way the Greenland model of plantation production, 'free trade' that in fact maintained tight control over people and trade through intensive state regulation of process and products, was parsed as custom and judicial precedent. Through these subsequent acts, whale plantations and sugar plantations were bound in common law and themselves rendered commons. Indeed, the cultivation of whales and of sugar had much in common, significant to the development of this legislation.

The importance of sugar to histories of plantations is significantly a product of the particular exigencies of sugar production. As chapter two described, unlike coffee, tobacco, or cotton, sugar required dramatic transformation, immediately after harvest, through an extremely precise sequence of complex processes lest the quality of the crop, and so its value, be lost. From cutting to 'boiling and curing', the rendering of sugar depended on precision temperature control and, at each stage, on a heavily prescribed sequence of complex processes, expensive specialised equipment, and highly skilled labour.[570] Sugar estates were much larger on average than those that cultivated cotton or tobacco, and, where coffee or indigo could be profitably grown with fewer than a dozen hands, the cultivation of sugar demanded an intensity of human labour that saw hundreds bound to a single estate. In the eighteenth century, the French plantations of Saint-Domingue produced forty per cent of all European sugar and in the process consumed more enslaved people from Africa than any other New World society save Brazil, then in the process of shifting from an economy based on sugar production to a new focus on mining and mineral extraction.[571] The material of that bondage is integral to this chapter, chains and shackles of iron, that, as chapter two described,

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[569] Plowden,1774,pp.130-5.
[570] Dubois&Garrigus,2017,pp.4-5.
[571] Dubois&Garrigus,2017,pp.2-9.

were remanufactured into plantation machinery.[572] From the very beginning of the eighteenth century, a sugar plantation represented an extraordinarily intense concentration of human and mechanical capital, with human labour subsumed to the rhythm and discipline of mechanical extraction.[573] As early as 1700, a sugar plantation was a factory economy. Crucially, the intense concentration of investment and procedural regulation entailed strong representation of the sugar industry, over and above other plantation products, in the formal administration of plantations, representation that has, in turn, been reflected in the historical analysis of plantations. Legislatively and historiographically, sugar has provided the mould. Yet for every one of these features, from the cutting, boiling and curing to law-making and the concentration of capital, the same was true of the whale fisheries, and it was a resonance of economies built on links of iron.

Chapter two described how the British, Portuguese and Dutch all relied on imported iron known as 'voyage iron', in particular for use in their dockyards,[574] and for export, for the transatlantic trade.[575] By the 1720s, the principal route for importing voyage iron into Britain was as follows: British merchants shipped goods from the Americas to be sold in the trading hub of Hamburg. The profits made on the banks of the Elbe were then carried from Hamburg to Stockholm for the purchase of Swedish iron. From Stockholm this voyage iron was shipped to three foci in particular: naval dockyards, pioneering developments in machine-building;[576] Hull, the capital of Britain's whale-ship construction;[577] and Bristol, the capital of its human trade.[578] The expertise of the whaling trade, and in particular those virtuoso Hamburghers, and 'other fishermen of the Elbe' who dominated its fisheries, was the connoisseurship of this voyage iron. Not a triangular trade but a quadrilateral one, where the fourth corner was the Baltic and its expert shoppers. The gift of the whale fisheries was iron to purchase African lives and oil to lubricate the machine into which they were fed.

[572] Goucher,2014,p.108.
[573] Dubois&Garrigus,2017,p.5.
[574] Evans,Jackson,&Rydén,2002,p.645.
[575] Evans&Rydén,2018,p.52.
[576] Evans,Jackson,&Rydén,2002,p.647.
[577] Scoresby,1820b,p.40,p.126.
[578] Evans,Jackson,&Rydén,2002,p.647.

Figure 4.2: medal commemorating the port of Hamburg, 1667, MEC0370, National Maritime Museum, Greenwich, London.

In 1805 engineer, political economist, and celebrated inventor of the pie chart, William Playfair, ghost-wrote an atlas of European commerce, 'shewing new and secure channels of trade with the continent of Europe', on behalf of Joshua Jepson Oddy,[579] a 'merchant of some consequence' in the Baltic trade. In 1809, Oddy would use the authority of this work as his platform to stand for election as Member of Parliament for Stamford.[580] In 1805, however, his motivation was to demonstrate the lucrative viability of this trade, in a period of fierce conflict as Napoleon sought to block British access to Continental and colonial commerce. In this survey Oddy and Playfair described Hamburg, on the banks of the Elbe, half a mile from

[579] Urban,1823,p.566.
[580] Stamford Election,1809,p.4.

Altona, as 'the first commercial city on the continent' (Figure 4.2).[581] With no docks to receive shipping, the source of Hamburg's significance was as a centre of commercial calculation, a vortex of information in the flow of the Elbe. There, in the Hamburg Exchange Hall on the river's northern bank,

> ..all the newspapers, commercial information, accounts and publications are taken in; lists of shipping from all quarters, and regular lists, every post, of ships arriving to and from all parts; in short it is a place where commercial information, in every shape, may be obtained..

The Hamburg Exchange Hall, Playfair stressed, was 'the first in Europe' which 'ought to be copied in all great commercial places.' Indeed, 'to the credit of Liverpool', it had already established 'two or three institutions of this kind', though smaller than Hamburg, 'of a scale becoming its commercial importance'.[582] Hamburg was not only a centre of whaling expertise but it was *the* centre of information, where, as attested by Playfair, British merchants learned the price they should pay for Swedish iron in Stockholm, and the price they would pay for human lives on the Bight of Biafra.

§2: nationalising the human trade

By the 1780s, British merchants dominated this trade. In his seminal work *The Black Jacobins*, C.L.R. James described the British government's alarm at the Privy Council *Report for Trade and Plantations*, published in the revolutionary year of 1789, which set out how some fifty per cent of the enslaved people imported into the British islands were sold to the French colonies. It was the British trade that fed the insatiable appetite of Saint-Domingue sugar plantations for African lives. James further showed how then Prime Minister, William Pitt, saw collaboration with the celebrated abolitionist William Wilberforce as the ultimate blow in the great rivalry of the two plantation powers.[583] In November 1806, Napoleon began the implementation of what would be known as the Continental System, designed to blockade British access to this Baltic trade, destroying the material economy of Britain's dockyards, and strangling the labour supply of British plantations: lives purchased with Baltic iron. On 25 March 1807 the British government retaliated with 'An Act for the Abolition of the Slave Trade', a declaration of war against *la traite* and French colonial production, followed closely by the siege of Copenhagen and the capture of the Dano-Norwegian fleet. Under the statutes of the famous 1807 Abolition Act came no mention of freedom, liberation or emancipation. Decreed to come into force on 1 May, the very day on which Greenland whalers marked out

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[581] Oddy,1805,pp.v-viii,p.417.
[582] Oddy,1805,p.424.
[583] James,2001,p.43.

the status of non-freemen with an induction in iron, the declaration simply redefined human bondage.

The Act licensed Officers of Customs or Excise or of the Navy to seize vessels engaged in the human trade, whereupon the human cargo was to be taken as a 'Prize of War', and the enslaved to become the property of the Captain and crew, their lives 'forfeited' and 'condemned'. These forfeited lives, these prizes, the Act stated, were to be exchanged in any Court of Record or Vice Admiralty for 'Head Money': £40 for a man, £30 for a woman, £10 for a child less than fourteen years old; rates that brought the Head Money into direct equivalence with the price paid in iron, on the West African coast.[584] From the Courts of Record these forfeited lives, purchased by the state, were to be 'apprenticed', fed into the plantation system to carry out unpaid indentured labour where the apprentice is the property of the master. These apprenticeships were to last a suggested fourteen years, but could continue indefinitely, on the master's discretion, if the enslaved person were not deemed to have learned what it is to be free.

[584] Solar&Rönnbäck,2015,p.825

Figure 4.3: bust of Jean-Jacques Dessalines, first Emperor of Haiti (1804-1806). Formerly a lieutenant to Toussaint L'Ouverture, Dessalines became emperor after successfully repelling the French attempt to reinstate enslavement in 1802-1803. ZBA2482, National Maritime Museum, Greenwich, London.

In this indenture, the 1807 Act had precedent. By 1791, the revolutionary uprising described in chapter two that had begun in the docks of Martinique, had swept the French Caribbean. By August 1791, this culminated in the massive and well-coordinated insurrection that seized Saint-Domingue. Within a year the insurgents had forced the revolutionary government in Paris, the *Convention Nationale,* to proclaim the citizenship of all free people of colour, and within three years the freedom and citizenship for all enslaved people in the French Caribbean. This emancipation would be revoked in 1802 (Figure 4.3), but even before that betrayal, built into the original proclamation were extensive labour regulations designed to keep formerly enslaved people working on the plantations. Only through this labour, it was decreed, would the new citizens repay the debt they owed the revolution for their freedom.[585]

The 1807 Abolition Act adopted this same model of indenture, where the state owned the debt. Significantly, however, the latter British decree was limited to the point of buying and selling. The state bought this debt not through revolution but through the payment of Head Money at rates equated to the value of Baltic iron on the West African Coast. In its text, the 1807 Act stipulated how this cash was to be raised. Head money, like the funds for the Excise and Admiralty that enforced its collection, was to come through the 1764 Sugar Act and 1765 Stamp Act. Explicitly and specifically as these acts were understood 'for explaining an Act made in the Twenty-fifth Year of the Reign of King Charles the Second, intituled: *An Act for the Encouragement of the Greenland and Eastland Trades*'. Far from abolition, the 1807 Act was the nationalization of the human trade. In its iron and its indenture the 1807 Act provided the physical, social and legal foundations on which the apparently *laissez-faire* free-trade policies of Britain's nineteenth century fiscal military state would be constructed.[586] While British merchants fed French plantations with shackled bodies, British politicians consumed the *laissez-faire* political and economic doctrine of French physiocrats, the liberal ideal: freedoms for an enfranchised few.

§3: *mondialisation*'s metre, globalisation's iron

From as early as the seventeenth century, distinct protectionist policies created a situation whereby French and English states differed in the maintenance of the boundary between the nation and its other. Under French policy, colonial products, such as sugar, could not be traded directly on the foreign market, but first had to be imported into France before re-export. By contrast, English protections, as in the Navigation Acts, focused on binding the

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[585] Dubois&Garrigus,2017,pp.16-20,pp.126-128.
[586] Ashworth,2017,pp.129-144,pp.221-42.

assemblage of vessels and crew to England and later the British Isles. In significant ways the 1772 Somerset Case simply formalised this mercantilism as English national identity. The distinction laid foundations for the incongruity between French and British concepts of *mondialisation* and globalisation. The former, *mondialisation,* describes a world apparently of two halves: French culture on the one hand, nature on the other. The latter, globalisation, describes a web of imperial trading networks that define a particular globular shape.[587] The successive enfranchisement fought for and won by the black revolutionaries of the French Caribbean in 1792 and 1795 forced the boundary of *mondialisation* to be re-measured. In 1792, speaking directly to this, elite French *savants* launched a campaign to derive a 'natural' unit of length, named the *metre* after *metron* - what it was to measure, 'for all people for all time'.[588] This length would be taken from the figure of the earth itself, which was to be discovered by a new survey of the French Meridian arc. This process of re-measuring the *mondial* would be stopped, started and revised in multiple surveys over the subsequent decades of turmoil just as the rights won in 1792 and 1795 were retracted and reconstituted.

British savants busy globalising understood this new metrological project as competition to establish rival trading standards. They responded by mobilising new interest in the reform of weights and measures, to be considered in chapter six, and their own meridian arc under Charles Hutton's favoured pupil, William Mudge. The final volume of the survey was published in 1811 and with it a crisis. The successive French surveys undertaken with European allies were all in agreement: the *mondial* figure was an oblate spheroid. But Mudge, figuring the global, found an oblong spheroid, and a barrage from the Continent focused on an anomalous result from 1801,[589] as indicative of poor practice.[590] The exchange was a bitter one, heightened by confusion over whether Clifton was in the North or the South of England, and brought the status of Woolwich mathematics into question. Mudge's defence, vocally supported by his Woolwich colleague Olinthus Gregory, is significant. The blame, they argued, lay not in a lack of skill but in the influence of local attraction, not of hilly ground but of iron.

Of the many voices that weighed in, John Playfair, mathematician, geologist and chair of natural philosophy at the University of Edinburgh, was the most influential.[591] Playfair had long argued that information about rock distribution and density was needed in order to determine the amount of deflection caused to survey plumb-lines.[592] The question had first

[587] Sorinel,2012,pp.27-30.
[588] Dawson,2006,pp.236-42; Alder,1995,pp.39-71.
[589] Mudge,1803.
[590] Rodriguez,1812,pp.324-5.
[591] Close,1969,p.59.
[592] Playfair,1811,pp.347-8.

arisen for the Edinburgh professor in 1774 visiting the survey of Schiehallion,[593] the results of which Hutton would famously combine to calculate the relative densities of the earth and its surface, taking the mountain to weigh the world.[594] In 1801 Playfair finally acted on his long-held wish and undertook a mineralogical survey of the geology of the mountain, combining this with Hutton's calculations to determine the specific gravity of the different rocks out of which Schiehallion was composed. It was only with the outbreak of the figure of the earth dispute in 1811 that Playfair presented this work at the Royal Society, who published it in the Society's *Transactions* shortly after. Ten years on from its making, nearly forty from its formulation, Playfair strategically deployed his account as part of his escalating call to reform the trigonometric survey with mineral logic.[595]

The second crucial argument in Playfair's campaign came in 1813, in the 'Edinburgh Castigator', as Mudge dubbed the *Edinburgh Review*.[596] In an article reviewing Superintendent Major William Lambton's account of the trigonometrical survey of India, Playfair offered as his decisive case inconsistencies observed by the Woolwich-trained officer. Quoting Lambton's note 'that between Dodagoontah and Bomasundrum (13° and 14°), there is a vein of iron ore which might be supposed to have affected the plummet', Playfair argued

> A more particular description, however, of the country would be necessary to enable us to judge of the probability of this hypothesis. A mere vein, in the strict sense of the word, would be a cause inadequate to such an effect as is here ascribed to it; but a great mass of iron ore, or a body of ferruginous strata, might be sufficient to produce the effect. We long ago remarked, in speaking of the trigonometrical survey of England, that it would have been of great importance to have added to it a mineralogical survey, as the results of the latter might have thrown some light on the anomalies of the former. The same thing is suggested by the objects now under consideration[.][597]

Playfair presented it as given that magnetism would cause the plumb-line to deviate. The argument that the North's premier natural philosopher introduced with explicit reference to Mudge's survey was that the fundamental principle of British fiscal rule, the trigonometrical survey, lay in natural relation with industrially and commercially significant masses of iron.

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[593] Playfair:Robertson,[1774],**NLS**: MS 3942/150; MS 3942/155; MS 3942/167; MS 3942/168-9.
[594] Hutton,1778,pp.782-3; Reeves,2009,pp.337-8.
[595] Playfair,1811,pp.347-8.
[596] Close,1969,p.59.
[597] Playfair,1813,p.323.

In 1814, in response to the controversy and Playfair's lobbying, the Ordnance appointed Woolwich chemistry lecturer, John MacCulloch, as official Geologist to the Trigonometrical Survey. Through MacCulloch it was intended that the landmark campaign to define the fiscal field should become a function of industrially-significant mineral resources.[598] While John Playfair mobilised print culture to galvanise the Ordnance, his younger brother, William Playfair, author of Oddy's *European Commerce,* campaigned in defence of indenture.[599] In every sense, geology and magnetic survey science were in direct dialogue with systems of labour extraction.

Despite the accuracy and extent of MacCulloch's efforts, Mudge noted 'Ignorance, Avarice, and Cupidity' continued to corrupt the mapping progress with the apparently universal attraction of base metal coin, rather than 'local difficulties peculiar to a region.'[600] The triangulation was not lost on the statesman Joseph Banks. Chapter one described how, as a member of the Privy Council Committee on Coin, Banks had long officiated over efforts to secure the authenticity of legal tender. In 1816, he found himself tasked with smoothing the liaison between representatives of British and French arcs, Mudge and Colby on the one hand and Dominique François Jean Arago and Jean-Baptiste Biot on the other, in the post-war effort at a co-ordinated Anglo-French survey. This task saw Banks intervening in the workings of the Customs House, taking special measures for Biot's instruments and baggage to be brought into Britain unmolested and without paying the tax on imports.[601] Though successful, the strain of these duties led to a rare outburst to his friend Davies Gilbert, grieving over the depressed state of Britain's mining interest, and cursing Napoleon's 'Execrable Carcase' for the loss.[602]

Conclusion

In 1817 the calibration of British survey science, the Royal Observatory, had been transferred from the Board of Ordnance to the Admiralty, heralding a new era of large-scale state-funded research in Britain. The new Anglo-French survey was to be its flagship,[603] but in the wake of the launch the vicious attack on Mudge resurfaced.[604] In the spring of 1819, sick, under fire, and seeking consolation from his colleague and friend, Mudge requested Barlow consider the

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598 Close,1969,pp.61-2, 65.
599 Playfair,1814.
600 Mudge:Colby,1816, in Close,1969,p.65.
601 Carter,1988,pp.517-8.
602 Banks in Carter,1988,pp.516-521.
603 Dunn&Higgitt,2017,pp.202-16.
604 Hewitt,2010,p.230.

problem. From the first Barlow saw the global defined by ships' construction and British maritime trade, and his research question to figure this global in relation to industrial iron. The conflicts of the last two decades had seen the militarisation of Britain's merchant marine. Now Barlow looked to magnetic navigation, and prepared for trade war, applying the principles of his timber essay to the raising and lowering of big guns.[605]

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[605] Barlow:Barrow,[23/08/1820],**CUL**/RGO/14/43

Chapter five: The map is the territory, the compass a gun

The previous chapter charted a quadrilateral trade bonded in iron for the purpose of surplus extraction, and then colonised by military force to secure its monopoly. A distinctly British concept of the global as a territory. This chapter considers the fraught and often frustrated experimental development of the magnetic survey and its instrumental standards as weapons to rule that territory.

As chapter three described, following Mudge's instigation Barlow constructed a table that, in its assemblage of wood, copper and paper, stood for one of the many sheathed hulls of the human trade that were now prizes in Admiralty possession.[606] Using a pulley block he loaded it with shells and mortars, then brought Admiralty magnetic instrumentation into line with those big guns. When Barlow looked out on the expedition preparing to hunt for an Arctic trade route to India and sought to pass the compass round the globe, he saw the territory. The world view from his window was of a coveted global monopoly that, figured by the assemblage of sheathing, pulley and gun, was also a cosmology of manufacture.

The cadets of the new physical sciences' cadre had long since learned to watch pendulums to see and know the force of military discipline.[607] Barlow's compass-cum-cannon concept presented just such a colonising force. For centuries Ireland had been used as the testing ground for English colonial policy.[608] Accordingly, Barlow's system was trialled on the Shannon before it was deployed as the mandate for an Admiralty committee to reform magnetic survey through its instrumental standards. This Admiralty Compass Committee's first act was to summon the authority on the quadrilateral trade, William Scoresby; and then to subject him and his work to a hostile takeover.

Nothing in these developments was determined by the physical and statutory laws respectively described in chapters three and four. Every event was fraught with resistance, contingency and administrative failure. Barlow's cosmology was initially rejected by the Admiralty institution. It took nearly two decades before the establishment openly acknowledged the research they had commissioned. The same patronage that marked Scoresby as an authority on the quadrilateral trade saw his intellectual property appropriated in the institutional memory, which had a particular weakness for names and

[606] Solar&Rönnbäck,2015,p.825.
[607] Werrett,2015,p.90; Johnson,1989b,p.217; Gregory:Vivian,[15/3/1838],**Sandhurst**/WO/150/19/13; Miller,1986,107-34; Gooding,1989,183-223.
[608] Hallinan,1977.

addresses. Meanwhile, on the banks of the Shannon, ships' navigation was the focus of insurgent activity.[609] Yet, for all the wrecking, mishap and incompetence, the interconnectedness of vested interests and globalising ambitions was a tight web. Chapter six will describe how the Walker compass that underwrote Cornish and plantation systems and gave them the character of natural law, would be reinvented and nationalised as a state standard - just as the human trade had been. Nothing about this extension was the disclosure of natural or moral laws, yet the interconnection of interests and ambitions allowed just such a retrospective. This chapter picks up the thread in order to pick apart the web.

§1: Barlow's cosmology of manufacture

Barlow took the influence of ships' guns on Admiralty compasses as the proxy for the reciprocal effect of iron and the magnetic needle, and, extending his principle of fibrous timber, identified a neutral axis or a plane of no attraction.[610] He read, at the centre of every mass of iron, a point where magnetic force, understood as the fibres of an organic body, underwent neither compression nor extension; and made this the principal point from which he claimed to reduce local attraction, the influence of iron over the magnetic needle, to laws of action that were mathematical and orderly: 'perfectly regular and susceptible of numerical computation'. Just as Barlow had proposed in his timber essay, fibrous iron was to be the model material of quantification, and just as he had witnessed in the dockyard reforms when he first came to Woolwich, this regimented quantification would reorganise the world to make possible effective mechanisation. Accordingly, his next proposition was 'to substitute instead of those computations a <u>mere mechanical operation</u>' that could correct for local attraction 'independently of all calculation'.[611]

Mudge read the report on Barlow's experiments to the Royal Society the following month, in May 1819. Yet, critically for this chapter, the Society's president, Joseph Banks, refused publication. The basis for Banks's decision will be explored in section two. Here it is significant that Barlow changed tack and submitted the manuscript of his method of mechanical correction to John Barrow, Second Secretary to the Admiralty, as a preliminary to his plan to present it to the Lords Commissioners of the Admiralty.

Dominating the pages of the premier literary periodical the *Quarterly Review* with his articles, Barrow had a reputation for successfully mobilising popular opinion in favour of his central

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609 Delany,1958,p.189; Parliament,1834a,p.23.
610 See Chapter three.
611 Barlow:Barrow,[23/08/1820],**CUL**/RGO/14/43

ambition: British imperial conquest. His advocacy, through the *Quarterly* and elsewhere, for the annexation of Fernando Po to establish it as the West African base from which to attack the human trade, led Colonial Secretary Lord Brathurst to complain 'if coveting islands is a breach of the Ten Commandments, then he is the greatest violator of the decalogue in the kingdom'.[612] When, in 1817, Banks received promising news of the Arctic ice conditions from the whaler William Scoresby, Barrow reproduced the pattern of print intervention he had deployed in 1815 and 1816 in calling for the steamship exploration of the Niger, to push for a search for the Northwest passage, the long-sought trade route to India.[613] If Barlow had sought to test the water, Barrow dropped him in it, forwarding the Woolwich mathematician's article to the driving force behind the Board of Longitude, the recently appointed secretary, Thomas Young.

In 1818, the Board of Longitude had undergone a major reorganisation around the new remit of identifying a viable Northwest passage, the prize and campaign to be orchestrated by Barrow.[614] Banks, Gilbert, Mudge, and Samuel Bentham's half-brother, Charles Abbott, were appointed to preside over this new mandate and with them, holding salaried positions, retired military surveyor turned compass designer, Henry Kater; entrepreneur of South American metallurgy, William Hyde Wollaston; and, hosting the Board meetings in his own home, physician and natural philosopher, Thomas Young. Within months of the 1818 Act, two expeditions embarked, one led by Captain David Buchan, the other by Captain John Ross with Commander William Parry, his nephew Lieutenant James Clark Ross, and Lieutenant Edward Sabine as astronomer.

This latter mission carried a Walker compass, which, on the basis of its performance on the voyage, Captain John Ross judged the best of his five. Ross's expedition turned back after finding the intended route through Lancaster Sound blocked by a mountain range. Both Buchan and John Ross failed to penetrate the ice, but on their return and with Parry's backing, Barrow and Sabine denounced John Ross's decision to turn back as founded on a figment. The painfully public row that ensued and was kept alive in the pages of the *Quarterly* served Barrow's purpose in sustaining sufficient public interest to ensure another attempt the next season under Parry's command, accompanied by James Clark Ross and Sabine.[615] This expedition departed 11 May 1819, also carrying a Walker compass as its reference instrument. In the first week of July, approaching the point at which John Ross had seen the

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[612] Brathurst in Cameron,2007,p.140
[613] Cameron,2007,p.140,p.146.
[614] Dunn&Higgitt,2017,pp.206-7.
[615] Cameron,2007,p.146.

mountain range, and in close correspondence with whaling fleets who maintained communications with Britain, Parry recorded the Walker instrument had failed. Chapter one described how, in 1795, the Admiralty took up the Walker azimuth as its standard reference compass following Walker's published explanation of its use in fixing permanent plantation patents. As noted in chapter two, the 1815 decision to dispense with the certificate of proficiency saw a massive surge in the order and purchase of Walker instruments.[616]

On 10 August 1819 the Admiralty ordered a total stop. When chapter three described how Barlow looked out his window in May 1819, and saw preparations for the second attempt, it was Parry's voyage and Barrow's vision he observed and thought to harness. Where previously Barlow had used finely graduated but unnamed instruments to find true North and calibrate his research, it was at this point he began to specify using an azimuth by Messers Gilbert, makers to the East India Company (Figure 5.1).

[616] May,1987,pp.161-2.

Figure 5.1: Gilbert Azimuth, 1838, ACO0005, National Maritime Museum, Greenwich, London.

Under Barrow's patronage, Young was the driving force of the Board and the Northwest passage was itself *de facto* in his possession. Following the failed first attempt, he had been commissioned by the Board to produce a guide to compass correction on the second, Parry expedition. Thus Barlow's solicitation of Sabine to extend his method placed the two in direct competition. Requested by Barrow to review Barlow's manuscript, Young gave no quarter:

> Mr Barlow is a very ingenious mathematician and author of some very useful publications ~~to which I am much indebted to for assistance in varied calculations~~: but he does not seem to be ~~perfectly well~~ very completely acquainted with all that has been done ~~with regard~~ relating to magnetism: or he could scarcely have fancied that "no one ever attempted" to reduce the material action of iron and the needle "to definite laws" or that he was the first that discovered the existence of a plane in which the iron has no action on the needle. If you turn to the little paper which I had the honour of transmitting to ~~you~~ the Admiralty from the Board of Longitude for the use of the Northern expedition, you will see that I have observed it in "art II"...[617]

In his 'little paper', Young presented the ideal numbers of an ideal dip circle as a correction table for the deviations of the compass. The following year he declared Parry discoverer of the Northwest passage for having attained a furthest west latitude.[618]

Early in January 1820, a frustrated Barlow published his research with The Architectural Library, the same who had previously published his timber essay. In a direct reference to Young's pamphlet, his preface noted

> [e]very one who is acquainted with the nature of the *dipping needle*, must be well aware that it is much too delicate, ever to have become an efficacious sea instrument… how is it possible to expect anything like accuracy in a result which rests upon such uncertain principles?[619]

As he had for timber, Barlow argued such instruments were 'too delicate to operate successfully upon the materials to which they have been applied.'[620] Responding to Young's criticisms, he questioned specifically how Coulomb's theories, of which Young was a vocal proponent, might be reconciled with observed phenomena.[621] His method, he argued, which found the plane of no attraction in the iron, proposed a more robust instrument of analysis and so correction. The conflict over Coulomb was picked up by a review comparing Young's and Barlow's works, published in June that year. The article, appearing in the evangelical literary periodical, *The British Review*, first asserted Young as Coulomb's representative in

[617] Young:Admiralty,[n.d.],**CUL**/RGO/14/43/510.
[618] Dunn&Higgitt,2017,pp.206-9.
[619] Barlow,1820,p.vi.
[620] Barlow,1817,p.58.
[621] Barlow,1820,p.110,p.120,pp.129-30

Britain, then generated a table to compare the value of Barlow's and Young's respective theories against the latest results from the first 1818 Arctic expedition just published by Sabine in *The Philosophical Transactions.* On the basis of the tabled comparison, the review claimed to show 'that in 15 cases out of 16 the formula deduced from Mr Barlow's practical investigation gives numbers that agree much more nearly with the actual results of observation than the numbers furnished by Dr Young's rule'.[622]

Chapters two and three described the extensive incorporation of iron into Admiralty vessels begun in the eighteenth century and accelerated in the early nineteenth. This galvanisation was true above all for vessels converted to Arctic service, where iron on the prow was extended back to protect the ship from the ice and to act as an icebreaker in forcing a passage.[623] No such adaptation was necessary for the expedition's flagship HMS *Isabella*, as a 383 tonne Hull-built whaler her construction was already integrally ferrous. In his account of the 1818 observations, that Sabine further explained, the expedition had employed 'a considerable quantity of iron articles (such as ice anchors, ice saws, &c.)' and that such iron equipment exerted a significant influence over the ships' compasses.[624]

The British Review article made much of this in arguing strongly for the value of Barlow's essay over Young's rules:

> Were there no iron, or other substance, capable of magnetic action, aboard a ship, and were the compasses freed from the defects which we have described at the commencement of this article, the needle would at once enable the mariner to ascertain the *true north* in any part of the world, by applying the correction for the needle's "variation," which is either known or readily determined by the aid of a simple astronomical observation. But, instead of this, how stands the case in fact? Every iron gun, every ball or shell, every iron bolt or screw, nay every *nail,* in a ship, has its greater or less tendency, according to its respective circumstances of magnitude, position, and distance, to disturb the needle… even if the hypothesis which he [Barlow] subsequently advances should be *proved* to be altogether untenable, that circumstance can no more affect the accuracy and stability of his experimental deductions in reference to the compass, than it can invalidate the experimental results exhibited in his former treatise on the cohesive strength of timber.

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622 The British Review,1820,p.296.
623 Terror,[1813],**NMM**/ZAZ5672.
624 Sabine,1819,p.118.

To this anonymous argument the reviewer added a note, that his attention had been 'accidentally drawn' to the results of the 1818 voyage as a potential test. The statement is suggestive: the results of the 1818 voyage were published in full, together with Sabine's account, in the appendix to Barlow's 1820 *Essay on Magnetism*. The document under review was not the final published article.[625] Friend and ally of the editor,[626] Gregory was almost certainly the reviewer responsible for tabling the comparison between Barlow's and Young's formulas, regarding their respective agreement with Sabine's observations.[627]

The technique of presenting numerical predictions derived from theory alongside the numerical results of actual observations was well-established in the publishing mechanics of the Woolwich school and in particular revisions of Hutton's *Course* under the editorship of Gregory. The gap between theory and experiment in such tables has been famously characterised as teaching what constitutes agreement: teaching the space of acceptable belief.[628] The strongly partisan *British Review* article is polemical but revealing. Far from theory on the one hand, practice on the other, both Young and Barlow put forward theoretical claims, and for both, their instruments were their theorems reified.[629] The difference between exquisite instrumentation and industrial machinery was a difference of cosmologies. Both Young's and Barlow's theories re-constructed the world in the image of their modelled ideal, but only Barlow claimed the authority of nature lay in manufacture.

In direct reference to Young's position on the Board of Longitude, Barlow's preface concluded with the request that the public 'judge of [his magnetic essay] uninfluenced by those petty views which too frequently direct the proceedings, not only of individuals but of associations.' Alongside this snipe at Young came a broadside characteristic of reform culture. Barlow expressed his disbelief at the state of compasses employed on Admiralty ships, 'all worthy of each other, equally clumsy and imperfect', so 'wretchedly defective' it was 'very unaccountable that vessels of such immense value and the safety of so many valuable lives should be endangered by the employment of instruments that would have disgraced the arts as they stood in the beginning of the 18th century'.[630] His condemnation proved productive, prompting a visit from Naval Lord and Tory MP, Sir George Cockburn, and John Wilson Croker, first secretary of the Admiralty. His attack on the Board had caught the interest of the highest echelons of Admiralty administration, and won him special access for experiments.

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625 The British Review,1820,p.290,p.292,p.296.
626 Roberts,1850,p.39,note; Gregory,1828.
627 The British Review,1820,p.296.
628 Kuhn,1977,pp.180-7.
629 Bachelard,1984,p.13.
630 Barlow,1820,p.ix.

Through the interest of these powerful figures Barlow was commissioned to review the Admiralty's compass store in January 1820,[631] mentioned in chapter three. He submitted his assessment that same month from where it disappeared into Admiralty's archives, sunk apparently without trace. Except, tellingly, that for all its suppression this second damning indictment of the state of Admiralty compasses won him further support and access from the very institution it condemned. Long after Barlow had forgotten the report's very existence, the institutional memory remained. Seventeen years on from its making, with Croker now a Tory politician and ardent supporter of Peel's protectionist policies; Cockburn now seven years Commander-in-Chief of the North America and West Indies Station incorporating Jamaica; and Barrow, the old imperialist, still coveting colonies, still in post as Second Secretary to the Admiralty, and now a baronet, the report would be salvaged by the Admiralty and published as an urgent call for reform of the hardware of magnetic navigation.

§2: something gotten in the state of Denmark

The previous section noted that while Banks had permitted Barlow's experiments to be read to the Royal Society in May 1819, when it came to publication he refused, arguing that 'some experiments somewhat similar have been tried in Denmark many years ago', though he did not have the results to hand, 'being ignorant of the Danish language'.[632] Surprised by this claim and after waiting some months for further explanation that never arrived, Barlow wrote to the eminent Professor of Astronomy in Copenhagen, Heinrich Christian Schumacher. The astronomer, unaware of the prior existence of any such work, checked with Commodore Wleugel, a Commander in the Royal Danish Navy, Director of Navigation, Superintendent of the Danish Nautical Schools, and Knight of the Order of Dannebrogen. In April 1820, the many-titled compass expert had performed the crucial role of witness to Schumacher's colleague, Hans Christian Ørsted, in his famous demonstration of magnetic induction using a compass needle, mentioned in chapter three. Quickly translated and published throughout Europe, Ørsted's experiment has been recognised by historians as a seminal moment in the history of electromagnetic research. Wleguel's presence, however, is a reminder of the significance to readers as the news broke. Magnetic induction was fundamentally associated with Danish compass needles.[633] Wleugel responded to Barlow in June 1820, just two months after witnessing Ørsted's demonstration. His reply was encouraging: Wleugel judged

[631] Barlow,1823a,p.84.
[632] Banks:Mudge,1819 in The Edinburgh Philosophical Journal,1821,p.266.
[633] Jelved,Jackson,&Knudsen,1998,p.413.

Barlow's experiments to be new, and of interest.[634] The discrepancy between Wleugel's opinion and Banks's confident dismissal is significant. The Danish authority to which Banks referred was neither the official state institution of science, nor that of practical navigation; it was the authority of the Greenland whalers, the industrialists of Britain's earliest plantations.

From 1811 onwards the evangelical whaler William Scoresby had served, in the words of Banks's biographer, as 'his most intelligent channel of information about the far north beyond the Arctic Circle', and further, through Banks, a vital channel of scientific news that shaped the Admiralty's governing ideas.[635] The two had met in 1807, in the aftermath of the bombardment of Copenhagen and Abolition Act, Britain's pincer movement retaliation to the French Continental System. Following the siege, the British government had made a call upon all seamen, 'especially upon those engaged in the Greenland trade', to assist the Admiralty in bringing the captured Danish fleet into the British port of Portsmouth. Scoresby was among the first to offer his services, but it would be a salutary experience, leading him to regret his impulsive support, denounce the injustice of seizing, by force, the fleet of a nation at peace; and question 'an opinion [he] had been taught to hold', namely 'that whatever government did must be right'.[636] In particular, the brutality of Admiralty discipline 'so unlimited and so arbitrary', which would carry out 'the most daring and unrelenting violations of every principle of justice and humanity', left the eighteen-year-old, raised on the strong principles of justice in the labour lore of the whale boats, physically sick.[637]

Returning from Portsmouth to his home in Whitby, Scoresby followed the advice of his father, a veteran of the Greenland fisheries, to present himself at Banks's house in London. In making the suggestion Scoresby Snr took care to equip his son with the very latest information on the weather and associated state of hunting and trade within the Arctic Circle. 'You may tear this off', advised Scoresby's father, 'to specify your business with Sir J.'[638] The old whaler's advice was astute, and so, still reeling from the capture of the Danish fleet and his disillusionment at the brutality of the state in contrast to, as he saw it, the justice of the labour lore of the Greenland plantations,[639] Scoresby Jnr presented himself to Banks, winning the close patronage of the aging statesman, at the very moment that Banks was preoccupied in

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[634] Schumacher in The Edinburgh Philosophical Journal,1821,p.266.
[635] Carter,1988,pp.505-7.
[636] Scoresby-Jackson,1861,p.39.
[637] Scoresby-Jackson,1861,p.57; Bulstrode,2019a,p.177.
[638] Scoresby Snr in Stamp&Stamp,1976,pp.30-31.
[639] Bulstrode,2019a,pp.175-7.

drawing up his advice to the Home Secretary on what was to be done with the Icelandic merchant vessels captured along with the Danish fleet.[640]

Iceland had been governed by a Danish trading monopoly since the beginning of the seventeenth century. In 1801 motivated by, as he saw it, the absolute necessity of maintaining free trade between Iceland and Great Britain, the premise of the 1672 Act, Banks had proposed the British government seize the Danish colonial possession by force. Developments in the war with France ran ahead of this proposal, but in 1807, following Napoleon's instatement of the Continental System, Banks was again pushing for a hostile takeover when the British captured the Danish fleet. Under these new circumstances he once more put aside direct military control as not in the best interests of securing the trade, and became completely absorbed in the workings of the Prize Courts, in his efforts to release the Icelandic merchant vessels. In this way, at the very same moment that the Prize Courts became the forum for the purchase of enslaved Africans under the newly nationalised human trade, Banks threw himself into understanding their process to protect the fourth corner in that quadrilateral market; and Scoresby, a fresh-faced expert on the Greenland trade, carrying the latest news of it and of the captured Icelandic merchant vessels, serendipitously appeared in his drawing room.[641]

At this point, in 1807, Scoresby was supplementary to a number of other sources, namely a corporation of merchants, intent on exploiting the Iceland trade. However, over the subsequent few years their sin of poor judgment regarding the weather conditions was fatally compounded by their short-lived coup of the Danish colony, undertaken without the permission of the British government. Banks, shocked by their actions, dismissed these one-time clients from his life. Despite succeeding in pushing through a Privy Council order in February 1810 that, with his thoughts focused on the rich resources of the whale fisheries, declared Iceland to be neutral with regard to trade, the old problem of prohibitively high protective duties on imports in British ports persisted. With the well-informed whaler now his principal channel for information, Banks secured a special dispensation from the Board of Trade, for the Anglo-Icelandic trade to follow the old iron route through Denmark.[642]

This was the basis of their relationship, with Banks an active patron, fostering and shaping the development of his protégé's scientific enquiries, which focused, in those initial years, on the climate, ice conditions, and natural resources of the fisheries. While Scoresby began to

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[640] Carter,1988,p.505.
[641] Carter,1988,pp.458-60,p.505.
[642] Carter,1988,pp.460-2,p.465,p.468.

attend to the variation of his ships' compasses as early as 1813,[643] his private papers note that he did not study the anomalies of the compass needle until 1815,[644] a shift in attention that coincided with that of his patron. For Banks, 1815 saw renewed scrutiny of Mudge's anomalous survey result, and concern at the local attraction of iron disrupting this valuable enterprise and the fragile post-war Anglo-French collaboration. As mentioned in chapter four, while the post-war Anglo-French collaboration made salient to Banks the concern of iron's attraction, it also enraged him at the depressed state of Britain's mining interests.[645]

Following the 1818 Longitude Act encouraging attempts to find a Northwest passage, Scoresby determined to stay home during the fishing season of 1819 to superintend the construction of a new whaling vessel, the *Baffin,* and at Banks's urging to take the opportunity to publish the results of his experience as a renowned Arctic navigator.[646] In the spring of 1819, he moved from Whitby to Liverpool to give close supervision to the construction process, and, in turn, himself received Banks's close supervision over the assemblage of his experiences, beginning with a natural history of the Greenland trade, and a natural history of iron used in ships' construction as diagnosed through the performance of the compass.[647] In those early months of 1819 following his move to Liverpool, what had been shipboard experiment between 1815 and 1817 became concerted efforts in the manipulation of iron to construct his own magnetic instruments.[648]

The culture into which he had entered was dominated by the peculiarity of the Liverpool maritime trading empire, and the technocracy that ruled over it:[649] dynasties of iron connoisseurs, expert iron traders,[650] with political power that extended the transatlantic reach of their trade.[651] Liverpool in 1819 was an exciting place and time for the shipbuilding trade. Four years earlier, the Liverpool nail-maker and iron magnate, Thomas Jevons, part of a Liverpool genealogy of ironmasters,[652] had built and launched onto the Mersey, a small pleasure boat made entirely of iron. Just the previous year, 1818, saw the launch of Edinburgh inventor Sir John Robison's iron vessel for passenger traffic on the Forth and

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643 Scoresby,1813, in Jackson,2009,pp.220-22.
644 Scoresby,[c.1854],**WHITM**/SCO/324/9.
645 Carter,1988,p.517.
646 Scoresby-Jackson,1861,p.146
647 Scoresby,1819,pp.96-106.
648 Scoresby,1823b,pp.243-4.
649 Reidy,2003,pp.45-71; Kitteringham,1982,pp.329-348.
650 Dickinson,1956,pp.90-91.
651 Birkenhead Improvement Commissioners,[1837-79],**Wirral**,B/104/4; House of Representatives,1839.
652 Dickinson,1956,pp.90-91

Clyde Canal.[653] It was a region intimately linked to Liverpool in the early decades of the nineteenth century, by the diaspora of dispossessed and starving Irish who crossed the Irish Sea to take up work in Glasgow and Liverpool shipyards, and by the power and wealth of the maritime trading network between Dublin, Liverpool, Glasgow and the Americas. From the industrial cultures assembled in Mersey's shipyards emerged a particular connoisseurship of iron working, a tradition so strong that it persisted even six decades on, as testified by William Laird of the Laird family of Liverpool shipbuilders. When asked by a Parliamentary Select Committee whether he approved of the Admiralty's adopted approach of using a hydraulic press to judge the quality of iron, Laird replied,

> The best way is to look at it, and the best of all is to put a piece in the fire and forge it, and knock it about. I might break the iron over and over again, in order to see what iron would do; it is very curious and interesting, but if I were buying I should go by the eye and by working in the fire.[654]

For Liverpool shipbuilders immersed in the iron trade, the commodity value of iron could only be manifested through working it. This was the core of Scoresby's magnetism, which understood magnetic phenomena as emergent properties, to be drawn out through percussion. For Scoresby all magnets were the product of artifice, and the quality of their properties depended on a combination of the quality of the material and the quality of the beating.[655]

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[653] Young,1867,pp.25-35.
[654] Parliament,1874,p.35
[655] Scoresby,[c.1854],**WHITM**/SCO/324/1.

Figure 5.2: "With a blow from the top-maul Ahab knocked off the steel head of the lance, and then handing to the mate the long iron rod remaining, bade him hold it upright, without its touching the deck. Then, with the maul, after repeatedly smiting the upper end of this iron rod, he placed the blunted needle endwise on the top of it, and less strongly hammered that, several times, the mate still holding the rod as before. Then going through some small strange motions with it—whether indispensable to the magnetising of the steel, or merely intended to augment the awe of the crew, is uncertain—he called for linen thread; and moving to the binnacle, slipped out the two reversed needles there, and horizontally suspended the sail-needle by its middle, over one of the compass-cards. At first, the steel went round and round, quivering and vibrating at either end; but at last it settled to its place, when Ahab, who had been intently watching for this result, stepped frankly back from the binnacle, and pointing his stretched arm towards it, exclaimed, - "Look ye, for yourselves, if Ahab be not lord of the level loadstone! The sun is East, and that compass swears it!""

Melville, Herman, 1892, *Moby Dick; or The Whale*, Boston: The St Botolph Society, p.482.

Melville, Herman, 1942, *Classics Illustrated -005-Moby Dick*, USA: Gilberton Company Inc., p.32.

This Liverpool iron trade is indispensible for understanding the development of Scoresby's striking magnetic researches, but also, crucially, to recognising how this research was understood by his contemporaries. The move to Liverpool concentrated Scoresby in every way on what it was that constituted the virtuoso knowledge of the Greenland trade, namely a peculiar kind of experimental natural history of commodity iron,[656] characterised by a particular 'mechanical violence.'[657] The American novelist Herman Melville provides a dramatic insight into how Scoresby was read and understood in his own time. On 29 April 1850, just days after registering for membership at the New York Society Library, Melville borrowed two books by Scoresby: *Account of the Arctic Regions*,[658] and *Journal of a Voyage to the Northern Whale-Fishery.* For over a year, between 29 April 1850 and 14 June 1851, while he worked on the composition of *Moby Dick*, Melville pored over the text of Scoresby's works. The resulting narrative is a testament to the closeness of his reading. In an episode taken directly from Scoresby's *Journal*, Melville described Ahab forging a magnet from ship's iron, after a lightning strike reversed the ship's compasses (Figure 5.2).[659] The hammering and 'strange motions' of Ahab, were the response of an awed reader to Scoresby's percussion and stroking, as the Whitby whaler, while at latitude of 79° 30', in the middle of the Greenland sea, dismantled the *Baffin* and re-forged her iron, to turn his ship into an instrument.[660] Scoresby's 1823 *Journal* described virtuoso experiments first begun as Banks's protégé in the years 1815 through 1817,[661] which found their fullest expression with Scoresby's move to the centre of the Liverpool iron trade.

Scoresby described the utility of his discovery through reference to a letter published in the Royal Society's *Philosophical Transactions*, detailing the experience of a Dublin shipmaster, on a voyage to Barbados, in company with another vessel commanded by a New-England captain.[662] In the latitude of Bermuda, the very same derived by Melville for his episode on the *Pequod*,[663] the ships were caught by a lightning storm, which broke the New-England vessel's foremast, tore its sails and rigging, and, the Dublin master realised, inverted the polarity of his compasses. Scoresby himself noted 'I have never seen lightning northward of latitude 65°', going so far as to state that 'Lightning, indeed, is seldom seen to the northward

[656] Bycroft,2013,pp.31-51.
[657] Scoresby,[c.1854],**WHITM**/SCO/324/1.
[658] Scoresby,1820a; Scoresby,1820b.
[659] Heflin,1948,pp.323-327;Melville,1892,p.482.
[660] Scoresby,1823a,pp.52-60; Sorrenson,1996,pp.221-36.
[661] Scoresby,1823b,pp.243-4.
[662] Scoresby,1823a,p.55; Anon.,1676,pp.647-8
[663] Melville,1892,p.468.

of the arctic circle'.[664] His interest in the challenge presented by lightning strike was part of the salient significance of Arctic expertise to the quadrilateral trade, where such a case 'has occurred hundreds of times.'[665]

Numerous factors converged in Banks's refusal to publish Barlow's research, not least long-standing animosity between Banks and Gregory over the Royal Society's poor treatment of Charles Hutton. But it is the aging statesman's given reason that is so telling: the existence of prior Danish work 'many years ago', though he was 'ignorant of the Danish language', and when Barlow raised the issue with the Danish authorities, Schumacher and Wleugel, no such work was known.[666] For Banks, Scoresby's knowledge of the Arctic trade and above all his expert shopper's connoisseurship of iron was so associated with the Hamburg trading nexus, Scoresby himself so associated with the cosmopolitan identity of the whaler, the information he fed Banks had become Danish. Banks saw Barlow and heard Scoresby because the significance of their respective researches lay in the deviation of the compass as a measure for the quality of iron. Above all, the moral of the evangelical whaler's message was that iron might be known in the disassembly of the ship and the manufacture of the compass. For the Woolwich mathematician, it was the disassembly of the compass and the manufacture of the ship.

§3: the wrong Schumacher

On Saturday 29 January 1820, as the Kingdom of Great Britain, Ireland and, since the 1814 Vienna congress, of Hanover, passed from George III to his son, Barlow sat in an office borrowed from a former pupil and pulled apart over a hundred Admiralty compasses. The 'great masses of iron' surrounding the Royal Dockyard Store made it impossible to examine the state of the instruments on site. So the professor had appealed to his student for the loan of his space. The test was simple: Barlow dismantled the compasses, and taking the cards, an assemblage of compass rose and magnetic needle, placed each in succession on the same pivot. The 'errors in bearing' were then determined against 'the true magnetic meridian,' as indicated by a Gilbert compass. Submitting his report to the Lords Commissioners of the Admiralty, he condemned the Admiralty compasses as 'mere lumber', that is, bad timber, 'which ought to be destroyed, on the same principle as we clip base coin, being wholly useless while in store, and extremely dangerous if suffered to pass out of it.'[667] Barlow's report

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[664] Scoresby,1820ap.415.
[665] Scoresby,1823a,p.56.
[666] Banks in The Edinburgh Philosophical Journal,1821,p.266.
[667] Barlow,1837b,p.664.

weighed the instrumentation of Admiralty navigation against that of Britain's trading empire, and found it wanting.

For nearly two decades this report would remain buried in Admiralty archives, but far from sanction, it won him further support, further institutional access, and his first opportunity for shipboard experiments. Just a few months later, in April 1820, Barlow was assigned the use of the HMS *Leven,* then fitting out at Woolwich in preparation for the anti-enslavement campaign. Historians have identified polar exploration and the Africa anti-enslavement expedition as coeval concerns in the wake of the 1818 Longitude Act. The concern of this chapter is their integral relation.[668]

For the *Leven* experiment Barlow identified true magnetic north just as he had done in January that year in Bonnycastle's office, by using a Gilbert azimuth compass. As ever his first preoccupation was to identify a neutral line of absolute authority. This bearing he then fixed with a Schmalcalder theodolite, positioned immediately over the azimuth compass, before removing the compass itself to the ship. On shore, Mudge was charged with the theodolite, and on board ship, survey officer Lieutenant Alexander Thomas Emeric Vidal with the compass. The *Leven* was then allowed to swing on the tide through a series of bearings, while Mudge and Vidal read bearings from their respective instruments in observations synchronised by a two-part cry, "look out" to be on their marks, and "stop" to register. This was surveyor's science and the metal of the ship under survey. Independent of local attraction, Barlow argued, these bearings should be diametrically opposite, and so any difference between the two was the error due to the iron on board. He assumed observations from the two different instruments, the Gilbert azimuth compass and the Schmalcalder theodolite, could be treated in direct equivalence. The experiments were made first without guns on 17 April, then repeated two days later with the guns loaded on board.[669] By taking the difference between the azimuth and the theodolite bearing, Barlow reproduced the effect of arranging the compass around the hub of iron, described in chapter three. By observing before and after the placement of the guns, he reproduced the effect of raising and lowering the shells. Precisely because of his cosmology of manufacture, Barlow was able to characterise the ship as a magnetic instrument.[670]

In 1821, Barlow began to elaborate his principle of magnetism as the science of ferrous manufacture, studying the relative magnetic power of different species of iron. This analysis

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[668] Dunn&Higgitt,2014,pp.237-248.
[669] Barlow,1823a,pp.90-2.
[670] Sorrenson,1996,pp.221-36.

then led to further experimentation, directly linked to Admiralty concerns, on the anomalous magnetic action of hot iron between the white and blood-red heat, and its consequent influence on the compass. In the wake of the Napoleonic wars, the Admiralty were under pressure to reduce the number of mobilised men and ships. At the same time the system of gun-boat diplomacy by which the fiscal-military state forced and maintained its monopolies, made the post-war government reluctant to lose military strength just as they were keen to cut costs. To solve the dilemma, in 1823 the overseas Post Office mail packets were transferred to the Admiralty. The contracts and agreements made between the Post Office and the individual packet captains transferred to the Navy Board, and as each contract expired a naval packet took the place of the privately owned hired vessel. The Admiralty was able to maintain the size of its force, and the state made savings while weaponising the nationalisation of the British trading empire.[671] In order to meet the needs of a packet service, the Admiralty now found itself either taking on existing packet steamships, and fitting guns; or continuing gunships and fitting steam engines.

The raising and lowering of guns, Barlow had shown, exerted a magnetic influence, but nothing like as powerful as that generated by a steam engine boiler made of iron. While 'Copper' was according to the 7th edition of the *Encyclopaedia Britannica,* 'the best of all substances for steam-engine boilers', by 1842 wrought-iron boilers were 'almost universal'. The 'mechanical point of view' was outweighed by the mercantile. '[F]or the explanation of the general use of iron,' the *Encyclopaedia* directed its readers 'to the state of mercantile affairs, and the value of money in the commercial community.'[672] Benefiting from Lord Liverpool's post-war policies, the new iron was cheap. Much more than iron hulls, which were no novelty in the longstanding history of composite ship construction, the crisis of compass deviation was an index for the coming of steam. Barlow's research on the anomalous magnetic action of hot iron between the white and blood-red heat showed that while heating iron destroyed any permanent magnetism, it generated a temporary induced magnetic state of far greater power.

As section two described, in 1820 Schumacher had written attesting to the originality of Barlow's compass researches. Encouraged, Barlow wrote again in November 1821 offering his observations on the relative magnetic power of different species and temperatures of iron for publication in Schumacher's recently established *Astronomische Nachrichten,* already the premier astronomy journal. Despite the highly theoretical and abstract status of the journal's content, the Copenhagen professor had good reason to attend to Barlow's paper. As director

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[671] Laakso,2007,p.84.
[672] Encyclopaedia Britannica,1842,p.676

of a newly founded observatory just half a mile from Hamburg in German-speaking Altona, he was now in charge of weights and measures and the commutation of standards from all the colonial trades that converged there on the bank of the Elbe; not least, as the introduction described, the iron trade. Unfortunately Barlow failed to specify which Schumacher his article was intended for, and, as a result, his paper initially spent nearly two years on the desk of Heinrich Christian Friedrich Schumacher, Copenhagen professor of anatomy, before it found its way to Heinrich Christian Schumacher, Copenhagen professor of astronomy. Frustrated by the delay, the editor of *Astronomische Nachrichten* published the paper directly without waiting on a translation.[673] However, its appearance in 1823 prompted a spate of German translations and publications of Barlow's research. Not only an extended write up of his research on iron, magnetism and blood red heat,[674] but also his 1820 *Essay on magnetic attractions*,[675] and an original paper on the experiment and theory of the magnetism of iron,[676] were all translated and published in the most important physics journal in Germany, *Annalen der Physik.*[677]

Edited by Ludwig Wilhelm Gilbert, the professor of physics at the University of Leipzig, *Annalen* was at the centre of the post-war fight for the German Confederation's soul; specifically, whether the depressed German lands should seek to recover through utilitarian or through spiritual reform.[678] Just as described in chapter one, where the Cornish steam engine brought into the Prussian garden afforded some unification of the two aims, so too did the publication of Woolwich research, carrying with it not just utilitarian data on Woolwich iron and steam, but also a theory of manufacture as natural law, such that in the subsequent period, the *Annalen* became a significant organ for Faraday's research described in chapter three.

§4: the wrong Johnson

If Barlow's research under Woolwich steam made it big in the *Bund*, still the Board of Longitude, now principally Young, kept him at arm's length. The contrast with their approbation and subsequent commission of Edward Johnson, a young survey officer from Newcastle, is significant. On 21 April 1826 Johnson wrote to the Lords Commissioners of the Admiralty with a report of numerous experiments he had undertaken in his own time, while posted overseas. Scrawl on the reverse of the last page of the report records the bureaucratic

[673] Barlow,1823b,pp.193-6
[674] Barlow,1823d,pp.229-244
[675] Barlow,1823c,pp.11-41
[676] Barlow,1823e,pp.1-10.
[677] Jungnickel&McCormmach,1986,pp.34-44.
[678] Caneva,1978,pp.123-59.

exchange that ensued. Sent to Parry, with the query 'is there anything valuable in this', the then hydrographer to the Admiralty noted:

> There is considerable ingenuity in some of these Experiments, which have been communicated to Drs Young & Wollaston

Under this, Young and Wollaston had signed their agreement with a courteous 'thank him for his communication.' Parry, Wollaston and, Young, all highlighted 'One fact' in particular in Johnson's report, 'viz the effect produced on a compass needle by the mere rubbing of the glass with a silk handkerchief in order to clean' to be 'new & of practical importance at sea'. Johnson himself noted that 'it is known that electricity may be excited by friction on glass yet I am not aware that it has ever been shown that [cleaning the glass to take an observation excites electricity].' He was concerned with 'the delicacy of [the needle's] movements on which the breath, the body, or a button may effect a change.'[679] If Barlow was concerned with the movement of guns, the Board was concerned with the movements of people and Johnson went on the books as a man who might come in useful.

Nearly a decade later, in 1835, Johnson found himself recalled from the institutional memory of the Admiralty archives, and selected as the right man to discover publicly what, through Barlow and Scoresby's research, the institution already knew: that each ship had its own magnetic character and that this character was dynamic with its career and construction. How the Admiralty proposed for Johnson to make the discovery mattered. Just two years before taking over the domestic packet service, the Admiralty commissioned Johnson to undertake a series of observations on the deviations of the compass of a celebrated iron steamer, the *Garryowen*, recently completed by Laird of Liverpool and in the service for The City of Dublin Steam Packet Company on the Shannon.

The City of Dublin Steam Packet Company, founded to maintain year-round shipping between Dublin and Liverpool, was formed in 1823,[680] under the directorship of Charles Wye Williams, an iron ship evangelist who contracted to Laird from 1831 onwards.[681] In 1834, newly built, the *Garryowen* had come aground with an impact that would have wrecked a wooden ship. Her survival was a source of great pride for Williams, and an important showpiece for public trust in iron ships in the evidence he presented to the Select Committee on Steam-navigation to India that same year.[682] At the same time the *Garryowen's* older sister, the *Alburkah*, toured Africa to demonstrate the potential of the iron ship as a tool of

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[679] Johnson:Croker,[21/04/1826],**NA**/ADM/1/2967.
[680] Tutty,1963,p.83.
[681] Delany,1958,p.190.
[682] Parliament,1834b,p.43.

empire.[683] Johnson's commission to trial the *Garryowen* in the Shannon was a powerful proxy for this global colonial stage.

County Clare, where Johnson trialled the *Garryowen* was a centre for Irish nationalism. In 1828, the County had elected former barrister, Daniel O'Connell, a Catholic Irish nationalist spectacularly successful at mobilizing organised popular support. In explicit alignment with popular radical and reform movements in Britain, on his election he announced: '[t]hey must crush us or conciliate us. There is no going on as we are'. From 1831 through to 1836, O'Connell and his supporters were central to the tithe wars, a reaction to the imposition of church tithes on the Roman Catholic majority, violently and fatally enforced by the British army. In 1834, a House of Commons Select Committee appointed to investigate and improve the state of navigation of the River Shannon and its tributaries recommended as an immediate step that the whole of the Shannon should be placed under the control of a single Board.[684] The committee noted that '[they were] aware, that in calling the attention of the House to the manner in which they recommend raising of the Funds which will be required for the improvement of the Shannon they are about to touch on a very delicate subject', nonetheless they proposed raising revenue through further taxation on the population of the County. 'The inland navigation of Ireland being extended would enable England to draw her supplies of corn from countries where both the land and the labourers are now comparatively idle'. In return, England would 'throw into the interior' of Ireland her produce, and the Irish 'would soon become consumers of [English manufactures] to a great extent.' The Irish would, they argued, benefit so greatly from this consumption, further taxation was justified.[685] Meanwhile, the inhabitants of the banks of the Shannon cut down the beacons that guided steamers, resisting by wrecking and running aground this colonial trade and creeping encroachment of direct rule.[686] Williams's enthusiasm for iron hulls was a dependence on iron that could withstand the violent impact of County Clare resistance. The iron ship steam navigation of the Shannon, its corn drain and its revenue stream was the focus of the radical politics of the region, and a microcosm of colonial tensions globally. At the core of this colonial extraction was a capital structure reconstituted in iron. This was the context in which Johnson trialled the *Garryowen*, linking the distant geographies of the Shannon and the Niger.

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[683] Headrick,1981,pp.27-30.
[684] Delany,1958,p.190.
[685] Parliament,1834a,pp.142-3.
[686] Delany,1958,p.189; Parliament,1834a,p.23.

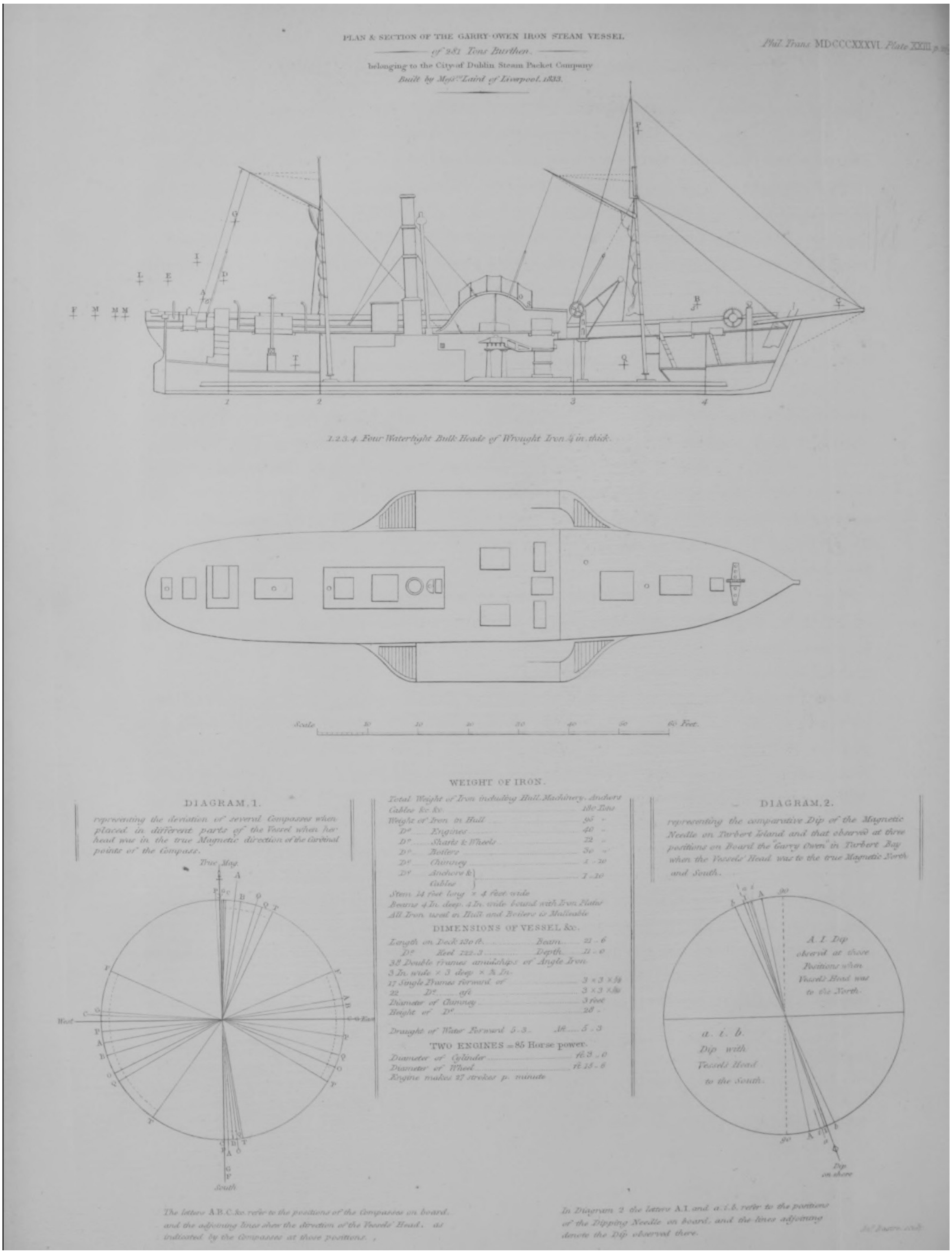

Figure 5.3: Johnson, Edward J.,1836, Report of magnetic experiments tried on an iron steam vessel, *Philosophical Transactions of the Royal Society of London*,126, 31 December, 266-288, Plate XXIII.

Having received extensive advice from Barlow,[687] Johnson tested the bow and stern of the ship in succession, swinging the vessel on a single anchor before a quay lined with magnetic instruments.[688] Despite Scoresby and Barlow's research, before Johnson's investigations it was widely believed that the local attraction disrupting compasses was due to a transient magnetism induced in the ship by the earth's magnetism, in contrast to the permanent magnetism of a bar magnet. The contribution of Johnson's experiments was to make explicit the overlap between the conclusions of Scoresby, with his focus on mechanical violence, and Barlow, with his attention on the ship's magnetic character and arrangement (Figure 5.3). In doing so, Johnson proposed that the local attraction was in fact a combination of induced and permanent magnetism; that, 'in the construction of iron vessels, hammering the numerous rivets might elicit magnetic influences' and further, that 'the directions of their heads and sterns [with respect to the magnetic meridian] when building' might determine its polarisation. He cautioned similarly regarding the furnace on board, '[a]s it is known that iron when it is heated to a red colour attains an extraordinary magnetic power'. Johnson's analysis revived the long-past forces of construction in the ship's present cold form and noted the worrying potential for the ship's properties to change in use. His report completed, the establishment machinery cranked into action and, though an unknown Lieutenant from a small village outside Newcastle, within a few months his report was accepted for publication in *Philosophical Transactions*, with Johnson himself elected a Fellow of the Royal Society later that same year after being proposed by Barlow and prominent figures among the magnetic lobby such as Beaufort, Franklin, Christie, among others.[689] To make a splash of Johnson's *Garryowen* experiments, the Admiralty made sure to make much of Johnson. On 27 December 1838, Secretary to the Lord Commissioners of the Admiralty, John Barrow, wrote to Naval Commander, Edward Johnson, promoting him to the rank of Captain.

On 15 March 1839, the Admiralty realised they had the wrong Johnson. Barrow's letter had gone to a notoriously indolent Johnson residing in North Thomas Street, Belfast. The intended Johnson was in London fully occupied with his appointment to the Admiralty's Magnetic Committee as of 18 July 1837.[690] Otherwise known as the Compass Committee, this was a council of six officers 'conversant with Magnetic Instruments,'[691] of which the intended Johnson was the only one occupied full time on the committee's business: to review and improve the state of Admiralty compasses, with Barlow's compass report as mandate.

[687] Johnson,1836,p.267.
[688] Johnson,1836,pp.281-5.
[689] 'Johnson,[1836],**RS**/EC/1836/16.
[690] Johnson (of Belfast):Barrow,[11/03/1839],**NA**/ADM/1/2001.
[691] Barrow,Beaufort et al,[18/07/1837],**CL**/ACO/11/16.

§5: the Admiralty Compass Committee

In 1837, the Admiralty had taken over the domestic packet service. Together with the overseas service nationalized in 1823, this meant the Admiralty now controlled the world's largest steam fleet.[692] The steam packets ran almost entirely on coal, a significant cost compared to wind or animal,[693] yet an indispensible part of binding globalization to British production. That year, in 1837, Parry was appointed Admiralty Controller of Steam Machinery. After a decade of Arctic exploration and Admiralty hydrography, he had taken charge of the Australian Agricultural Company overseeing coal exports to India. He then served as a Norfolk Poor Law commissioner between 1835 and 1836, before being called upon by the Admiralty to reorganize the packet service and negotiate its steam contracts. In this latter capacity he researched the best coals to burn, joined in the 1840s by the jobbing geologist and Jamaican enslaver Henry De La Beche, introduced in chapter one, who ran the Admiralty Coal Enquiry between 1845 and 1850. While these researches sought to optimise the efficiency of coal, Admiralty steam was already powered by the optimization of labour extraction: child labour in British coal mines, and maintenance of enslaved labour in colonial coaling stations, including the West Indies, long after the 1833 Abolition act.[694] With characteristic *au courant* for over a year before the domestic packet service was transferred, Barlow had been conducting Admiralty experiments on the most efficient speed to run a steamer for coal consumption, experiments in effect to measure the duty, in the Cornish engineering sense, of a steamer.[695] At the same time, he had been serving on a Royal Commission to report on the establishment of railways in Ireland, the origin of the notorious broad gauge,[696] which would in the second half of the nineteenth century bind India in an indenture of iron.[697]

While technically still only a lowly third mathematics master at Woolwich Academy, Barlow had long since established an international career as the authority on his pattern science of manufacture: magnetism, expressed in fields ranging from optics to steamships and locomotives. Honoured by the Tsar Alexander for the direct benefit of his magnetic research to the Russian Navy, made a corresponding member of the Académie des Sciences, and

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692 Owen,2002,pp.155-175.
693 Malm,2016a,p.90,pp.159-60; Malm,2014.
694 Anim-Addo,2011,pp.65-84.
695 Barlow:Barrow,[7/11/1836a]; [7/11/1836b]; [15/11/1836], **NA**/ADM/1/4400. Barlow:Barrow [7/11/1836]; [15/11/1836]; [5/04/1837], **NA**/ADM/1/4401.
696 Brunel,1870,p.101.
697 Headrick,1988,pp.276-9; Dutt,1950,pp.353-370.

elected to the Imperial Academy of Brussels and the Royal Society, which learned institution subsequently awarded him their prestigious Copley Medal, most recently in 1832 Barlow had been elected to the American Academy of Arts and Sciences. In March 183,7 one of Barlow's fellow American Academy members, electromagnetist and first Chair of Natural History at the College of New Jersey, Joseph Henry, sought him out at Woolwich while visiting Britain, but

> could not without much difficulty find his residence… One man of whom I inquired for Prof B. said no such man belongs to our regiment. Another said I am sure he is not a member of the 79th. A third I have heard of the person but do not know where he is to be found.

Baffled, Henry wrote in his diary: 'I was much surprised to find tha[t] a person who[se] name is know[n] where ever science is cultivated should not be better known in his own village'.[698] Barlow had moved on from that brief report on Admiralty compasses submitted some seventeen years previously, a small pilot grant from the earliest days of his celebrated decades. When, in August of 1837, hydrographic officer and editor of the seafarer's monthly, *The Nautical Magazine,* Lieutenant Alexander Bridport Becher wrote asking permission to publish his compass report, dredged from Admiralty archives, Barlow had no idea what he was talking about. But of course, he responded, he was happy to comply, 'if you have any Report of mine it is quite at the service of N[autical] M[agazine] I do not know which it is or rather what it is but be it what it may it is at Lt Becher's service.'[699]

In October 1837, Barlow's report was finally made public. The human trade had been putatively abolished three decades previously, but it was only four years since enslavement itself had been declared illegal in British territories, not including any of those in the possession of the East India Company, the Island of Ceylon, or the Island of Saint Helena. James Robertson's account of Jamaican plantation patents was described in chapter one for its explanation of the Cornish-derived system based on divisions decided using the magnetic compass. In 1832, the year before the enslavement Abolition Act, Robertson's account was re-published by the Royal Society in a condensed form.[700] Now in 1837, four years on from the Act, Becher's editorial framing deployed the big guns of the language of reform to compass deviation. First, he highlighted 'the danger of the evil so clearly pointed out', and then he called for the urgent necessity of 'a total abolition of such grievances'. Having set up the crisis he immediately presented the solution, declaring his 'satisfaction' in announcing,

> the recent appointment of a committee by the Lords commissioners of the Admiralty… hydrographer to their lordships' captain Beaufort; Professor Christie, of

698 Henry,1837 in Reingold,1979,pp.195-6.
699 Barlow:Becher,[15/08/1837],**UKHO**/MLP102/1529.
700 Robertson,1832,pp.241-2

> Woolwich; Commander J. Johnson; Captain [James Clark] Ross; and Major Sabine, names which combine science with long experience.[701]

Becher's fine denouement to the proffered compass crisis was only slightly spoiled by forgetting to list East India Company engineer Thomas Best Jervis among the committee's number. Of the six, Jervis was the only one not already a fellow of the Royal Society, though by February of 1838, Beaufort, Sabine, and Ross, nephew of John Ross, among others, had proposed him, citing his 1835 essay on the discovery of a universal standard of length he believed to be discernable from passages of Holy Writ,[702] his long engagement with the Great Trigonometric Survey of India, and his recent purported appointment as Surveyor General of India.[703] Chapter one set out how, the following year at the Newcastle British Association meeting Jervis argued vocally for the reform of the magnetic compass and survey as instruments of population control.[704]

The Committee met for the first time on 24 July 1837 and in drawing up their plans recalled Scoresby's presentation at the previous year's Association meeting, where the former whaler had demonstrated two of his instruments. The first, built to measure magnetic attractions, was so exquisitely sensitive that it could detect the magnetic effect of the faintest touch on soft iron, and, Scoresby claimed, sense the relative goodness of different species of iron. The second was a variation compass, a fundamental component of survey science used to measure the difference between True North and Magnetic North. In his variation compass the needle was made from the layered busks of ladies' corsets, interposed with thin card-paper, to prevent touching, lest the inequalities of the individual materially weaken the combination of the whole. This 'combination', as Scoresby called it, was then suspended on a single untwisted fibre of silk.

The assemblage was significant. Whalebone was exclusively the product of baleen whales, and, in particular, the bowheads, which are specific to Arctic waters. Until the end of the eighteenth century, whalebone was generally discarded. However, over the first decades of the nineteenth century, while Scoresby was active, demand for the strong, flexible whalebone for use in whips and suspenders grew steadily, until the 1830s, when a shift in corsets and hooped skirts put the whalebone market under extraordinary strain. In the 1830s alone, the amount harvested increased seven-fold while the real price of whalebone per pound almost

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[701] Becher,1837,p.666.
[702] Jervis,1835,pp.2-3.
[703] Jervis,[1838],**RS**/EC/1838/17.
[704] Jervis,1838,pp.3-6

doubled.[705] In 1836, corset busks stood for the property and prosperity of the Arctic whaling industry and the potential delicacy of the industrial instrument. Soft iron, like the iron Scoresby stroked at the Association meeting, was critical for whalers because soft iron bent rather than broke in the whale. To claim the kill not only were these harpoons marked with parchment, like the paper that interleaved Scoresby's corset busks, but the line to the harpoon, like the single thread of unspun silk, had to hold.[706]

Scoresby's demonstration made an impression on the Association audience, not least Christie, Sabine, and Ross, all of whom were presenting on their own magnetic researches. Mastery of the magnetic needle was key to the whaling captain's power. When Ahab demonstrated the compass he had forged, he called out to his audience of awed seamen, 'Look ye, for yourselves, if Ahab be not lord of the level loadstone! The sun is East, and that compass swears it!'[707] In Ahab's pride Melville showed what was salient in Scoresby's mechanical theatre. In his *finale*, Scoresby claimed that, 'Professor Christie… had even stated his conviction… that by this [instrument], the magnetic effect of the solar rays, and the change caused by the passing of a cloud, would become perceptible.'[708] Even three years on, Scoresby would still recall Christie's response with hot shame.[709]

Christie was the British Association and Royal Society's designated expert on magnetism, with over sixteen years of experiment and prestigious publications, specialising in the magnetic effect of solar rays. His comment that '[h]e did not mean to convey to Mr Scoresby the impression that he had tried any experiments upon the magnetic effects of the solar ray, or of clouds being interposed' reveals the scorching sarcasm of his mock praise. In front of the learned audience, Christie made clear that Scoresby was not to quote him, that theirs was a different science, and others before had observed what Scoresby only manufactured. In so saying the mathematician took from Scoresby the property of his skill, rendering the whaler and the dramatic power of his layered busks, his 'Magnetic Combinations',[710] mere show. Christie was a principal figure in the campaign to establish a network of magnetic observatories. Described by Sabine as 'a great combination, embracing the whole globe in its field of action, and all civilised nations as co-operators',[711] this was a magnetic combination in the social, political sense. Since his earliest researches, however, Christie had taken care to

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[705] Deal,2016,p.21.
[706] Bulstrode,2019a,pp.167-85.
[707] Melville,1892,p.482.
[708] Athenaeum,1836,pp.628-9
[709] Scoresby:Ross[1/2/1839],**CL**/ACO/11/6.
[710] Scoresby,1839,pp.133-185.
[711] Sabine:Lloyd,[20/12/1839],**RS**/MS/119/80.

distinguish his work from those of men like Scoresby, noting that his was 'more of a philosophical nature', pertaining to the influence of the sun.[712] If Scoresby's cosmology was labour and the lode-stone, Christie was a sun-worshipper. In reviewing the work of peers, Christie would strike out any mention of the heat employed in and generated through working metal.[713] His interest in the influence of heat on magnetism was itself a discrimination of status. The heat of labour was too plebeian, and to be excluded. So, according to Christie, was Scoresby's mechanical theatre, which through beating and stroking brought iron into submission.

When the committee met in late July 1837, and, remembering Scoresby's Bristol demonstration, wrote him 'very desirous to avail themselves of any improvements which you may have been able to arrive at', they already had history.[714] In particular, it was the 'aggregate power' of Scoresby's 'combinations', 'considered to possess greater energy than any other', to which the committee were drawn.[715] For this trial Scoresby was required to provide two needles that would illustrate his proposed improvements.[716] The Admiralty provided steel 'not worse than the average supply taken from the dockyards' and Scoresby was commissioned to draw out the most powerful magnetism using his improved mechanical techniques. These needles were then to be submitted to a comparative examination with others,[717] manufactured under Christie's supervision. On Christie's specification, the trial was to adopt 'the <u>Balance of Torsion</u> for the determination of the force of different needles.'[718] The balance design was explicitly based on that developed by Coulomb, in his efforts to turn magnetic compass navigation into a precision science, on behalf of the French government and Paris Académie des sciences.[719] Coulomb's work on torsion carried him from military engineer to astronomer at the Paris Observatory, where he curated his exquisite balance. It was in Coulomb's famous researches that Christie, the ambitious Military Academy professor, saw his practice and purpose.[720]

Scoresby's biographers have noted that, at this stage, 'there was no unpleasantness, nor unwillingness to give freely... just Scoresby's request to personally demonstrate his patented

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[712] Christie,1822,p.173.
[713] Christie,[26/11/1832],**RS**/AP/17/7.
[714] Ross:Scoresby,[24/4/1838],**WHITM**/SCO/1317.1.
[715] Christie, 21/2/1838,**CL**/ACO/11/6.
[716] Johnson:Scoresby,[11/4/1838],**WHITM**/SCO/578.1.
[717] Sabine:Ross,[26/2/1839],**CL**/ACO/11/6.
[718] Christie,[21/2/1838],**CL**/ACO/11/6.
[719] Dörries,1994,p.123; Gillmor,1971,pp.140-6.
[720] Christie,[21/2/1838],**CL**/ACO/11/6.

laminated needle.[721] But his private correspondence in the same months indicates otherwise. Scoresby suggested that the hostility of Sabine and jealousy of Christie had led the 1837 British Association committee to refuse him a grant for support to work on his compound magnetic needle.[722] Unsurprisingly, when Ross wrote to Sabine early the following year regarding the upcoming compass-needle trial, he anticipated trouble between Scoresby and Christie.[723] Eight days after Ross's warning, they assembled in the Admiralty Library,[724] and the committee pulled apart Scoresby, and his compound needles, in a heated contest of disputed ownership. With the needles disassembled, the committee saw no novelty in Scoresby's claims and produced, tellingly, a Danish compass to show that the principle of construction he proposed had long been in use. In 1819, Banks had rejected Barlow's authorship, claiming prior Danish work, where Danish stood for the knowledge of the Greenland fisheries conveyed to him by Scoresby.[725] Now the Committee used the institutional memory of this information, and prizes taken from the Icelandic merchant vessels captured in the 1807 Siege of Copenhagen, to deny Scoresby's priority.

Crushed and confused, Scoresby immediately wrote to Ross on the surprise, pain, and grief the meeting caused him, and then another long missive a day later, stressing the originality of his principle of construction, the combination of layered tempered steel, and his humiliation at the 1836 Bristol meeting by Christie. For their part the committee heard a petulant and unruly artisan, and responded that the results had fallen far short of expectations. Scoresby argued the needles 'were not good specimens, the steel not being sufficiently hard', but the Committee claimed

> The practical question, whether plates of this description will prove themselves to be, all respects considered, the best material to be adopted for the ships compasses is a distinct question.

For the whaler, the quality of iron could not be separated from the skill of its working, and the skill of working was the knowledge of the quality. As Scoresby's shipboard experiments demonstrated, good iron was both subject and measure. By contrast, Sabine attributed the weak magnetism of the needles to Scoresby's mechanical ability alone, with the damning verdict: 'the artist has failed in the steel'.[726] Christie, avoiding even the assessment of mechanical labour, focused on the Danish design. His concern, that '[p]retensions are advanced which would tend to shackle the Committee' was telling. Far from poor work, he

721 Beaufort:Scoresby,[16/10/1838],**WHITM**/SCO/578.7.
722 Morrell & Thackray,1981,p.321,fn.109; Stamp & Stamp,1976,p.169.
723 Ross:Sabine,[22/1/1839],**NA**/BJ/3/16.
724 Beaufort:Scoresby,[16/1/1839],**WHITM**/SCO/578.9.
725 Banks:Mudge,1819 in The Edinburgh Philosophical Journal,1821,p.266.
726 Sabine:Ross,[26/2/1839],**CL**/ACO/11/6.

was concerned with the valuable property claim of the workman, and, as at the Bristol meeting, used precedent to attack Scoresby's mastery over process.[727]

Conclusion

In the wake of the catastrophic meeting, Scoresby joined forces with brewer and chemist, James Joule, to design and build electro-magnetic machines of extraordinary power intended to outcompete steam engines. While unsuccessful in this specific, what the collaboration produced was a machine that could calibrate 'duty',[728] the Cornish measure for calibrating the efficiency of a steam engine, described in chapter one. At the same time, dismissing the virtuoso judgment of the Liverpool iron trader or Greenland whaler, the Committee turned to indirect surrogates; contracting for a supply of steel from Strasbourg because, in Sabine's words '[w]e can have what quantity of it we please: & always the same,'[729] and, with appropriate irony, adopting Scoresby and Joule's galvanic battery for calibrating the duty of steam engines, to magnetise their needles to a uniform power. Yet the utility of this Cornish system of 'duty' was precisely in its integral relation to Greenland and Liverpool trades. British whaling was, as chapter four described, defined by the complex tariffs of the 1672 and subsequent acts, together with the commutation of iron in the Hamburg Exchange. Meanwhile, from Liverpool the Lairds had been lobbying American Congress since the mid-1830s. Using the *Garryowen* as a particular case study, they sought to intervene on the duty imposed on their flat-pack iron ships, either by temporary exemptions to remove the duty entirely, or by a reclassification of the material.[730] Following materials, their production and reproduction reveals the militant geopolitics of this political economy of extreme labour extraction: the necessity, dependence and inequality manufactured through acts of contingency. The steamers that ran the plantations of Georgia were made with British iron, as the hulls of Britain's gun boat diplomacy and the tracks of India's railway debt would be.[731]

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727 Christie:Ross,[8/3/1839],**CL**/ACO/11/6.
728 Marsden&Smith,2005,p.81.
729 Sabine:Johnson,[1/01/1841-1847],**CL**/ACO/11/16; Johnson,1847,p.35.
730 House of Representatives,1839.
731 Headrick,1981,pp.33-7; Headrick,1988,pp.276-9; Dutt,1950,pp.353-370.

Chapter six: Capital standards

Where the iron links of the quadrilateral trade carried chapters four and five from the Greenland fisheries to the founding of the Admiralty Compass Committee, this chapter is concerned with the Admiralty Compass Observatory which that Committee became. The previous chapters have considered the way in which systems of labour extraction were built into the novel materials of early nineteenth-century Britain, and above all into a new kind of iron. The Compass Observatory, established to be the watchtower of British maritime power, was an institution with the regulation of iron built into its workings and structure. What the Compass Observatory oversaw was the extension and maintenance of an iron machinery that would re-organise labour economies globally. Chapter two noted how, following Réaumur, European metallurgy understood the properties of a metal as determined by its structure, where structure was inferred from the character of the fracture. In the transposition of human and material properties this relation was then geometrically reproduced at different orders of social organisation. While the word fractal is anachronistic, the concept as described here was born in this post-Cartesian moment.[732] Recognising the fractal relation between iron, Observatory, and imperial power is crucial to this chapter. The repeating character was that of the capitalist optimisation of labour extraction, and in seeking to secure each recursive step of this global vision, savants of the fiscal-military state mobilised standards in striking ways.

Before the mid-nineteenth century, weights and measures in Britain and Ireland were local anomalies born out of regional customs, as disparate from one another as they were from the designated national standard. By the later eighteenth century, attempts to centralise and standardise these units of exchange, underway since the 1660s, had culminated in statutory law declaring that they be founded upon two purportedly natural standards: the weight of a cubit of water and the length pendulum vibrating seconds of mean time in London. Through these processes, the standards were verified and, should they ever be lost, could be restored. Still, the geography and practice of Britain's trade remained very far from this vision.[733] The previous chapter described how, in the 1790s, French *savants* sought to derive a 'natural' unit of length from the dimensions of the earth that would establish the French concept of *mondial*, carrying specific trade rights and privileges, human rights and identities, as a principle of nature. In response, a rival British campaign sought to mobilise new national interest by connecting the reform of weights and measures with arguments for free trade and the repeal of the Corn Laws. Goaded by *mondialisation*'s metre, leading British savants fought

[732] Smith,1969,pp.482-7.
[733] Hoppit,1993,p.104.

for their concept of globalisation, where the world as natural category was defined by its engagement with universal capitalism. Standards were to be decisive weapons in the reorganisation of national and international labour economies as subjects of capital. And the apparently universal power of that capital, fetishized in the unified system of standards, was to be centralised in the British fiscal-military state.

This chapter is concerned with the fractal assemblage of the Admiralty Compass Observatory as a giant standard, and its deployment as a recursive step in a global institution of indenture in iron. To understand this assembly, it is first necessary to review the labours of the early nineteenth-century protagonists of British standards reform. Since the late-eighteenth century these labours had clustered just east of Cavendish-square, London, around fashionable Portland Place (Figure 6.1).

Figure 6.1: 1822, View of the West Crescent at the end of Portland Place, New Road. The Crescent, Portland Place, *Ackermann's Repository of Arts*, Vol. XIII, No.78.,June 1, Plate 31.

§1: cuts and burns

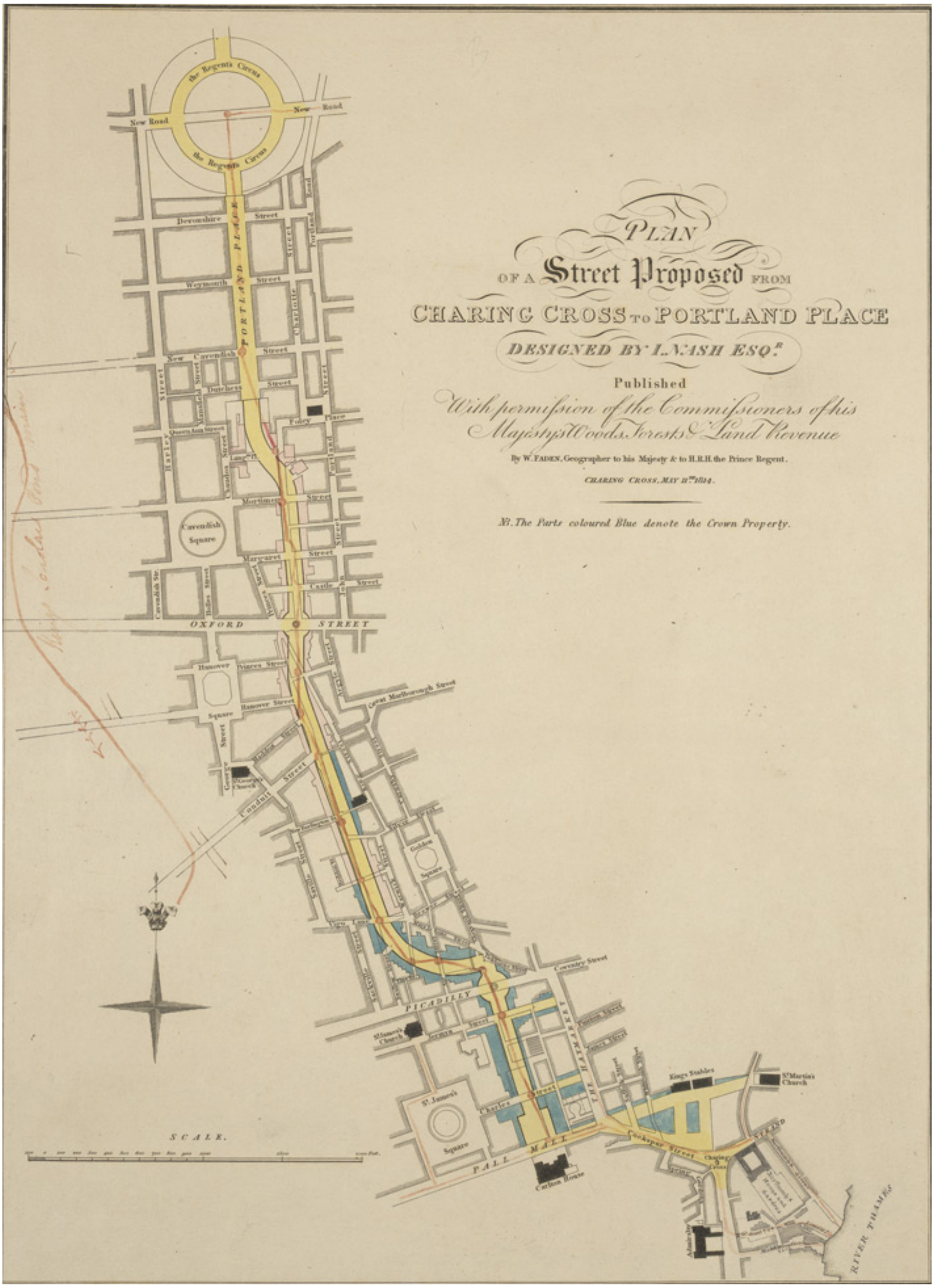

Figure 6.2: John Nash's design for a street from Charing Cross to Portland Place, constructed 1813-1822, with only half the proposed 700ft diameter Regent Circus realized as the monumental Park Crescent (see Figure 6.1). Faden, William, 1814, Plan of a street proposed from Charing Cross to Portland Place designed by J. Nash Esq.

In 1809, Michael Faraday moved with his parents to no. 18 at the end of Weymouth Street (Figure 6.2), where it joined with and looked onto the Portland Place thoroughfare. It was here he was inspired by popular political economy and science writing to attend his first scientific lectures.[734] Even after 1813, when he moved to the Royal Institution to work for Humphry Davy, he would call at no. 18 every evening.[735] While Faraday went back to his mum's for his tea, Charles Babbage took up residence less than two hundred yards round the corner at 5 Devonshire Street (Figure 6.1). From here Babbage sought a position as mathematics master to the East India Company's college, with testimonials from his friends, Hutton, Mudge and Gregory. In the comment by Barlow cited in chapter three, mentioning '*spinning* with [Herschel] and Babbage in town', 'town' referred to Marylebone, '*spinning*,' not only to the textile industry origins of his electro-magnetic rotations, but the carriage ride between Woolwich and Devonshire Street.[736] Just a few minutes walk from Babbage's residence, past Faraday's family home on the corner of Weymouth Street, stands Portland Place (Figure 6.2), home to Davy's mother-in-law, enslaver Jane Tweedie, and the site of his society wedding in 1812.[737] Jane Tweedie's neighbor was Henry Browne, formerly chief of the East India Company's intensely regulated settlement at Canton,[738] eighteenth-century China's sole concession to foreign trade.[739]

Browne had been on the frontline of efforts to prise open the Chinese tea-silver monopoly by establishing a Chinese dependence on British-traded Indian-grown opium, and militarizing Canton East Indiamen, necessary, it was claimed, to discipline the crews that flooded Whampoa.[740] During the 1793 diplomatic embassy undertaken by Lord Macartney with Barrow as adjunct, Browne, a member of the Canton Secret Committee,[741] was responsible for arming the mission and instructed to impress on the Emperor the 'idea of our military Character and discipline.'[742] Following his retirement in 1795, the wealthy veteran subsequently acted as the Company's accessory in fashionable society, as well as advisor in various branches of survey science.[743] In 1797, he was elected Fellow of the Royal Society for his experience projecting the position of stars and the security of long-distance

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[734] James,1991,p.xxvii.
[735] Faraday:Abbott,[8/03/1813] in James,1991,p.46
[736] Barlow:Faraday,[4/05/1825], in James,1991,p.368.
[737] Wheatley,1891,p.109.
[738] Browne,[1797],**RS**/EC/1797/08.
[739] Pritchard,1938,p.201.
[740] Sutton,2010,p.165,ft.49.
[741] Pritchard,1938,p.207.
[742] Morse,1926a,p.236.
[743] Schaffer,2012,pp.169-70.

investments.[744] In 1810, fifteen years on from his retirement, Company officials voted overwhelmingly to recall him to active service in Canton. As President of the Select Committee in China, he was personally invested with new discretionary powers beyond those of his predecessors, powers he used to facilitate illegal surveys of the rivers and coastline around Whampoa.[745] Concerned for his health, the 57-year-old Browne returned to London the following year, succeeded by John Fullarton Elphinstone, eldest son of the Company's Director, appointed to continue Browne's much-respected legacy. It was his opinion that to teach the Chinese to 'be civil' would require 'sending your compliments attended by 3000 men and field pieces', the men, he suggested to his father, 'can be easily supplied from Bengal'.[746]

Portland Place was the Canton committee's unofficial embassy in London, with chief of the Company's Canton Factory, George Thomas Staunton, a few doors down at no. 19. He and Browne were old acquaintances from the Macartney embassy, when Staunton had served as Macartney's deputy and Browne had brought the guns. For Browne, retirement meant a return to behind the scenes work for the Company.[747] Through the India Office, he was introduced to veteran of the Great Trigonometric Survey of India, Henry Kater, mentioned in chapter four. In 1816, government formally requested the Royal Society to assemble a committee to investigate the accuracy of the Parliamentary length standard. Banks was put in charge, Young made secretary, and Kater appointed to carry out the observations. In addition, there were the regular committee-men Mudge, Wollaston, and Davies Gilbert (formerly Giddy); together with civil engineer John Rennie, celebrated for his dramatic substitutions of wood and stone for iron; master instrument-divider Edward Troughton, responsible for the novel six-foot mural circle and giant measurement standard just installed at Greenwich; Banks's close ally, Royal Society Secretary, Charles Blagden; and the hospitable Mr Browne.

To Kater, Browne not only offered his 'excellent time-pieces', 'transit instrument', and 'indefatigable zeal', but also the use of his 'substantially built' Portland Place house.[748] From 1816, Browne's house became the centre of a range of astronomical and geodetic programmes at the very foundation of British survey science.[749] That same year, the Company began to invest significant sums in surveys of the China Sea. Where previously any disbursements on surveys had been so negligible as not to appear in the annual summary of

[744] Browne,[1797],**RS**/EC/1797/08; Ashworth,1994,pp.409-441.
[745] Morse,1926b,pp.130-56.
[746] Fraser,1897,p.20.
[747] Schaffer,2012,pp.169-70.
[748] Kater,1818,p.40.
[749] Schaffer,2012,p.170.

the Company books, in 1816 the Company in China spent 45,692 Tls (Canton currency Taels), equivalent to over half that year's total bonds to China and Hong merchants combined.[750]

In helping Kater set up to take observations at his house, Browne took the opportunity of introducing his brother-in-law to the retired India officer. In 1797, the then 43-year-old Mr Browne had married Caroline Sabine,[751] the 17-year-old daughter of a Hertfordshire family who owned plantations in Ireland. Just two years after the union, Caroline's widowed father sold the family home, Tewin House, and moved his remaining children into North Mymms Park, a Hertfordshire country seat occupied by Pitt the Younger's foreign secretary, Francis Godolphin, until his death in 1799, when it was purchased by Browne.[752] With the young Sabines established at North Mymms Park, Sabine senior then retreated to Teignmouth, Devon.[753] Caroline and Henry would not have a biological child until the birth of their only offspring, Henry Sabine Browne, in 1808. At the time of his sister's marriage, Edward Sabine was just nine years old, his mother had died within months of his birth and as eldest daughter Caroline had long since taken on the role of surrogate. In this Sabine-Browne union, he was the baby. He was introduced in chapter three as the Royal Society's *protégé* and in four as influential scientific advisor to the Admiralty and Compass Committee member, but in 1797 he was just a child and for him and his siblings, growing up at North Mymms Park, Browne was father.[754] Sabine senior died in 1814, while Edward was on active service in Quebec.[755] In 1816, Browne engineered for his *de facto* offspring to become Kater's assistant and to learn the art of pendulum instrumentation directly from the famously virtuoso observer.

The most crucial part of the pendulums themselves, the knife-edges, were made by an Edinburgh cutler, James Stodart, operating from Russell Square, London, using 'that kind of steel which is prepared in India, and known by the name of wootz'.[756] Renowned in Europe for its quality but rarely seen on that market 'unwrought',[757] the wootz for the pendulum knife-edges came from a slice of a metal cake sent to Joseph Banks in 1794 by Bombay-based East India Company physician, Helenus Scott.[758] Banks passed one piece of the cake to his ally in coining, Matthew Boulton, for analysis,[759] and another to his ally on the Royal Society

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[750] Morse,1926b,pp.307-8.
[751] Urban,1830,p.571.
[752] Glawin,2001.
[753] The Oxford Journal,1814,p.3.
[754] Glawin,2001.
[755] The Oxford Journal,1814,p.3.
[756] Kater,1818,p.38.
[757] Evans&Withey,2012,p.548.
[758]Dube,2014,p.2391.
[759] Carter,1974,p.299

council, physician George Pearson. In turn, Pearson then passed his to '[t]hat ingenious artist Mr Stodart [who] forged a piece of wootz at the desire of the President [Joseph Banks], for a penknife.' The physician went on to report that '[n]otwithstanding the difficulty and labour in forging, Stodart from this trial was of opinion that wootz is superior for many purposes to any steel used in this country.'[760]Pearson considered the ingenious Stodart an authoritative judge of such metallurgical hierarchies because of his mastery of a particular tempering technique.[761] This used a bath of molten fusible metals to heat the metal being tempered, with a thermometer placed in the molten metal for regular registration. The container of fusible metals served as a *bain marie* to help regulate temperature changes, and the registration of the thermometer in the molten metal was taken as a proxy for the temperature of the metal being tempered. In this way metal regulated metal. Qualitative colour judgments might be substituted by quantitative measures.[762]

Following Stodart's initial experiments, interest in wootz increased, Scott sent more cakes, and in 1805 Banks commissioned Monmouthshire ironmaster David Mushet to attempt its replication.[763] Banks and Mushet were already well known to one another through Pearson,[764] but 1805 saw a further cementation in relations. As chapter one noted, Banks had long dominated the Privy Council Committee to reform regal coinage. Mushet's younger brother Robert had just been appointed a junior clerk in the Mint and, in 1805, as Banks commissioned David to investigate wootz, Robert took over the entire melting house contract from the then deputy master; an unprecedented responsibility for someone in such a junior position.[765] In this capacity he carried out metallurgical experiments for Banks's coining investigations.[766] By 1815 his brother had transformed the Scottish iron industry, and he was now friend and informant to eminent persons in political economy, such as the East India Company College lecturer Thomas Malthus, and the sucessful financier turned author David Ricardo.[767] That year he was appointed chief melter and clerk at the Royal Mint.[768] Kater's choice of wootz was much more than a touch of nostalgia from an old India officer. In their structure and forging, the pendulum knife-edges established a direct relation between reformed regal coinage, the ferrous focus of East India Company industrial espionage, and the big metal industry of the quadrilateral trade, with all three in Banks's pocket-knife.

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[760] Pearson,1795,p.326.
[761] Evans&Withey,2012,p.552.
[762] Parkes,1812,p.320,footnote.
[763] Dube,2014,p.2392; Mushet,1805,p.163.
[764] Mushet,1840,p.662.
[765] Craig,1953,p.275; Parliament,1848,p.127
[766] Morrison,[1807],**SH**/MS.151.
[767] Ricardo:Malthus,[1810] in Bonar,1887,pp.2-3
[768] Parliament,1848,p.135.

Having gone to great lengths to secure the moral authority of the pendulum, Kater and Sabine began observations at Mr Browne's, and reported to the Royal Society on the initial results early in 1818.[769] Following their report, Banks, Gilbert, Wollaston, Young and Kater, together with Tory MP for Midlothian Sir George Clerk, baronet of Penicuick, were appointed to consider how far it might be practicable to develop a more uniform system of weights and measures than that then in place. Within months of joining the pendulum committee, Clerk was appointed one of the Liverpool administration's Lords of the Admiralty, as chapter four described, a centre of the British maritime iron trade. As part of the national metrological enterprise, in 1818 the Commission inquired into standards, and, with a view to combining actual practice with scientific investigation, tried to find some natural standard with which to compare the actual standard. The same year as the 1818 pendulum committee's appointment, Faraday and Stodart were directed by the Royal Institution to focus their energies on establishing how to synthesise wootz, an early commission in the mould that would shackle Faraday through the 1820s and 1830s in striving to replicate Bavarian optical glass.[770] Their analyses and attempts at synthesis were based on Stodart's original piece of cake used for Banks's blade and Kater's knife-edges. After several years of painstaking labour, they still could not make a passable cake.[771] Yet despite ignorance of the process by which it was manufactured, the material, defined by Banks's first cake as type specimen, was nonetheless better mathematically characterised than the heterogeneous ferrous products of domestic manufacture. As chapter one noted, Boulton and Banks had been determined to reform both industry and regal coinage under Royal Society weights and measures since as early as 1797.[772] Faraday's and Stodart's researches were not only another link in this chain, but through their assays and chemical analysis, the Portland Place pendulum-researchers acquired extremely precise measures of the specific gravity of the metal out of which the knife-edges were made.

In his campaign for further research to refine standards, Davies Gilbert had mobilised such connections with coin reform, representing fraudulent practice as a problem of lack of standardisation. His claim further spoke to the travails of the Ordnance Survey, described in chapter four, obstructed by international attacks on the integrity of its standards as by internal corruption and embezzlement. For Gilbert, frustrated by the sleight of engineers and the heterogeneous local standards that undermined his efforts to calculate and compare the

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[769] Kater,1818.
[770] Jackson,2000,pp.99-170.
[771] Faraday:De La Rive,[1820], in James,1991,p.195,p.198; Faraday,1819,p.289
[772] Boulton:Banks,[17/12/1798],**Sutro**/Banks/Co.5:66.

duty of Cornish steam engines, standards reform and accompanying self-regulation by industry in a *laissez-faire* state was a more efficient and effective resolution than interventionist policies. In this argument his contemporaries recognised debates over industrial and commercial legislation, and above all over the Corn Laws, the most salient system of economic regulation in early nineteenth-century Britain. Gilbert's call for the reform of standards was a powerful argument in support of self-regulating industry and free exchange. To insist on this form of standards reform was to argue for the repeal of the Corn Laws.[773] While these protections kept the price of bread artificially high, their repeal would enable industrialists to lower the rate of wages and thus the cost of coal. His mobilisation of standards reform followed directly on the launch of Lord Liverpool's new fiscal policy, mentioned in chapter four, to create novel markets for the coal-based domestic iron industry.[774] Further, it coincided with the systematic replacement of Post Office sailing vessels by coal-powered steam,[775] with engines built, sold, and maintained from Gilbert's home county of Cornwall,[776] just as the Admiralty stepped up its post-war campaign to take over the packets.[777]

Following Banks's death in 1820 Gilbert was pipped to the Presidency by Davy, one of the Royal Society's vice-presidents. Within months Stodart was elected an F.R.S.[778] That same year, in 1821, Sabine embarked on his diplomatic tour of the transatlantic trade under Gilbert's aegis, acting as entourage to that highest authority of the British fiscal-military state: pendulums calibrated at Mr Browne's. The instruments Sabine escorted were 'precisely similar' to the pendulum employed by Kater in Portland Place; in particular, the knife-edge was the angle of a 'prism of wootz'. At his first stop, Sierra Leone, Sabine was hosted by his old friend from London, Charles MacCarthy, Governor of British possessions in West Africa. That same year the African Company of Merchants was abolished as part of British government policy to nationalise the human trade, and MacCarthy seized the Gold Coast as a crown colony. At the Portuguese possession of St Thomas, Sabine's reception from the governing powers was frosty and the Junta President took the opportunity to convey his strength of feeling at Britain's violent take-over of their human traffic. Tracking on, the pendulums took in the West Africa squadron's victualling station, Ascension Island, and in Bahia received news of revolution in the Brazils. At Maranhão, they met His Majesty's Consul,

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[773] Waring,2014,p.70.
[774] Liverpool,[1817],**BL**/Liverpool/Add.MSS.38367.f.121.
[775] Laakso,2007,p.73.
[776] Parliament,1841a,pp.86-7.
[777] Laakso,2007,p.84.
[778] Stodart,[1821],**RS**/EC/1821/25.

Robert Hesketh,[779] compiling and mapping statistics on free Africans in Brazil.[780] The Governor of Trinidad, Ralph Woodford, was another friend from London, and, following a prolonged stay in Jamaica, Sabine and the pendulums arrived in New York in December 1822, to be greeted by the Liverpudlian James Renwick, now a Professor at Columbia College.[781] Renwick was so taken by the pendulum endeavour that when his son was born the day after they concluded their observations, he named him Edward Sabine Renwick. A valuable conquest: in 1838, James Renwick would be appointed one of the United States commissioners to explore the boundary line between the States and British North American colonies. With a special relationship secured, Sabine's pendulum embassy departed for England to prepare for the fourth corner of the quadrilateral trade: the Arctic circle. They reached Portsmouth on 5 February 1823.

That month, as the overseas packets were transferred to the Admiralty, Captain of the *Conway* Basil Hall took observations on behalf of Barlow and made a telling triangulation between the arguments at stake. In a letter to Kater that was read to the Royal Society and published shortly after, Hall argued that pendulum research calibrated in England before extending overseas should be carried out

> not under the hospitable roof of Mr Browne, to whose valuable assistance every one who has attended to this subject, is so deeply obliged, but in the fields, and with no advantages save those [the observer] could carry with him. He would thus in good time discover omissions in his apparatus, which are not to be supplied abroad, and be aided in surmounting difficulties before he had sailed, as I did, beyond the reach of appeal.[782]

The survey officer Hall had been elected F.R.S. in 1816 while on active service in China, at the same moment that the Canton Committee began spending significant sums on surveys.[783] Now his public letter acknowledged his debt to Browne, and broke with it. He called for standards work to be taken out of the hands of the Company and put into those of the fiscal-military state. It was an argument for the nationalization of standards work and with an eloquent touch characteristic of the budding writer, Hall echoed Gilbert's call for reformed standards over mercantile protectionism. To bring the pendulum into the English fields was a call for Corn Law repeal. Early the following year would see Browne and Beaufort called upon by the East India Company to advise on a similar such case, which rapidly became

[779] Sabine,1825,p.4,p.7,p.10,p.27,p.40,p.52,p.71.
[780] Williams,2016.
[781] Sabine,1825,p.88,p.101,p.118.
[782] Hall,1823,p.213.
[783] Morse,1926b,pp.307-8.

notorious,[784] and led to the bankruptcy of the Company's Leadenhall makers,[785] William and Thomas Gilbert, whose compass had calibrated Barlow's magnetic researches.[786]

The introduction noted that the apparent threat of *mondial* metrology generated new impetus for a uniform centralised system. The year 1824 marked the first major advance in this struggle with an Act passed to define imperial standards on the basis of Kater's research, and Kater appointed to supervise the construction of the new sets. To secure his involvement, Sabine collaborated with Arago and Schumacher, introduced in chapter four, to compare pendulum and magnetometer observations between Greenwich, Paris and Altona. The project was in full swing when Schumacher, overseeing the trading standards of the Hamburg Exchange, wrote to Kater requesting an accurate copy of the English Imperial Standard Troy Pound. The copy Kater provided was identical to the one he had described the previous year in 1826, and was made by Robert Bate of the Poultry. Bate was hydrometer maker to His Majesty's Excise, and as such, Kater noted, accustomed to 'nice operations in weighing.'[787] Indeed, his weighing supplied standards to hundreds of government offices throughout the United Kingdom and overseas, as well as bullion balances for the Bank of England and East India Company. Bate brought British globalisation into the balance. In addition to the copy of the published pound, Kater also provided Schumacher with a balance such as he had used, not a Bate, but rather made by one Thomas Charles Robinson, 38 Devonshire Street, Portland Place, just a few hundred yards from Browne's house where the standards were being investigated.

Concerned with perfect frictionless suspension for compasses and pendulums, it was Kater who first established Robinson's credentials to his disciples and reviewers alike. From 1826, Robinson worked closely with Kater to improve the design of instruments.[788] Reporting on the construction of the new standards, Kater noted,

> In all beams I have seen, with the exception of those made by Robinson, the whole weight is sustained by short portions of the extremity of the knife edge, and the weight being thus thrown upon a few points, the knife edge becomes more liable to change its figure and suffer injury.[789]

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[784] Schaffer,2012,pp.169-70.
[785] Bankrupts,[3/29/1828],**NA**/B/3/2035.
[786] Barlow,1837b,p.664; Barlow,1823a,p.90.
[787] Kater,1826,p.9; McConnell,1993,pp.19-28.
[788] Stock,1968,pp.254-7; Stock,1969,pp.22-29,pp.48-49; Stock,1971,385-7; Stock,1980,1518A-29A.
[789] Kater,1826,p.36.

Beams, other than Robinson's, destroyed themselves in use. This work of standards rested on replication. On Kater's showing, replication rested on Robinson. As Robinson became pivotal to Parliamentary Standards, his reputation was established among the magnetists.

Kater's comparison only gave one set of figures for working out the balance error. Concerned that the copy could not then have been made with sufficient care, Schumacher requested a second. Receiving the request in late 1827, Kater obliged, but rather than returning to Bate, Maker to the Excise, he chose Robinson.[790] In preferring Robinson to Bate, over the authority of Customs, Kater chose the replication that makes and teaches custom itself. Over the strong national tradition of gauging liquids, from brewing to the coal measures that recalled the water raised by the mill or the pump,[791] he chose the weighing of metal that carried with it the European fetish of West African trade.[792]

With Kater thus occupied, the Royal Society appointed Sabine to determine the difference in pendulum vibrations between Browne's house and Greenwich, bringing Portland Place into direct comparison with the Royal Observatory, and through Sabine's prior collaboration, with the observatories in Paris and Altona.[793] While authority was being redistributed, the Royal Society secured its continuity in Browne's surrogate son. In late 1827 the Company instrument scandal broke.[794] In 1828, Sabine was appointed one of three scientific advisors to the Admiralty, the controversial replacement to the Board of Longitude. To make the manoeuvre count required the manufacture of links between Browne's house, Altona, and Greenwich and that in turn required some displacement from Bate to Robinson.

Armed with two copies, Schumacher put the Troy Pound on trial, with Robinson's balance as the scales. The initial measurements, undertaken in 1827 through 1829, revealed 'discordance… far too considerable for the powers of Robinson's balances'. Schumacher began to further doubt the care of Kater's observations and became convinced that 'a copy from two copies would hardly answer [his] purpose.' Instead, the man at the axis of the Hamburg exchange determined 'that, to obtain the accuracy at which [he] aimed, [he] must have a copy from the *original*'. Removing the responsibility from Kater with the courteous excuse that he wanted 'more numerous comparisons than [he] could with any propriety

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[790] Schumacher,1836,p.457.
[791] Ashworth,2004,pp.1314-1317.
[792] Schaffer,2002,p.31-4,p.43.
[793] Sabine,1829.
[794] Schaffer,2012,p.170.

charge [his] English friends with', Schumacher dispatched Captain Nehus of the Royal Danish Engineers, to Robinson's Devonshire street workshop in 1829.[795]

On 18 June 1830, Mr Browne, Sabine's surrogate father and patron of Portland Place, passed away.[796] In October that same year, Babbage enflamed decades of discontent at the representation of men of science in the oligarchical Royal Society, deploying statistical methods to question the miraculous precision, accuracy and agreement of favoured Royal Society protégés, and the science of political economy to pull apart the structure of the Society itself. His barrage focused on the fêted accuracy of Kater, Sabine and the Banksian nepotism of the old-Browne system.[797] Scorched by what Herschel described as Babbage's 'powerful caustics', Sabine's wife Elizabeth took to her bed for a month. Seizing on the symbols of 'Old Corruption', Babbage's call for reform spoke directly to the distress of agrarian communities, dispossessed and impoverished by extractive landlord farmers and an indifferent political class. This distress was at that moment mobilising into loud demands for electoral reform, to which *bourgeois* reformers added their calls for Corn Law repeal. Such national upheaval provided public support for Royal Society reform that would culminate in a tense election a month later, with Babbage and Beaufort, newly appointed as Admiralty hydrographer, calling for Herschel for president.[798]

On 30 November 1830, as fellows of the Royal Society placed their votes in this critical contest of representation, country F.R.S agonised between the 'urgent necessity' to vote and to safeguard their property, in 'hourly expectation of a mob' as the fields surrounding Oxford burned.[799] Herschel narrowly lost the vote, to the bitter disappointment of his supporters, and in the very days that followed unrest irrupted in conflagration that reached within a mile of the Cambridge Observatory, where George Biddell Airy, introduced in chapter one, was director. The recently appointed Plumian professor of astronomy described the unfolding scenes as

> the most extraordinary panic that I ever saw. I do not think it is possible, without having witnessed it, to conceive the state of men's minds. The gownsmen were all armed with bludgeons, and put under a rude discipline for a few days.[800]

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[795] Schumacher,1836,p.460.
[796] Urban,1830,p.571.
[797] Babbage,1830.
[798] Morrell&Thackray,1981,pp.36-56.
[799] Buckland,[1830] in Gordon,1894,pp.151-2.
[800] Airy,1896,p.92.

In the space of a few months it seemed to some as if Babbage's caustic scorching of Royal Society reputations had caught the stubble in the fields as the flames of the Swing riots closed in on the tithe-rich old university towns (Figure 6.3).[801]

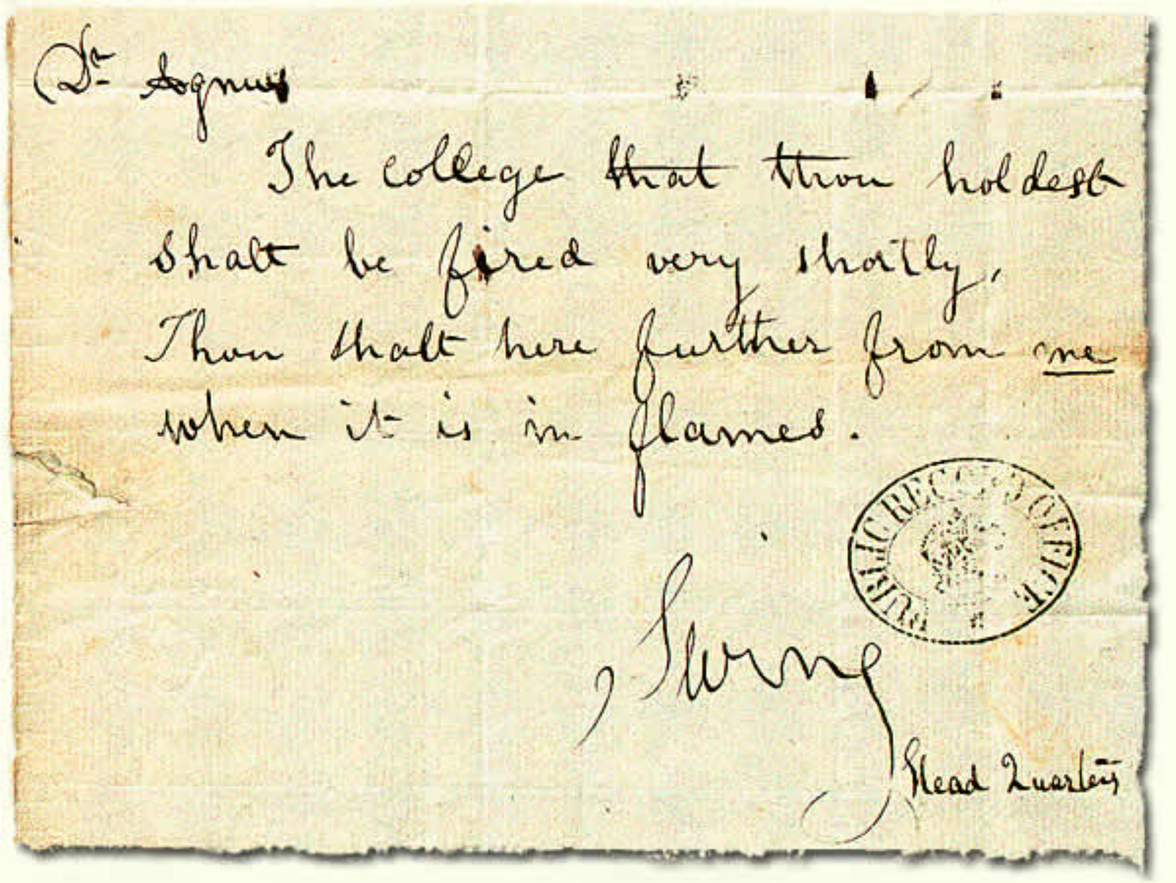
Dr Agnus
The college that thou holdest
Shalt be fired very shortly.
Thou shalt here further from me
when it is in flames.
Swing
Head Quarters

Figure 6.3: 'Dr Agnus. The college that thou holdest shalt be fired very shortly. Thou shalt here further from me when it is in flames. Swing Head Quarters.' Letter sent to John Lamb, Master of Corpus Christi College, Cambridge, 8 December 1830. A second letter, sent the same day to Charles Simeon of Kings College read 'Revd. Sir, Thou wilt soon see, that I have not forgot thee, nor the college that thou belongist to. Thou shalt hear further from me when Kinngs College is in flames.' Swing letters, December 1830, NA HO 52/6, National Archives.

§2: made in the balance

In response to these violent upheavals, in 1831 Beaufort was commissioned to report on the borough boundaries proposed to reform representation in the British electoral system. To assist him in this he was also allocated two adjuncts, veteran of Colby's Ordnance Survey, Lieutenant Thomas Drummond, one of Barlow's favourite former pupils; and Edward John

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[801] Schaffer,2003,p.283; Schaffer,2018.

Littleton,[802] Tory-turned-Whig M.P. for South Staffordshire, and a leading figure in the campaign to insist that 'workmen must be paid in money'.[803] With Daniel O'Connell's backing, Littleton was a prominent advocate for Roman Catholic emancipation and central in tithe debates. The Reform Bill required boroughs be ranked in order of economic importance, measured by their number of houses and total assessed taxes for the previous year. How to apply these two criteria caused heated debate over the best way to take the average.[804] For Beaufort, tasked with bringing a motley accumulation of Admiralty charts into working correspondence, the problem was familiar. Following the Boundary Commission's report, Beaufort, Barlow, Herschel, and Airy were called upon to identify the best mathematical method for the representation of boroughs: how best to weigh them, and take the average.[805]

All four were central figures in pendulum research. In response to Hall's call to take to the fields, Airy undertook pendulum experiments down the deepest Cornish mines: not fields of corn but copper and coal with a labour economy borne out of commutation. The displacement of where observations were to be made was a crucial part of manufacturing and securing the link between reformed standards and reformed parliament. Chapter one described how the effect of the 1832 Bill, ostensibly enacted to eliminate rotten boroughs, was to extend a political system long-standing in Cornwall, whereby powerful industrial interests bought votes and influence. Well-disciplined in the tortuous labour of coaxing pendulums to agree, the testimony of Airy, Beaufort, Barlow, and Herschel closely concurred, and would prove decisive in choosing the mathematical method with which to represent boroughs.

For these four this weighty project of national interest converged with the closely related concerns of the perceived decline of science, international comparisons, and desire for standard reform and better representation of industrial interests. In 1831, this convergence of concerns was mobilised in the founding of the British Association for the Advancement of Science. The editor of the newly published *Edinburgh Encyclopaedia*, David Brewster, was Babbage's polemical ally in the attack on the Royal Society. Following the failure of their attempted coup, it was Brewster who first proposed the founding of the Association, urging Babbage in the reformist language of political combination that their efforts would all be for nothing 'unless you great men in the Metropolis *combine*, and *meet*, and *petition*'.[806]

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[802] HC Deb,16/02/1832,vol.10,cc417-21.
[803] HC Deb,12/09/1831,vol.6,cc1357-64.
[804] Craik,1999,pp.256-7.
[805] HC Deb 20/02/1832,vol.10,cc536-70.
[806] Brewster in Morrell&Thackray,1981,p.51.

Brewster's vision was inspired by Babbage's account of a scientific meeting in Hamburg, which Brewster published in 1829 and Babbage then reprinted in 1830, appended to his attack on the Royal Society.[807] The significance of Hamburg was evident to both, with Brewster a vocal promoter of Scoresby's work, in particular his 1820 natural history of the Greenland trade,[808] while he and Scoresby had long corresponded on deriving the magnetic character of the earth from its geographical distribution.[809] Interests united in Scoresby's article for Brewster's 1830 *Edinburgh Encyclopaedia,* for which Brewster credited him as a principal contributor.[810] The whaler-turned-clergyman's application of the terminology of combination to magnetism through his mechanical theatre and industrial evangelism were headline attractions of the earliest British Association meetings.[811] Just as it had for the recently deceased Joseph Banks, Scoresby's mastery over magnetic attraction presented a connoisseurship of the labour history and commodity value of this iron trade. In setting out expectations for future magnetic research, the report of the first Association meeting brought together the expertise of a Liverpool social statistician, Dr. Thomas Traill a Cornish mine engineer, Robert Were Fox and Norwegian astronomer, Professor Christopher Hansteen.[812] The Professor constructed and distributed standard needles as part of promoting his geomagnetic theory,[813] which, significantly for Scoresby's awed audience, necessitated polar exploration for its investigation,[814] and thus reinforced the cosmology of the quadrilateral trade. From the very first, it was a principal ambition of the Association that this Norwegian standard should be used to survey and rationalise local attraction across England as indicative of metalliferous seams. Through such an international standard, English iron would be brought into direct correspondence with one of the centres of the Baltic trade, and through such a survey the labour history so dramatically characterised by Scoresby might be rationalised and re-organised as geography.[815]

Chapter one described how the East India Company surveyor Thomas Best Jervis used the 1838 Association meeting to push this correspondence further, to rationalise local and contingent labour history by reforming and reducing geography with the statistical methods of astronomers;[816] where astronomers were the curators of trading standards, and in the

[807] Orange,1972,p.156.
[808] Brewster,1830b,p.15
[809] Brewster:Scoresby,(1821-1852),**WHITM**/SCO/562
[810] Brewster,1830a,p.xiii
[811] Morrell&Thackray,1981,p.90.
[812] British Association,1832,p.vi.
[813] Multhauf&Good,1987,p.15; McConnell,1980,p.28; Enebakk,2014,pp.587-608.
[814] Cawood,1979,p.578; Morrell&Thackray,1981,pp.524-525.
[815] British Association,1832,p.vi,p.52.
[816] Jervis,1838,pp.3-6.

business of long distance speculations.[817] Extending this ambition to a global campaign emerged as the Association's *cause célèbre* between 1831 and 1838, precisely because of its direct material correspondence between these international, industrial and political concerns and the reform of trading standards: precisely because of the combinations such a campaign might forge. From the very first 1831 meeting, the particular formulation of the magnetic ambitions of the Association had a burning significance. The application of statistical methods to a survey of labour history was the instrument of Babbage's incendiary attack on the Royal Society. While individual positions with respect to Babbage's firebrand were varied and complex,[818] magnetic research in Britain in the 1830s was cut with the tools of revolutionary reform in labour organisation.

In planning the first Association meeting, Brewster had assumed that Babbage would give an account of his Difference Engine, intended to re-organise on rational, metal and mechanical lines the costly and fallible labour of calculation on which British military and merchant maritime power depended. Given the 'unquenchable' curiosity for the machine, Brewster thought it natural Babbage would attend and expound as a central attraction. But caught in fraught negotiations with government departments over further support for the engine's construction, Babbage declined.[819] *On the Economy*, his literary difference engine, would be published the following year in 1832.[820] In the absence of an oral account, curiosity only grew and just as his scorching of the Portland place practitioners prepared the ground, so the ambition of his engine and its realisation in print form framed the vision of the infant Association.

Each of the Reform Bill advisors, Beaufort, Barlow, Herschel, and Airy, crafted excuses not to attend the 1831 Association meeting. The same iconoclasm that energised the extension of electoral reform into learned institutions elicited wariness from those in positions of influence. Airy and the Cambridge philosophers responded coldly to their invitation; while Herschel, unwilling paragon of the movement's ideals, was characteristically evasive. The Woolwich mathematicians cited other commitments; while Beaufort, adjusting to his new role as Admiralty hydrographer, also felt he could not spare the time.[821]

Beaufort's position was crucial in the allocation of Admiralty resources, but his influence required manufacture and maintenance. On taking up the role in 1830, he appointed Bate as

[817] Ashworth,1994,pp.409-441.
[818] Morrell&Thackray,1981,p.49.
[819] Morrell&Thackray,1981,p.73.
[820] Schaffer,2003,pp.280-2.
[821] Morrell&Thackray,1981,p.84,pp.74-5.

sole Admiralty Chart agent. This was not only annexation of the East India Company through its maker, but also, through Bate's role as maker to the Excise, annexation of a constituency at that same moment being forged in the Admiralty publishing machine. Two years on, Beaufort appointed Bate co-publisher of the newly founded *Nautical Magazine*, his principal means of shaping public and political opinion of the Admiralty. In particular, the *Magazine* existed to frame his cartographic reforms. When surveyors and navigators saw the lines on charts link and overlay, what they saw was Bate. When the strikingly wide readership of the *Nautical Magazine* saw itself represented as a cohesive community,[822] collectively engaged in 'one vast science'[823], they saw an argument for universal free trade guaranteed by British standards. When Beaufort wrote to the Association meeting organisers that he was 'flattered by the invitation' but found the 'press of business in this office, at that period of the year, will not allow me to indulge myself in such gratification',[824] he was absorbed not just in reforming cartography but the views of Admiralty commissioners and what they understood to be the views of their constituency.

Writing to explain the lack of interest among the Woolwich mathematicians, Barlow set out the problem. Men of science, he argued, were not willing to subscribe to yet another society if it brought no new benefit beyond their existing subscriptions. Just as for Beaufort machinating through the *Magazine*, what mattered to Woolwich was government support and the industrial commissions that followed. Barlow's progression from a lowly mathematics master to a name of international renown had not come through institutional promotion, but rather the acumen with which his research had followed the interests of the state. Chasing these interests facilitated research and funded not only his publication but also his time in reducing the results of observations. It was a view confirmed by Arago, who pointed out that if the Association did not have the support of its own government, he could hardly invoke its authority in dealing with his. Not least in the wake of the 1830 revolution that saw the Bourbon monarchy brought to a definitive end. The 1831 and 1832 Association meetings won community support for their spectacle, in particular Scoresby's dramatic performances both in the lecture hall and the pulpit, but it was the efficacy with which Airy deployed the Association in 1833 as a lobby group to forward his own pet projects that impressed Herschel and others who had shared his ambivalence.[825]

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[822] Barford,2015,pp.208-226.
[823] Bauza,1832,p.3.
[824] Morrell&Thackray,1981,p.74.
[825] Morrell&Thackray,1981,p.86,p.330,pp.328-9.

When the Association assembled in Cambridge in July 1833, the fires that had scorched the earth around the university town were not so long extinguished. Nonetheless, a culture of lobbying increasingly painted cohesion where the marks of division would not quite fade.[826] In pushing for a major international venture to survey terrestrial magnetism, the Association mobilised the rhetoric used to goad international surveys to establish length standards; and the meeting's local secretary, professor of mineralogy William Whewell, coined the term 'scientist' to give new currency to the uneasy community. Even Sabine, the most badly burnt of all but still standing as Admiralty scientific advisor and Royal Society darling, watched with rising interest.[827]

§3: double standards

The Cambridge meeting established a standing committee on terrestrial magnetism composed of Samuel Hunter Christie, Edinburgh Professor of Natural Philosophy James David Forbes and Dublin astronomer Humphrey Lloyd, together with a commitment from Lloyd to undertake a survey of the magnetic intensity of Ireland.[828] A year later, with the August meeting imminent, Sabine was still publicly declining to join the Association, while at the same time writing to Arago that he yearned to be a member, but 'do [not] know exactly how to become one. I think I might ask [the director of Armagh observatory] and yourself to propose me if such is a preliminary is requisite'.[829] Sabine looked for allies among those furthest from the fire, and in the same manoeuvre, sought to showcase his international influence and remind the Association that, through his recent collaboration with Lloyd, the calibrating standard of its prized Irish magnetic survey was himself.

In the year that had elapsed between third and fourth Association meetings, Sabine had taken advantage of a military posting in Limerick to solicit the interest of Humphrey Lloyd at Dublin Observatory. At the same time, the Admiralty scientific advisor was able to further parade to Lloyd the resources at his command, when, through 'some influence at work in the military',[830] the Admiralty seconded his friend and colleague navy Lieutenant James Clark Ross to Ireland, to undertake a magnetic survey. Just as Browne had done on the Macartney embassy to China, Sabine presented to Lloyd the military character and discipline at his disposal.[831] Through Sabine's social engineering, the Irish survey launched with two sites,

[826] Morrell&Thackray,1981,p.84.
[827] Cawood,1979,p.500,pp.503-5.
[828] Morrell&Thackray,1981,p.525.
[829] Sabine,1834, in Cawood,1979,p.504.
[830] Cawood,1979,p.504.
[831] Morse,1926a,p.236. 8/9/1792

both Dublin and Limerick acting as standards for the comparison of field observations, Lloyd in Dublin, and Sabine in command of Limerick.[832]

In July 1834, Ross wrote to Sabine requesting 'a very minute account of your *modus operandi* in order that the observations may be actually comparable'. They secured the correspondence by sending needles, to and fro between them, by post.[833] It was not until 1835 that Sabine was prepared to acquiesce to be elected to the Association,[834] but in the two years since the 1833 meeting he had covered his burns with epaulettes of indispensible authority and resource. By mobilising Browne's lessons, through comparison and calibration, he made himself into an obligatory reference. The needles Sabine and Ross posted between them were courtesy of Robinson, Portland Place.[835]

Figure 6.4: 'The Houses of Lords & Commons as they Appeared on fire Thursday, October 16th, 1834.'

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832 Goodman,2016,p.253.
833 Ross: Sabine,[3/07/1834],**NA**/BJ/3/16.
834 Cawood,1979,p.505.
835 Ross:Sabine,(1834-1840),**NA**/BJ/3/16.

Around six in the evening, 16 October 1834, the Houses of Parliament began to burn (Figure 6.4). Earlier that same day, as part of reforms to the Exchequer's accounting system, the Clerk of Works had ordered two cartloads of old tally sticks to be incinerated in the under-floor stoves in the basement of the House of Lords. The fire of reform caught fast, and with terrifying speed the conflagration consumed both Houses of Parliament, and the parliamentary standards with them. The left-hand side of the legal standard yard was 'completely melted out', the bar bent, and discoloured in every part. The legal standard troy pound was missing, destroyed without trace.[836]

With the devastation, Schumacher's study and Robinson's balance took on new significance.[837] Schumacher's research, now half a decade old, was presented at the Royal Society and published for the first time. Framed by Schumacher's courtesy and consideration of the devastation of Babbage's caustics and the Parliament fire, the Altona astronomer's presentation focused on material concerns. Not Captain Kater's dubious 'care', reduced to ashes by Babbage's polemic half a decade earlier, but rather the ambiguous material of the original standard, now melted away. As previous chapters have shown, the cultures of remanufacture in metalworking produced apparent categories of materials whose properties and compositions were, in practice, in constant flux. The fire dramatised the fluid quality of what had been presumed unchanging. For such reasons the calculation of the specific gravity of Banks's particular cake of wootz had been peculiarly significant, despite the failure to synthesise the material. This synchronic heterogeneity and diachronic transformation of iron was true too of copper and brass. It was no longer clear what, in the metallurgical classifications of the time, the original standard weight had been made of.[838] Early in 1834 Robinson became one of several respected makers used for the survey of Ireland; by the end of the year he was the principal link in the reconstitution of the parliamentary standard weight. In June 1836, as Schumacher's paper was read out, the magnetic survey extended across Britain, with Robinson instruments as standard. The final report included observations taken at Portland Place, down the road from Mr Browne's, in Robinson's workshop.

As the thesis introduction detailed, a month before Schumacher read his paper Airy and Christie had reported on a letter written by Humboldt, urging Britain and her colonies to join the continental magnetic project. This required him to choose between the two different approaches of French and German magnetic observatories, embodied in their respective

[836] Parliament,1841c,p.5
[837] Miller,1856.
[838] Schumacher,1836,pp.474-95.

instruments: the Parisian Gambey compass and the Gauss magnetometer. The decision caused him 'mortal anguish' in his fear 'of displeasing both worlds of the East and the West'. Humboldt was well aware that even the words 'Gambey compass' provoked 'tensions with the noble, but irritable Gauss;' but remained torn, asking 'should I now write to Pekin to suggest they destroy their [Gambey] compass?'[839]

At this point Gauss and Humboldt were not on speaking terms and would communicate only through Schumacher, who was both Gauss's former pupil and Humboldt's friend. Schumacher became like the trading standards he curated in Altona, the point of exchange and a crucial route for the Association magnetists to lobby for government support.[840] It was Schumacher who pushed Humboldt to abandon his preferred Gambey compass, and 'resort to the help of the strongest' in Gauss's magnetometer. While Humboldt's final letter retained reference to both, the successive revisions make clear his decision to back Gauss's instrument and recognise the primacy of Göttingen instrumentation.[841]

Schumacher's messages to Göttingen in 1836 were dominated by Gauss's particular preoccupation with the reform of Hanoverian weights and measures. In Paris, Gambey was responsible for the construction of weights and measures as well as magnetic instrumentation,[842] while in Göttingen, Gauss relied on mechanic Moritz Meyerstein for both. Aggressively critical of French metrological regulation, Gauss used these reforms to perform the rivalry between Gambey compass and Gauss magnetometer. Even so, in the course of his observations Gauss tempered his hostility, as he became aware of the transformation of metals as well as the ignorance around variation of the specific weight of metals with the same name, depending on their purity. Gauss's system of observation, as with his work on magnetism, attained unprecedented levels of accuracy and precision. The system referred particularly to the mechanism of the balance to achieve these levels, above all the symmetry prompted by the instrument. His method of weighing, to consistently interchange the loads of each scale pan to compensate for any hidden asymmetries in the equal-arm balance, also ensured that the distribution of measurements was symmetric around the mean value, and thus adapted for the statistical evaluation of results.[843] With symmetry, Gauss could subtract himself from each observation, and the statistical mean of his observations could be given as if absent the labour of the observer.

[839] Humboldt:Schumacher,[1836]; Humboldt:Encke,[1836] in Dörries,1994,p.133.
[840] Cawood,1979,p.507,ft.50.
[841] Dörries,1994,p.133.
[842] Hallock&Wade,1906,p.69,p.232.
[843] Hentschel,2007,p.43,p.53.

§4: Visions of the cross

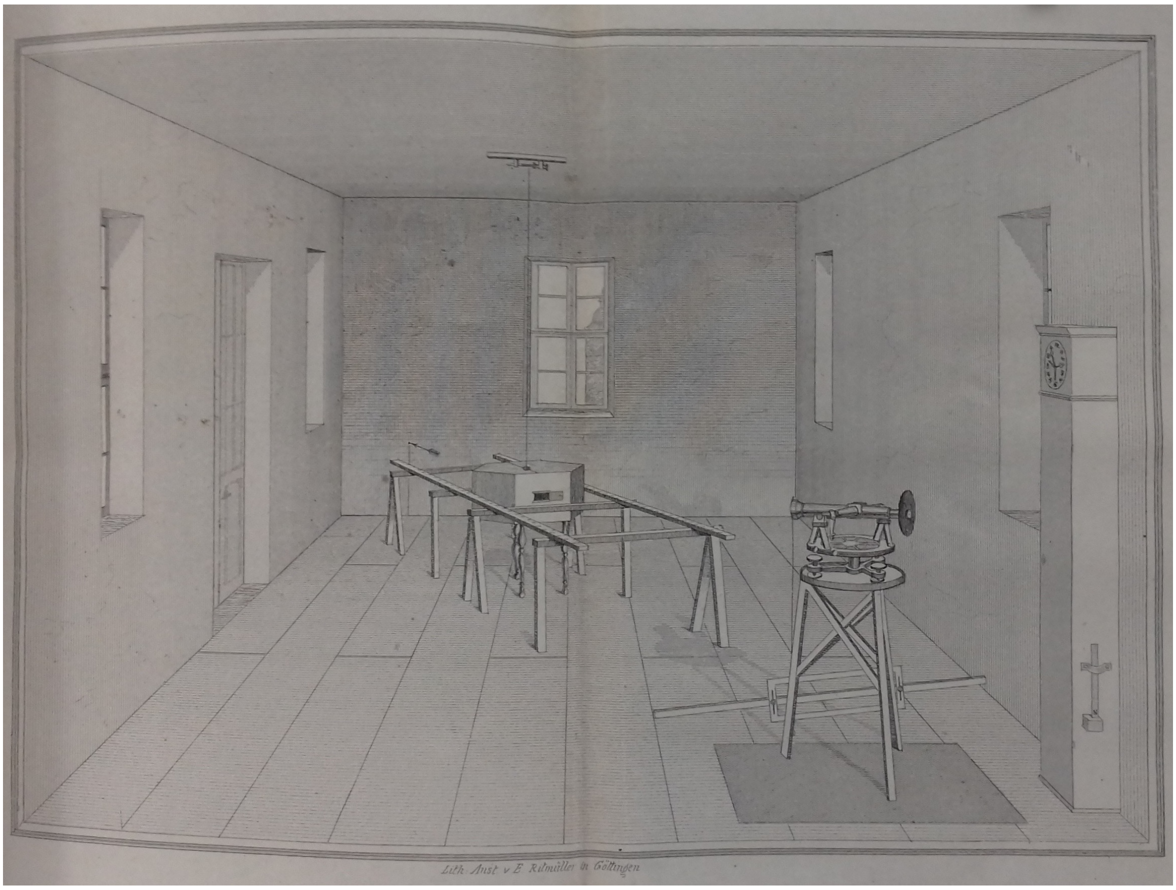

Figure 6.5: Göttingen Magnetic Observatory, main room with magnetometer, theodolite and scale, Gauss, Carl Friedrich & Weber, Wilhelm, 1837, *Resultate aus den Beobachtungen des magnetischen Vereins im Jahre 1836*, Göttingen: Dieterichschen Buchhandlung,

The Göttingen astronomer applied the same system to his magnetic researches, which revolved around the giant suspended bar magnet of his enormous magnetometer (Figure 6.5). A direct descendent of Coulomb's prize-winning compass design, Gauss's magnetometer was a torsion balance.[844] As with the equal-arm balance of his weighing scales, its instrumentation depended on measuring the symmetry around the pivot. For the torsion balance this point was the axis of the 200 conspun silken threads on which his four-pound needle was suspended:[845] the thread that suffered neither compression nor extension in the process of torsion. In principle, this thread was at the same neutral point that Barlow read into the fracture structure of timber and iron. The statistical mean of Gauss's observations was presented as the ideal referent, a kind of neutral point, except not of fibres but of people. Gauss's statistical mean represented his magnetometer without human or error.

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[844] Dörries,1994,p.121,pp.123-4.
[845] Gauss:Airy,[24/03/1836],**CUL**/RGO/6/675/45.

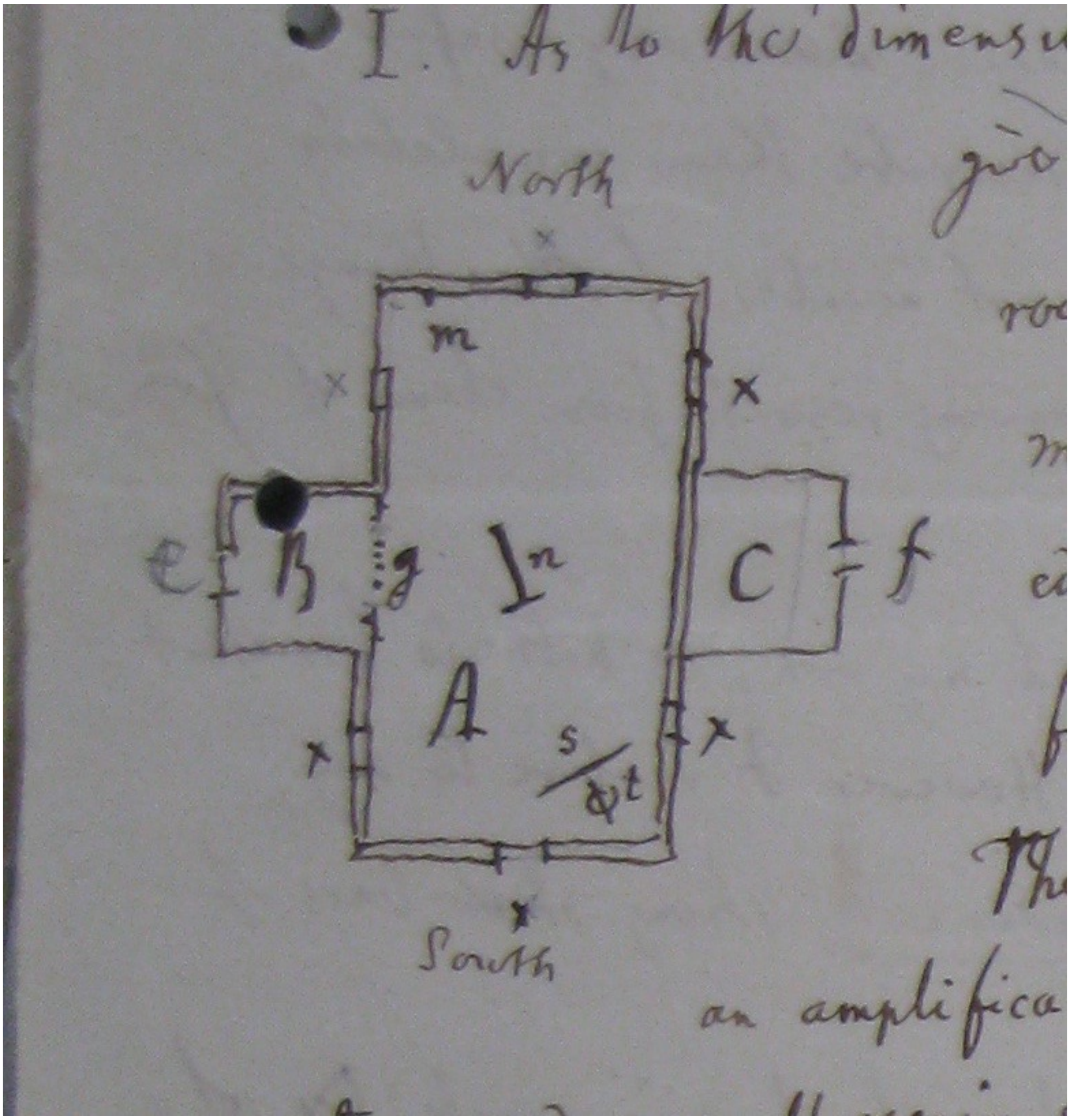

Figure 6.6a: (compare with **Figure 6.6b**), Gauss to Airy 'sketch of Göttingen', 24 March 1836, RGO 6/675/45, Cambridge University Library.

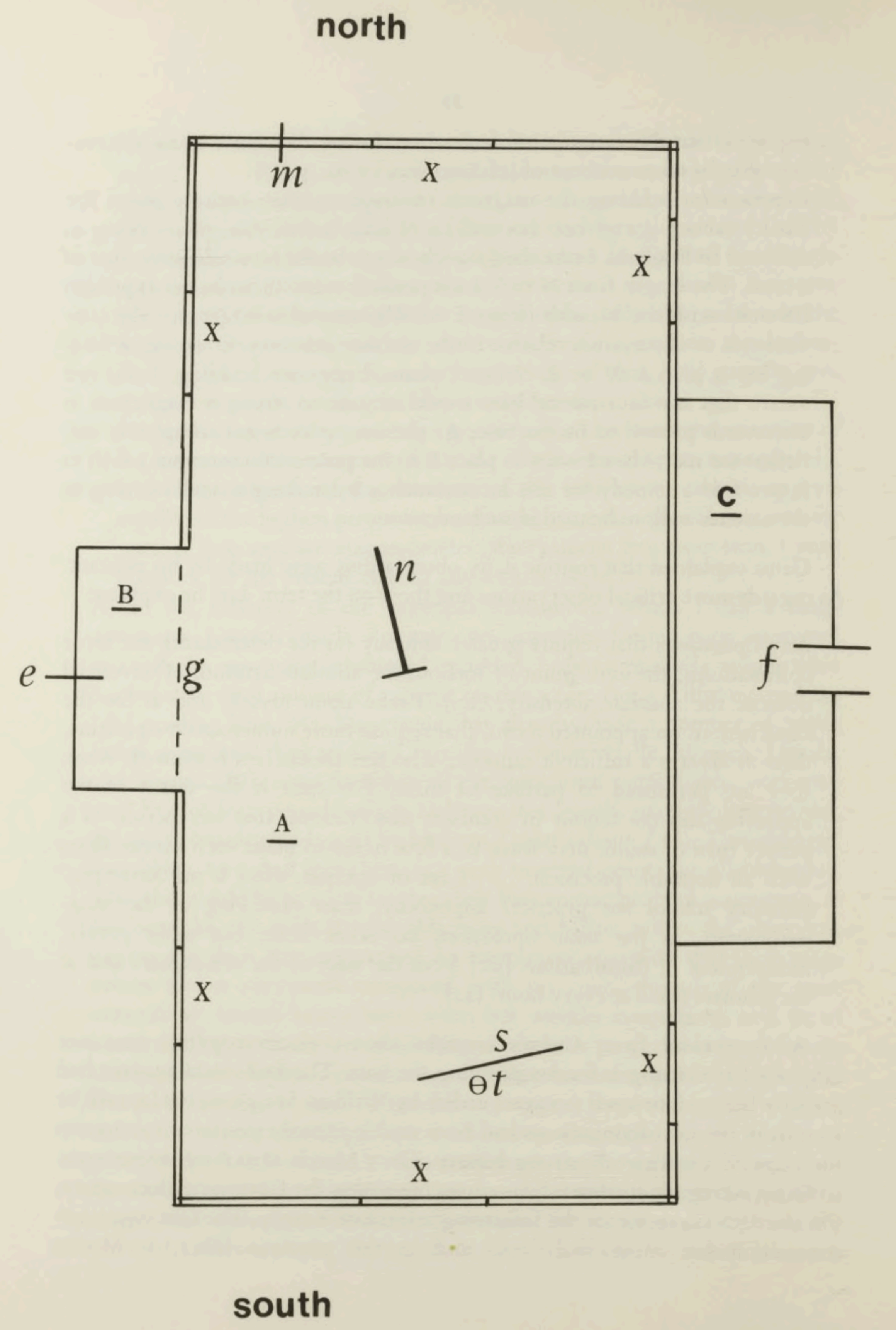

Figure 6.6b: Line drawing based on actual dimensions in 1836, O'Hara, James Gabriel, 1983, Gauss and the Royal Society: The reception of his ideas on magnetism in Britain, (1832-1842), *Notes and Records of the Royal Society*, Vol. 38, No.1, 17-78, p.36, plate 4.

Gauss described Göttingen as a cuboid, A, running North to South, where B and C are subsidiary lobes (Figure 6.6a): a symmetry not present in the actual dimensions (Figure 6.6b). For Gauss, Göttingen took 'the form of a cross' around the single magnetometer and the symmetry of its observations. In the horizontal plane of this cruciform house, his magnetometer lay crucified, its arms stretched out, the crosspiece at right angles to the weighted wooden *stipes* that took the magnetic meridian.[846] Gauss would determine the moment of inertia, the neutral point, by observing the *patibalum* against the *stipes* through the silk cross-hairs of his telescope.[847] The architecture which housed Gauss's instrument design and practice was a geometrical figure, each part of which, from magnetometer to the cross-hairs and method, exhibited the same statistical character as the whole. This arrangement both produced and reinforced his statistical method that constructed the magnetometer as a standard. In his metrology as in his magnetism, Gauss improved accuracy using a system introduced by Kater to control against the influence of the observer's body heat; and precision by increasing instrument size.[848] Meanwhile, in Greenwich, Airy took Gauss's advice, giving the new magnetic observatory 'the form of a cross', and deriving observations from the symmetry of the balance.[849]

In 1838 at the Newcastle meeting of the British Association described in chapter one, the newly elected Sabine reported on his and Lloyd's survey.[850] While drafting the report, Ross had written to him with an emphatic reminder to include a note on the superiority of Robinson's skill.[851] The survey was intended to form a model national survey, and the basis for future imitation.[852] It was intended to serve as a standard in its own right, and reference to Robinson was deployed to make it so.

In January of 1840, Gauss wrote to Sabine asking that he procure 'what you call a Dipping needle "partem pro toto"…. *as perfect as can be executed by an English artist'* and specifying 'Mr Robinson'. He used the phrase 'partem pro toto,' because he recognised 'the needle' as a metonymical argument. When he extended this metonymy into his architecture and statistical method, he produced a fractal relation, as surely as those who studied fracture for signs of the labour economy, or those who schematised the fracture to make metal machines that would reorganise that economy. Gauss went on to enquire after an instrument Lloyd was

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[846] O'Hara,1983,plate4
[847] Gauss:Airy,[24/03/1836],**CUL**/RGO/6/675/45.
[848] Hentschel,2007,p.71-2.
[849] Gauss:Airy,[24/03/1836],**CUL**/RGO/ 6/675/45.
[850] Sabine,1839,pp.49-197.
[851] Ross:Sabine,[c.9/1838],**NA**/BJ/3/16/129.
[852] Morrell&Thackray,1981,p.527.

developing in collaboration with Robinson: the balance magnetometer.[853] Completed that same year for Lloyd's newly constructed Dublin observatory, the instrument employed a magnetic needle resting on a knife-edge, just as the beam would rest on a knife-edge in one of Robinson's exquisite balances. The magnetic needle then measured the vertical component of magnetic force as if it were a mass.

When Gauss made his request, he found the instrument on verge of completion before installation in the Dublin Observatory. By May 1842, Lloyd could boast in his *Account of the magnetical observatory at Dublin* that British observatories in Toronto, St Helena, the Cape of Good Hope and Van Diemen's Land, and East India Company observatories in Simla, Madras, Singapore and Bombay, all carried the same instruments as those in his Dublin station. So too did the observatories of Brussels, Cadiz, Cairo, Algiers, Lucknow, Trevandrum, and, of particular significance, Harvard University in Cambridge and Girard College in Philadelphia. The pride of Lloyd's Dublin undertaking lay in the strict similitude and synchronisation between this enormous magnetic union, described by Sabine, now well-versed in the Association rhetoric, as 'a great combination, embracing the whole globe in its field of action, and all civilised nations as co-operators'.[854] The correspondence of instruments was the cornerstone of this achievement. Each observatory carried the same, and pride of place went to the balance magnetometer of Lloyd's design, made by Robinson,[855] and built to be globalisation's standard. The introduction to this thesis detailed how Harvard professor Joseph Lovering and college astronomer William Cranch Bond coined the phrase 'magnetic crusade' in 1841, in their September report to the American Academy of Arts and Sciences that described their engagement in the magnetic campaign. It was a phrase they then sought to promote. Within a few months of the publication of Lloyd's *Account*, Lovering and his Harvard colleague Benjamin Peirce reprinted the Dublin astronomer's introduction under a new title: 'History of the present magnetic crusade by Rev Humphrey Lloyd'.[856]

As the introduction to this thesis noted, Alexander Dallas Bache had been responsible for recruiting the Harvard school's interest in the magnetic campaign. In the latter half of the 1830s, Bache had toured Europe with New Jersey professor Joseph Henry, introduced in chapter four. Their stay in England happened to coincide with the British government lifting the duty on scientific instruments.[857] On 17 April 1837, they went together to Robinson's workshop and Henry drew the form of a cross as he observed the needle of the dip circle

[853] Gauss,[1840], in O'Hara,1983,pp.61-2.
[854] Sabine:Lloyd,[20/12/1839],**RS**/MS/119/80.
[855] Lloyd,1842,p.6; Bache,1847,p.vi.
[856] Lovering&Peirce,1842.
[857] Morrell&Thackray,1981,p.327

come into the magnetic meridian.[858] Four days later, they met with Christie at Woolwich Military Academy to discuss joining the international magnetic combination. Christie repeated the Royal Society's position established with Airy the previous year, instantiated in the magnetic observatory at Greenwich then under construction,[859] and underpinning Lloyd's boast of 1842.[860] Observatories, instruments, and observations should follow Gauss in taking the 'form of a cross' (Figure 6.7).[861] In European observatories they saw the same again: the cruciform space, the crucifix formed by the magnet, and the mark on the wall 'to regulate the telescope which has a cross hair in its focus', a mark, as Henry conscientiously drew, in the form of a cross.[862]

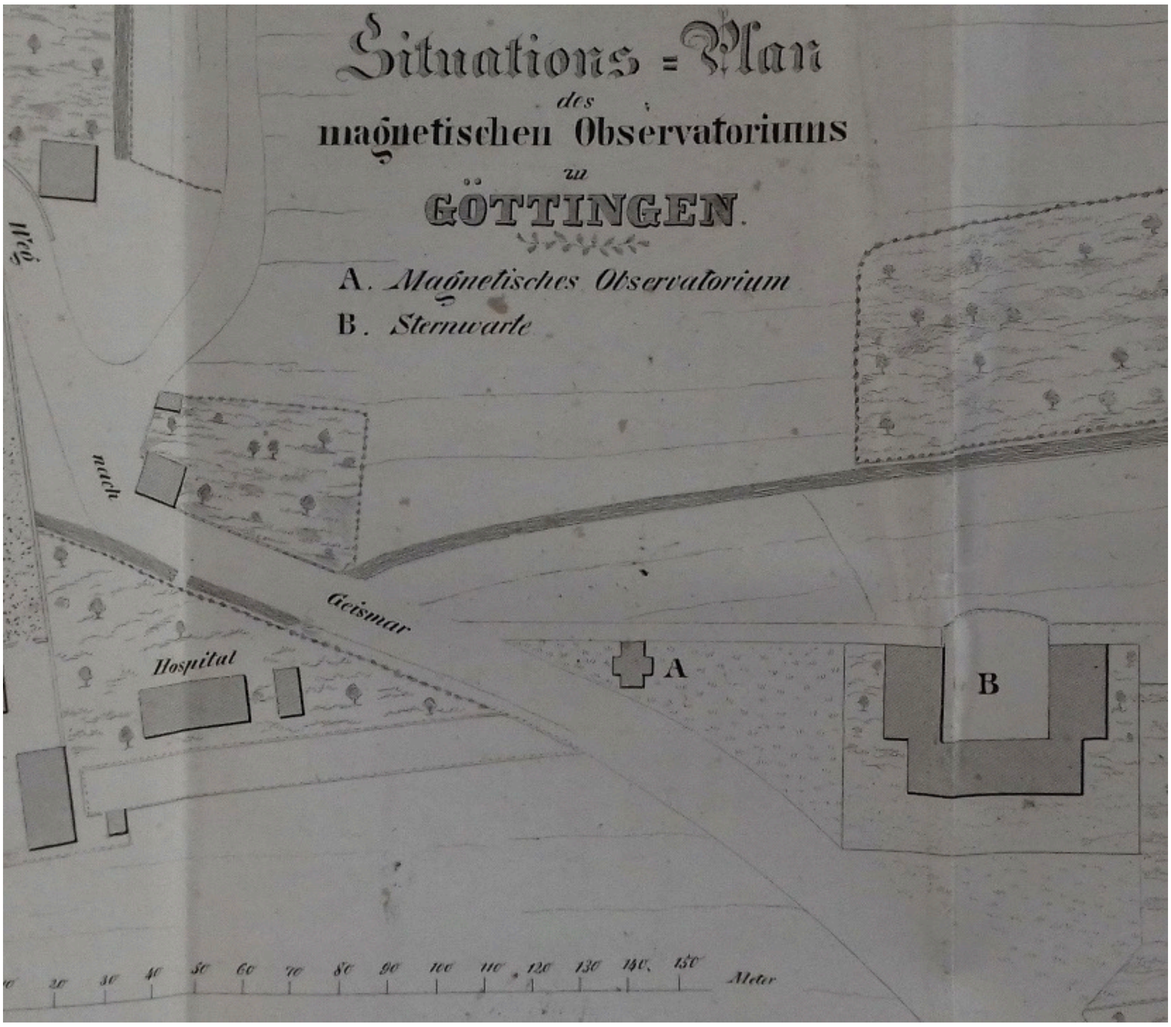

Figure 6.7: Situations: Plan des magnetischen Observatoriums in Göttingen, Gauss, Carl Friedrich & Weber, Wilhelm, 1837, *Resultate aus den Beobachtungen des magnetischen Vereins im Jahre 1836*, Göttingen: Dieterichschen Buchhandlung, Taf. I .der Saal.

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858 Henry,[1837], in Reingold,1979,p.276,
859 Henry,[1837], in Reingold,1979,p.276,p.303.
860 Lloyd,1842,p.6
861 Gauss:Airy,[24/03/1836],**CUL**/RGO/6/675/45.
862 Henry,[1837], in Reingold,1979,p.494.

From the specification of design and insistence on new constructions, to the distribution of instrument standards, both magnetic and trading, the campaign advanced through state building. For Bache, the great-grandson of 'First American' Benjamin Franklin and nephew of powerful political figure George Mifflin Dallas, Vice-President of the United States 1845-1849, the figurative sense of state building was literally true. Bache's education in engineering took place in the centre of military freemasonry in America, West Point military academy.[863] In 1835, seven years after he resigned from the army and eight since taking up the post of professor at the University of Pennsylvania, Bache's uncle Dallas stepped down as Attorney General for Pennsylvania, was initiated to the Scottish Rite of Freemasonry, and immediately appointed Grand Master of Freemasons in Pennsylvania. In 1836, the year after his uncle was appointed Grand Master, Bache left his Pennsylvania professorship to take up the presidency of Girard College, Philadelphia, monument to one of the wealthiest men in American history, noted mason Stephen Girard.[864]

This decision was closely bound up with the political ambitions of his uncle, then head of 'The Family Party'.[865] Indeed, with Bache's father described as a 'calamity', a pariah for his financial difficulties and his mother treated as if she were a widow,[866] Dallas was not just head of The Family Party, but head of Bache's family too. Girard College was a school for 'fatherless boys',[867] founded in 1833 at the bequest of banker Stephen Girard, with Bache as a trustee.[868] Girard had long been one of Dallas's crucial political allies when he died childless in 1831. In Bache's words, through the College, 'Mr Girard has put himself in the place of father to an orphan'.[869] At his death, Girard had been a Master of the Ancient York Masons for over four decades, and was devoted to the organisation. The masonic ties were such that his funeral procession was forbidden entrance to the church because they would not remove the insignia of their order. This vast legacy which Dallas was bound to and for which Bache was a trustee was not just that of a childless banker seeking to establish perpetuity, but the bequest of a man whose Lodge had been his family. After the fracas over masonic insignia, it had required special dispensation for Girard's body to be permitted, temporarily, on consecrated ground. Three years after the College's completion, his body was removed and re-interred with full Masonic rites in a 'marble sarcophagus' prepared for it in Girard College.[870]

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863 Bullock,1996,p.121.
864 Jansen,2011,p.126.
865 Jansen,2011,p.132.
866 Barbour,[1825] in Jansen,2011,p.58.
867 Romano,1980,pp.138-9.
868 Jansen,2011,p.135.
869 Bache,1839,p.2.
870 Henry,1918,p.289,pp.277-8.

Masonic tradition was heavily invested in claims to ancient Greek antecedents. In marking these claims, masonry combined what its tradition termed 'heathen aruspices' with Judaeo-Christian semiotics. 'Faith' was depicted as a woman holding a key in her right hand and a cross in her left, where the key was the symbol of 'knowledge and power', the cross the symbol of 'perfect religion', and the key and the cross went hand in hand.[871] Girard's will bequeathed an unprecedented $2 million for the construction of the College building. As a memorial to Girard, the College was to be a monument to masonry, and in particular its claims to ancient knowledge. It was these claims that underpinned the striking choice of design: a Greek Corinthian temple with a peripteral colonnade. This Greek temple would take fifteen years to complete, and was only three years underway in 1836, when Bache was sent to report on the state of education in Europe. When he arrived in Greenwich the following year and saw the magnetic observatory under construction in the 'form of a cross', Bache was primed to see the evangelism in the architecture and instrumentation of the magnetic campaign. On his return, with another eight years before the building work would be completed, Bache immediately threw himself into persuading the Girard College Building Committee they needed a magnetic observatory,[872] persuading the masons that the house of their 'heathen aruspices' needed a cross to complement its key to knowledge.[873]

In 1843, Bache was appointed head of the United States Coast Survey, which resources he mobilised to establish a vast principate of 103 magnetic registration stations across the States.[874] In correspondence he often referred to his surveyors as 'aruspex' or 'aruspices', for the way in which they carried their markers as attributes of the knowledge and power they unlocked.[875] Still heading the Survey at the outbreak of the American Civil War, Bache supported the Union war effort, providing the army with accurate maps, but he was outraged by the waste and destruction of the fighting.[876] In particular, the Unionist army pillaging his survey markers, ignorant that the markers they carried off as trophies were the masonic signs of his state building, infuriated him. He pictured the Union soldiers with his key in one hand and their cross in the other, saying 'Is it not rather heathenish to carry Aruspices with a x'n army?'[877] His shorthand for 'Christian' was more than the classicists' substitution of 'X' for Christ: with 'heathen' and 'Aruspices', it was explicitly masonic. Just as he had seen the scientific servicemen in Europe evangelise with knowledge and power in one hand and

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871 Oliver,1850,p.187
872 Bache:Lloyd,[19/09/1839],**CUL**/RGO/35/182.
873 Oliver,1850,p.187
874 Lefkowitz,1981,p.8
875 Bache in Jansen,2011,pp.300-302.
876 Jansen,2011,p.301.
877 Bache in Jansen,2011,p.302.

crosses in the other, now he saw the Union troops perform the same gesture without thought for what a key they held in his markers. To Bache these military men fighting for union were an 'x'n army', a crusade.[878] It was an association formed two decades previously, when Bache introduced Peirce and Lovering to the military campaign for a global union of magnetic research forged through the proliferation of Gaussian crosses. In Bache's introduction, Peirce and Lovering saw a 'crusade'.

§5: masters of fetish

The previous sections have considered the way in which astronomers such as Airy, Arago, Gauss and Schumacher were the curators of trading standards. The authority of these weights and measures was not some innate quality of the material or esoteric practice, but came rather from the power relations projected onto them. Astronomers were the masters of this fetish, but such mastery was not without cost, and the previous sections further considered the vast labour mobilised in this process. The fixed observatory astronomers of the 1830s onwards worked closely with those who projected the pattern of the astronomical science into the field, in particular the servicemen turned scientific administrators, Beaufort, Sabine and Bache. Commanding manufacturing contracts as they did military observers, this alliance went to great lengths to unite communities in military, science, industry and politics in their effort to create a powerful fetish, a standard of universal exchange.

Beaufort, Sabine and Bache held in common with Gauss and Schumacher a shared ambition for state-building, but the interpretation and expression differed from each according to his tradition, to each according to his contingent concerns. While Gauss's Göttingen labours looked to establish a relation between instrument, practice, and architecture, its global extension saw individual traditions express that recursive organisation in different ways. For Sabine, the internal logic married with the lessons of his brother-in-law and foster father in Company diplomacy. By contrast, Bache saw in this organisation observance and the interpretation of signs. For Schumacher, such reorganisation was part of negotiating boundaries and seeking to forge new unions in rebuilding post-revolutionary and post-war Europe. While Gauss shared similar such duties, for him the priority was the reorganisation of space to determine the practice of the observer. His concern was to drive down the cost of human error in the production of observations. To do so, Gauss sought to produce statistics: political mathematics concerned with the distribution of people and variables related to

[878] Jansen,2011,p.302

them. How this was understood and interpreted by the members of the Compass Committee, leading figures in the magnetic campaign and standard reform, is crucial to this section.

As was set out in chapter one, in his 1832 literary difference engine, *On the Economy,* Babbage offered up the Cornish system as his model of political economy. The principle Babbage drew from this model was that the division of labour does not directly increase profit, but rather drives down the total cost of production: a principle for the optimisation of labour extraction. The spectacular success of Babbage's work, already on its fourth edition and with translations into six European languages, was not necessary for the text to be of principal importance to the Committee members. Section two noted that the Difference Engine was an Admiralty contract to reform the calculation of navigation tables. As such, its printed principles were of immediate relevance to the Compass Committee. Gauss reorganised space to reorganise labour into political mathematics that could drive down the cost of human error. This section argues that the Committee read the Babbage principle into Gauss's assemblage.

On 29 June 1840, the Compass Committee submitted its final report to the Admiralty. The document summarised the history of compass investigations, the Committee's progress, and the material research of its expert advisors, in particular Robinson and Scoresby. On the basis of their results and recommendations, as well as experiments by Johnson and by Christie, the Committee agreed upon a series of principles to reform the construction of compasses. Beaufort, Committee chairman as of September 1839, signed the June 1840 report with a proposal suggesting that twelve compasses, constructed on these principles, should be ordered for more extensive trials.[879]

Within a month, Beaufort was negotiating with Robinson over how to put a price on the construction of the instrument, asking the balance maker to 'break up' the compass into individual items, 'twenty two in number', and apportion a price to each item. Robinson's response was revealing,

> to but few of [the listed items] can I offer an estimate & that a rough one & to the majority I can offer no estimate at all… If these compasses, having been already made & work in them well understood, were afterwards required in great numbers a Master workman & his workmen would perchance for mutual convenience arrange

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[879] Report,[1840],**CL**/ACO/11/16.

> them in portions & affix to them a separate workman's price, but they would never break up the matter into such items as are in the list before me.[880]

The essence of the Babbage principle lay not simply in its disassembly, but specifically in its derivation from the Cornish system. As Chapter one noted, other mine economies, such as the Durham 'cope system', were based around a strong division of labour. The significance to Babbage of the Cornish mine economy was that the governing principle under which labour was reorganised was the rhythm of the steam engine. In the bench-artistry of Robinson's instrument production, Beaufort's request was incomprehensible. Robinson's description of the evolution of a system of portioned work through great demand further highlights what was at stake. As early as the 1840s the development of machinery to meet the navy's demands for huge numbers of precisely divided instruments was considered a dramatic advance toward automation.[881] The scale of Admiralty contracts transformed the instrument trade and machinofacture generally. In the London clocktrade, there had long existed a highly developed division of labour distributed across separate workshops. It was precisely this moment, in 1840, that saw the first total factory for clockmaking with steam-powered machinery.[882] Proponents of automation saw the scale of naval demands as an opportunity to transfer from manufacture to machinofacture. This scaling vision was made to work like the cyclopean gaze described in chapter two, to generate the mechanical fetish of labour.

The price Robinson quoted for the Committee compass was twenty-five pounds, twice to four times that of a top of the range azimuth compass.[883] To understand a commodity's value in terms of its equivalents was acutely of the culture of the moment. A principal tactic of the abolition movement since the early 1790s had been to use calculations in the style of school textbook problems to divide up African bodies into pounds of flesh whose value was to be explained and understood as commodities.[884] By the 1820s and early 1830s, such equivalences were used to promote the purchase and consumption of East Indian products and push for the boycott of West Indies goods.[885] Robinson's pricing brought the compass in line with the cost of precision surveying instruments such as a six-inch theodolite or twenty-four inch transit instrument,[886] or the average compensation for an enslaved African in post-

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[880] Robinson:Beaufort,[30/07/1840],**CL**/ACO/11/16.
[881] Chapman,1995,p.108; Simms,1846,pp.83-90.
[882] Dent:Blunt,[c.7/01/1840],**G**/MS/18010; Bulstrode,2018b,pp.278-313.
[883] Clarke,1842,p.63
[884] Williams,1944,p.183.
[885] Williams,1944,p.159.
[886] Palmer,1840,fig.216; Clarke,1842,p.16; Riddell,1844,pp,98-9; Clarke,1845,p.2; Riddell,1846,p.14.

abolition Jamaica: less than half the average value paid in Guyana,[887] where, as chapter two noted, African ironworking skill was concentrated. The Admiralty accepted the expense. The cost was covered by the Admiralty Scientific Department, and the twelve compasses were sent for trial: three to the ships of the Niger expedition, others to America, South Africa, the Torres Strait and the Indies, West and East.[888]

In 1842, following Robinson's unexpected death, the Admiralty turned to William Gilbert of Fenchurch Street, one half and all that remained of the partnership that had supplied the East India Company and Barlow in his early magnetic investigations.[889]As mentioned, in 1827 William and his brother Thomas had become embroiled in a notorious and costly controversy over the quality of their instruments supplied to a Company Observatory in Bombay, upon which Browne and Beaufort were called to adjudicate. On Browne and Beaufort's advice, by May 1828 the Company had decided the Gilberts were not at fault.[890] This was too late for the Gilbert firm, declared bankrupt in late March that year.[891] Two years later, in 1830, the same year that Babbage launched his attack on Browne's Portland Place school, the creditors moved in on the Gilberts, challenging their claim that they could not pay their debts.[892] Six years on, in 1836, Thomas Gilbert was appointed first Colonial Storekeeper of South Australia. He emigrated that same year, and retained the position until his retirement in December 1854.[893] William Gilbert set up shop alone, initially operating from 97 Leadenhall Street, a few doors down from their former joint premises,[894]opposite the entrance to the Company's headquarters: East India House.[895] But by the time of Admiralty's compass commission in 1842, William Gilbert was set up at 138 Fenchurch Street. In addition to the twelve compasses then in circulation, the Admiralty ordered the manufacture of 200 more, each at Robinson's price of twenty-five pounds.[896]

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887 Beckles,2013,p.152.
888 Fanning,1986,p.11.
889 Barlow,1837b,p.664; Barlow,1823a,p.90.
890 Schaffer,2012,pp.169-70,p.152.
891 Bankrupts,[3/29/1828],**NA**/B/3/2035..
892 London Gazette,1830,p.431
893 Supplement,1873,p.15.
894 Clifton & Turner,1995,p.113.
895 Schaffer,2012,p.151.
896 Fanning,1986,p.14,p.11.

Figure 6.8: Admiralty Standard Compass, adapted for small ships 1840, ACO0033 Greenwich National Maritime Museum, Greenwich, London.

The reformed Admiralty compass was constructed on a series of adaptive principles. Rather than a uniform assemblage of standardized parts to be put together in large numbers, each compass was tailored to the specific needs of a ship (Figure 6.8).[897] The reformed Admiralty Compass was to act as 'Standard' in the same way the Walker compass described in Chapter one had done: as a reference compass for all other shipboard compasses. It was a standard in the same sense in which weights and measures were deployed, just as Kater's pendulum length standard had derived its authority from Browne's Portland Place, and as such depended on being taken as a reliable representative of established power relations. For the Admiralty Standard Compass to function as a delegate of institutional authority, the object had to declare the integrity of its representation.

The original principles were as follows. Four edge bar needles, forged from clockspring steel,

[897] Correspondence:Compass makers,[1842-1883],**CL**/ACO/13/6.

were secured together with the card within a light ring of brass (Figure 6.9a). The balance of the card was aided by this circumferential ring, suspended beneath; and by sliding balance weights on bars radiating from the centre of the card, while the needles were arranged so as to give a uniform displacement of mass about the central pivot. The card was made of mica, covered with thin paper; the impression of the cardinal points struck off subsequently to its being cemented to the surface of the 'talc', the artisanal term for mica, so as to avoid all distortion of the surface by shrinking (Figure 6.9b). A card lifter was also incorporated, operated by a screw at the side of the bowl. The caps were made of agate or ruby, worked to the shape of the points of suspension which, on Robinson's recommendation, were made of 'native alloy', a by-product of smelting platinum and silver in Spain and the Urals, sometimes called iridium. Six spare points of steel, gilded by the electrotype process, were also supplied. The pivot, which screwed into a pillar and was adjustable by tangent screws for centering, could be replaced or substituted according to the variable demands on the compass. For example, each compass was furnished with two spare cards. 'A cards', which employed a native alloy point in a sapphire cup, were generally used (Figure 6.10); but in rough weather or when firing guns a special heavy card known as a 'J card' was substituted. The J card made use of speculum metal in a pivot made of ruby (Figure 6.11), further, J cards tended to use a larger gem-stone for the pivot. The compass-bowl was generally made of copper, with a view to damping the oscillations of the needle (Figure 6.12). Of equal if not more importance than these principles of construction was the simple fact that the Standard Compass was both carefully and beautifully constructed.[898]

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[898] Harris,1850,pp.145-6; Fanning,1986,p.7; Alexander & May, 1907-1951,p.33; Admiralty Standard Compass in binnacle,[1840],**NMM**/ACO0031.

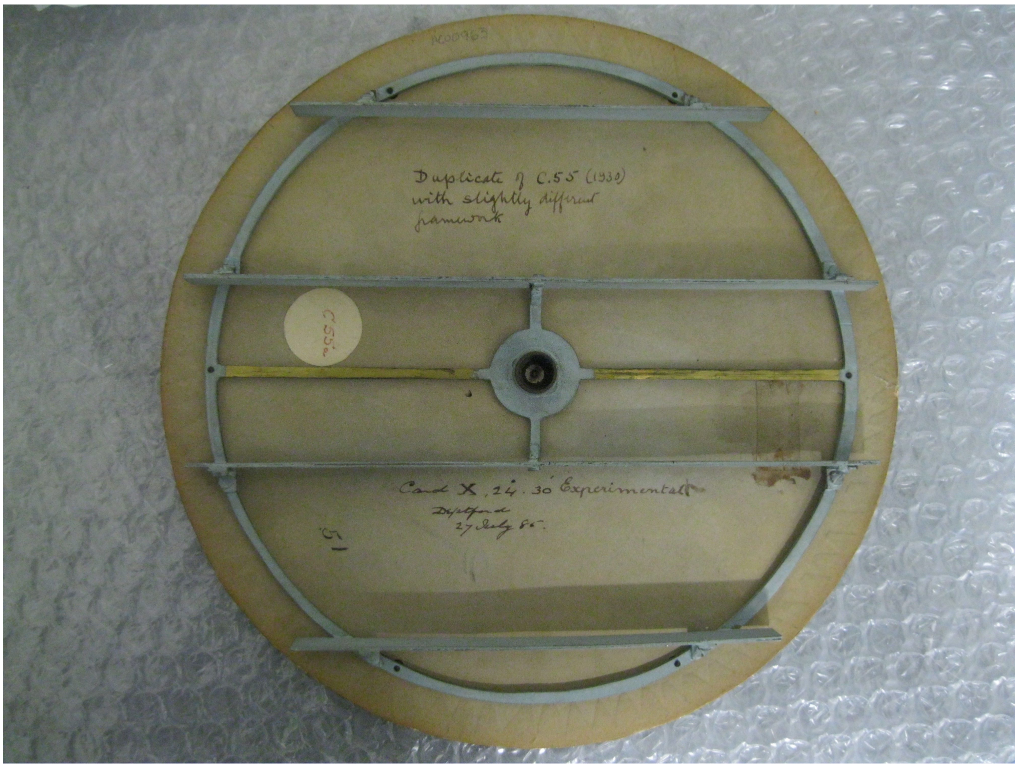

Figure 6.9a back of Admiralty Standard card 'A-type', showing the arrangement of the compass needles.

Figure 6.9b: front of Admiralty Standard card 'A-type', where the card is slightly scuffed, tiny patches of mica are exposed. 1840, ACO0963, Greenwich National Maritime Museum, Greenwich, London.

Figure 6.10: Sapphire cup and iridium tipped pivot (point down), 1837-40, ACO0972, Greenwich National Maritime Museum, Greenwich, London.

Figure 6.11: Ruby-tipped pivot, 1840, ACO0432, Greenwich National Maritime Museum, Greenwich, London.

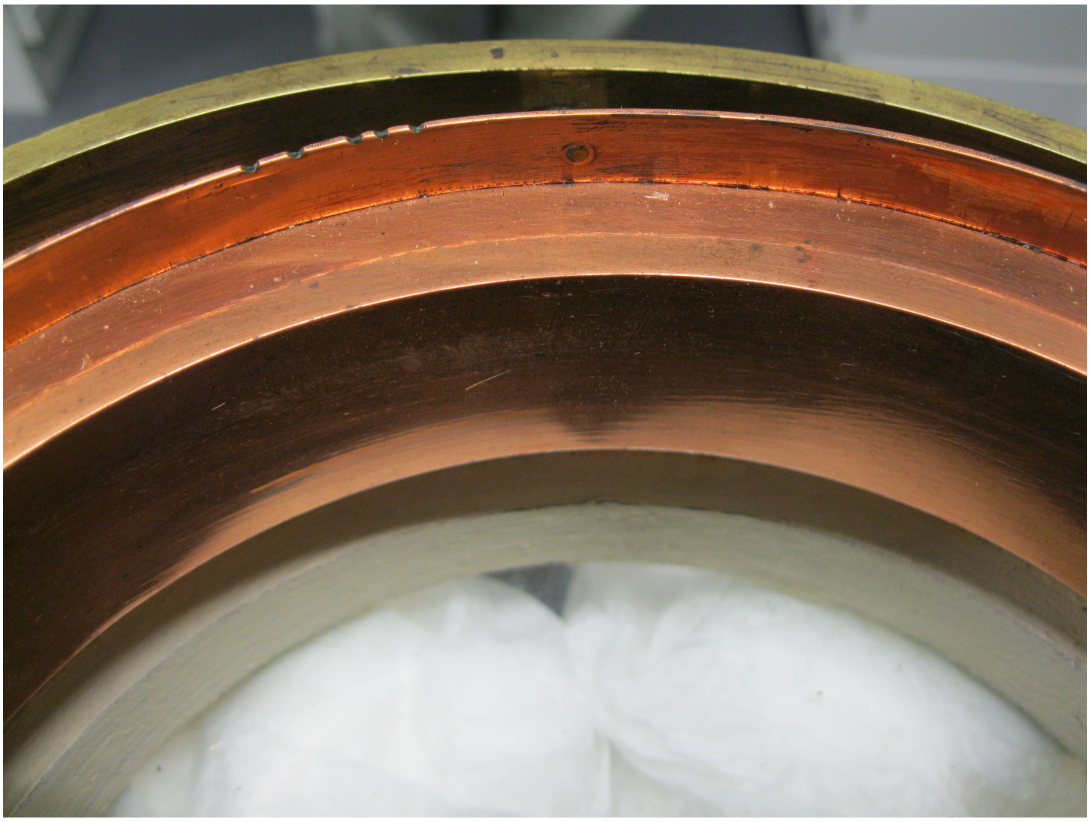

Figure 6.12: Heavy copper ring to insulate needle, 1831, ACO0016, Greenwich National Maritime Museum, Greenwich, London. The 1840 Standard Compass specification drew on this specific design instrument design to recommend a copper bowl.

Figure 6.13: silver scale set into the verge of the azimuth ring, ACO1363, Greenwich National Maritime Museum, Greenwich, London.

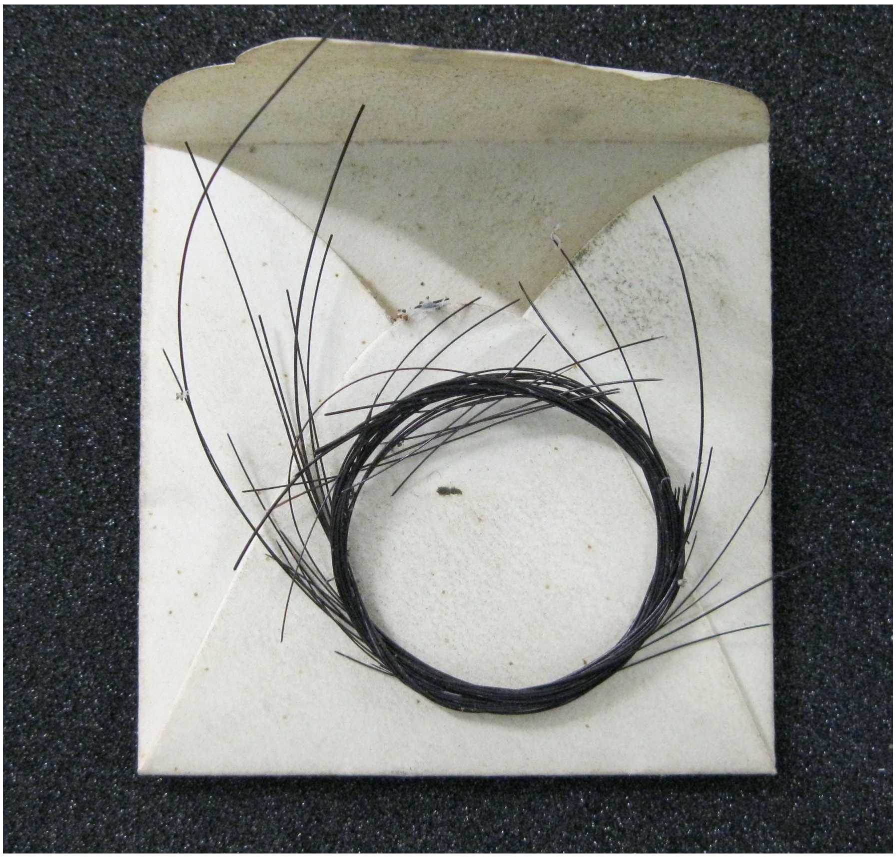

Figure 6.14: spare wire 'for fore sight' 1837-40, ACO0972, Greenwich National Maritime Museum, Greenwich, London.

One particular adaptation, however, was the focus of special attention in the construction and the peculiar mark of the Admiralty Compass. This was the incorporation of an azimuth circle, a circle of silver let into the verge ring, as in the arc of a sextant, and graduated every half degree to 360° (Figure 6.13).[899] The circle was mounted on a central boss and carried an elaborate prism-box with dark shades, as well as a folding sight-vane, horsehair thread (Figure 6.14), and black glass reflector for taking bearings of celestial objects. By placing the instrument on a stand, the glass cover removed, and the azimuth circle fixed on its upper margin, the compass was converted to an azimuth compass. The arrangement was such that the sight-vane and prism could be turned without interfering with the other parts of the instrument. The bottom of the compass-case could be removed so as to light the card from beneath.[900]

Since 1840, Johnson had been occupied full time with supervising the manufacture and testing of compasses. In March of 1842, the Lords Commissioners requested the Committee publish a guide for ascertaining the deviations of the compass caused by ship's iron. These

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[899] Alexander & May,1907-1951,p.33.
[900] Harris,1850,pp.145-6; Fanning,1986,p.7; Alexander & May,1907-1951,p.34,p.35.

specified that every ship should be provided with a reference compass, dubbed the 'Standard Compass', against which other ships' compasses were to be regularly assessed. Regulating compass deviations was stressed as a constant and on-going process of checking and correcting. When Beaufort submitted the draft of the *Practical Rules* to the Admiralty, he included a proposal for the appointment of 'some intelligent person' to supervise the swinging of the ship to detect compass error, until such time as it became habitual for officers. The Admiralty's response, just four days later, was to appoint Johnson to take on this responsibility, to be paid as a surveyor. The abstract and market equivalence of the theodolite and the compass were further institutionalised. In addition, Johnson was to carry out 'severe examination' of the construction and adjustment of the 200 compasses commissioned from Gilbert, and to supervise the construction and position of binnacles on ships; 'and more especially all steam vessels.'[901] For the first time, binnacle construction became the authorised and explicit concern of the Superintendent of Compasses.[902]

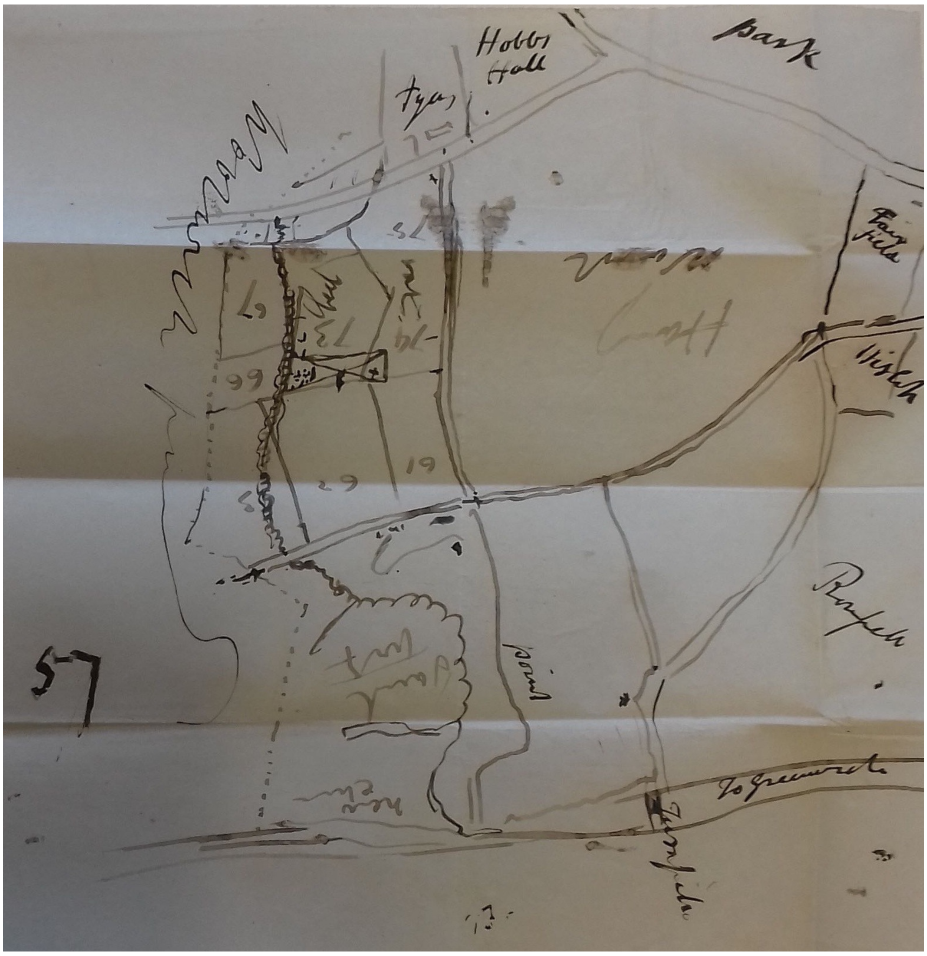

Figure 6.15: Untitled sketch of the area of the planned Compass Observatory. The number '57' refers to where the plan is to be included in the lease. Drawn c. October 1843, E/MW/C/1609/2/2, London Metropolitan Archives.

[901] Fanning,1986,pp.13-4.
[902] Alexander & May,1907-1951,p.34.

Figure 6.16: 'Clauses for Leases', from the stipulations of the Charlton Vale lease. The octagonal observatory can be seen to the right, the house centre. Drawn c. October 1843, E/MW/C/1609/2/2, London Metropolitan Archives.

It was not until 1844 that a suitable site for the Compass department was found in the form of a strip of newly-reclaimed land in Charlton (Figure 6.15). Here a brick house was built with an octagonal wooden structure in the garden, specifically for testing compasses (Figure 6.16).[903] The department took its official name and address from the wooden octagon, becoming 'The Compass Observatory'.[904] It would come to be one of the longest-running technical departments of the Admiralty and oldest Government Scientific Establishments, preceded only by the Royal Observatory and the Royal Ordnance Factory.

In 1836, Gauss had communicated to Lloyd that his magnetic observatory in Göttingen was 'a peculiar building free from iron'. While the exclusion of iron was not itself an imperative feature for Gauss, he considered that for the sake of comparison it was 'of the greatest importance' that Lloyd provide a similar building in Dublin.[905] Accordingly, Lloyd's Dublin observatory had been constructed to be entirely free from iron,[906] and following Lloyd, so too was the construction Bache requested for Girard College.[907] When in 1850 the journalist Frederick Knight Hunt visited the Compass Observatory, for an article on swinging the ship for Charles Dickens's publication *Household Worlds*, he found an octagonal, not cruciform,

903 Draft Leases,[13/02/1844],**LMA**/E/MW/C/1609/1.
904 Fanning,1986,p.15.
905 Gauss,[1836] in O'Hara,1983,p.41.
906 Lloyd,1842,p.11.
907 Bache:Lloyd,[09/1839], **CUL**/RGO/35/182.

wooden building, elaborately constructed to be entirely free from iron. A copper lock opened by a copper key released a door hung on copper hinges and gave admittance via stone steps only after the dirt from a visitor's shoes had been removed by a copper scraper. When, in 1841, Peirce and Lovering set out to Harvard their requirements for a magnetic observatory based on the description given by Bache of his European tour, the expenses included 'one coarse coat without buttons'.[908] Johnson's jacket was fastened with specially made copper buttons omitting any iron shank. Within the Observatory, iron was a 'forbidden metal'. In accordance with the Royal Society's 1842 *Revised Instructions for the use of the Magnetic and Meteorological Observatories,* the building incorporated a fireplace to ensure variations of internal temperature were kept as small as possible;[909] but the fireplace, the chimney, the poker, the shovel, were are all alike: 'Nothing but copper, copper, pure Copper,' tirelessly remanufactured Cornish metal, which, since Matthew Boulton's entrepreneurship described in chapter 1, ran together in its smelting, the Cornish system and state mercantalism. The copper of the Observatory must be understood as an argument in support of the emergence of a new world order, designed to materially pervade the existing global structure. When this Observatory first began operations, a minute variation of the needle had led to a scouring the building and its vicinity for any morsel of iron. Nothing found,

> [a]t length the *brass* bolt on the window was suspected, and though brass had a good character, not being thought capable of coaxing the magnet from its truth, it was in despair of finding any other delinquent, unscrewed from its position. No sooner was this done, than the wayward needle returned to its true position; the brass bolt was ejected in disgrace and no morsel of the brazen metal has since been allowed to show itself within the precincts of the building sacred to the mysterious fluid that draws the iron needle to the North.[910]

The keepers of the Compass Observatory made a fetish of the bolt, and the Observatory an instrument that discovered, and naturalised, fetish.

Inside the building, three masonry pedestals rose through the Observatory floor, isolated from any vibrations in the building itself by a gap. They stood in a row running north to south. The southernmost supported a torsion magnetometer; while the central pedestal carried a telescope for observing the scale of the torsion instrument and bringing it into correspondence with that of a distant reference object, either a scale mounted on the wall up a nearby hill known as Cox's Mount, or a star. On the third pedestal, the most northern, and

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[908] Peirce&Lovering,[25/09/1841],**Harvard**/UAI 5.125/v10/fols 298-99.
[909] Royal Society,1842,p.10.
[910] Hunt,1850,p.416.

the Arctic of the arrangement, was 'a bed of trial – a place of ordeal', where compasses were brought to be tested.

The instruments of the Compass Observatory, the Observatory building itself, and the scale on Cox's Mount, presented a giant, deconstructed compass: the same fractal organisation as on the Gaussian plan, only here the statistical character of the whole was defined not by a cross but by a compass, specifically a compass designed on the principles of the Admiralty Standard. The complex whole of the instrument of Observatory operations was broken up into a series of ideal instrument forms corresponding with component parts of the Admiralty Standard: the torsion balance to the suspension of the compass card; the telescope to the sight; the scale on Cox's mount to the silver ring; even the Observatory building took its octagonal wooden form from the binnacles constructed under Johnson's supervision. Metonymy meant that 'needle' had long denoted both the component part and the whole instrument. Here, the slippage was enacted, as the compass under trial formed the needle of the giant disarticulated instrument. From the Niger to America, South Africa, Torres Straits and Indies: West and East, all Admiralty compasses were here on trial, and the globally distributed labour force surveyed. In this abstraction and exchange, the Compass Observatory was a commodity machine.

As described in the opening chapter, this was precisely the moment when the principles of commodity exchange and the emergence of the system of machinofacture were discussed in detail by Babbage and thence analysed in the political economy of Marx. For this political economy, abstract value, external to the commodity and imposed by society, is only manifested when commodities of different qualities are brought into exchange, through some common factor; while the commodity only exists as commodity when it participates in this exchange. The form only comes into being in a negotiation between correspondence and difference. By setting apart a commodity that embodies general value, abstract from material use-values, it becomes possible for the first time to compare the quantitative proportionality of all commodities, their relative magnitude.[911] It is only through such universal equivalent that a world of commodities comes into being, a balance that could bring all commodities into relation at the same time, weighing different qualities into correspondence, scaling between different magnitudes: a universal balance.

The instruments of the Compass Observatory, and the Admiralty Standard Compass articulated precisely these factors. The beautiful construction of the Standard Compass, and

[911] Marx,1954,p.66,pp.71-2.

its movement between azimuth and steering functions, not only converted a rough wind direction into a quantitative measure, inscribed on the exquisite silver scale, but provided a separate equivalent form to bring cruder boats' compasses into correspondence. In the Observatory, the Standard Compass was compared with qualitatively different instruments, which simultaneously represented the ideal forms of the values the Standard Compass represented. The giant Observatory Compass corresponded with the stars to put everything to scale, and in the pans of that balance made commodities of it all.

Conclusion

On May 11 1838, the Chancellor of the Exchequer Thomas Spring Rice wrote to Airy, requesting him to act as chairman for a committee on the steps to be taken for restoration of the 'Standards of Weight and Measure', the same that had been destroyed in the 1834 fire.[912] In the event of the Standards being lost or destroyed, statutes put in place under George IV set out that they should be recovered by reference to two natural standards: the weight of a cubit of water and the length pendulum vibrating seconds of mean time in London. In addition to Airy himself, the Commission comprised the familiar Gilbert and Herschel as well as Lowndean professor of astronomy and geometry, George Peacock; banker-astronomer, John Lubbock; stockbroker-astronomer, Francis Baily; Reform Act boundary commissioner Richard Sheepshanks; political economist and poor-law commissioner, John Shaw Lefevre; and counsel to the Home Office, John Elliot Drinkwater Bethune, responsible for drafting the 1835 Act to establish a uniform system of municipal boroughs, and the 1836 Act for the commutation of tithes. Of these, Airy, Gilbert, Herschel, Peacock, Lubbock, and Baily were all core members of the magnetic lobby. Through Herschel's influence, Spring Rice was the crucial advocate of the lobby in parliament.[913] At every level, the magnetic campaign was directly and explicitly bound to the reform of standards and wider social reforms.

Drawing on their own experience of the frustrations of pendulum research, and the intolerable variance between international results of the weight of a cubit of water, the Commissioners rejected the pendulum and cubit for the recovery of the parliamentary standards. Instead it was agreed to work backwards to reverse engineer the original standard by comparing the several extant material copies across Europe. Among the conclusions of their report, submitted 21 December 1841, were recommendations to reform the system of maintaining standards by introducing a new system of checks and balances between sets of material copies. This system further reinforced the Commission's decision to work

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[912] Airy,1896,p.134.
[913] Cawood,1979,p.498,p.509.

backwards from copies. The new Standards were produced by comparison of extant international copies. They were in fact just an average of the existing international standards. But, once made, these new derivative Standards were now figured as the model and archetype, and the international standards once again as replicas. What was derivative was then treated as original.

Initially, Gilbert had 'really expected the most accurate results' from the pendulum. It seemed as if any necessary corrections would be 'quite obvious', self-evident from the relation of principles. In the event, the pendulum was eloquent of error not accuracy; its variance reported 'different degrees of smoothness', where even the polish of the workmanship was understood as variance in minute quantities; and the difference between and within materials.[914] As Gauss had put it, during his contemporary and connected project in Hanover, even materials 'of the same name' were found to differ depending on their degree of purity.[915] For the Commission, the pendulum had become so synonymous with error that when a beam balance underwent an increase in temperature it was described as having become 'an over-compensated pendulum'.[916]

For Gilbert, '[t]he pendulum involve[d] so many difficulties in respect to determination of its exact length, that [the Commission's] reference must be to one having all minute circumstances detailed, as to substance, bearing on knife-edges, &c'. He argued for reference to an instrument that had been broken down into the detail of its component parts, as in the division of labour that Beaufort requested of Robinson in the previous section. Herschel had set out the central tension in 1833:

> though we are entitled to look for *wonders* at the hands of scientific artists, we are not to expect *miracles.* The demands of the astronomer must always surpass the power of the artist; and it must, therefore, be constantly the aim of the former it make itself, as far as possible, independent of the imperfections incident to every work the latter can place in his hand.[917]

The task of the astronomer as master of commodity fetish was to drive down dependency on the skill of the artisan. For them, Gauss's method provided a means of dealing with instrument makers. The Göttingen astronomer's deconstruction did not remove error; rather, it derived a system of constant correction from the mechanism of the balance itself. As was described in the previous section, Gauss was explicit on the direct significance of the

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[914] Parliament,1841c,p.27.
[915] Hentschel,2007,p.52.
[916] Miller,1856,p.765.
[917] Herschel,1833,p.66; Schaffer,2011,p.711

mechanism of the device both for identifying material error, and for the development of his analytical method. His equal-arm balance enabled the loads placed on each scale pan to be consistently interchanged, thus revealing any hidden asymmetries.[918] This method gave rise to a set of data, which, as if of its own accord, formed a symmetrical bell curve around a mean value. It was as if the balance spoke in bell curves.[919]

As noted, six of the eight-strong body of Commissioners were leading members of magnetic lobby of the British Association, a congress organised to reform the standard of science in Britain. In the experience of those six magnetic Commissioners, the link between the magnetic campaign and the reform of weights and measures was immediate and direct. The magnetic campaign emerged as the Association's *cause célèbre*, not least because this survey science linked astronomical science and geodesy with industrial interests in the land of coal and ironstone. As early as the second meeting in 1832, leading Association members sought to galvanise widespread support for an international magnetic campaign through comparison with international surveys to establish length standards.[920] Within their respective traditions, when the six Commissioners saw Gauss attain unprecedented accuracy and precision through the balance and the bell curve, what they saw was the possibility of a different kind of legislation. Rather than reference to fixed natural laws, the balance and the bell curve proposed systematic correction;[921] legislation over forces and material standards, enacted through relentless reform. The same was true of the length standard, where the Commissioners fought for and won line-measure, derived the length from between two engraved points, over end-measure, where the extent of the bar was the length, precisely because it drove down the dependency on the hands of the artisan.[922]

The Commission's solution to the loss of originals and the unreliable pendulum and water systems was to propose standards defined by reference to a material form: such as the whole length of a certain piece of metal, or other durable substance; or by the distance between two points or lines engraved on said piece. Material copies of the standards of length and weight were to be made, with one set 'in a case hermetically sealed and imbedded within the masonry of some public building… the place in which it is inclosed [to] be pointed out by a conspicuous inscription on the outside'. Of the remaining standards, one set, chosen arbitrarily, was to be designated the Parliamentary Standard. This Standard and all the copies, except the one embedded in the public building, were to be compared with one

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918 Hentschel,2007,p.53.
919 Wise,1993,pp.207-256.
920 Cawood,1979,p.500.
921 Simpson,1993,174-90
922 Airy,1857,p.629; Schaffer,1997,p.440.

another at ten-year intervals. Between these comparisons, each set was to be deposited in different offices, in a glass case, within a wooden or metal case, to be inspected at periodic intervals, under defined precautions. In 1843, a new Commission was formed to bring the changes into effect. Baily was in charge of constructing the new Standards of Length, a task taken over by Sheepshanks, following Baily's death in 1844. Cambridge Professor of Mineralogy, William Hallowes Miller, was placed in charge of constructing the weight standards using balances made by Robinson.[923]

For Gilbert and the Commission, such standards offered to 'invert the natural order'. The designation of the newly forged standards as models and archetypes was to present them as a natural form from which the artificial world is derived.[924] Of the newly constructed Parliamentary Standards, one set was bricked up at Westminster, another at the mint. Once embedded in Westminster masonry, and removed from direct comparison with trade goods, the standard was removed from the economic circuit and its value as a weight,[925] yet became a weight that weighed all weights. In nineteenth-century galleries, removal from economic circulation and special spatial conditions constructed exhibits as apart from and separate: not of the world but for it. Privileged in this way, the display became an ideal 'Form'. Such displays were curated to teach visitors to suspend the worlds of production and use, and accept the symmetry and ordered balance of commodity and standard. Airy was at the centre of 'a great deal of correspondence' preoccupied with the materials out of which the standards should be made, but in particular the collection of historical standards.[926] To the astronomer and his fellow commissioners, 'either from their antiquity or from the purposes to which they have been applied', such historical standards were of great importance.[927] The assemblage of old standards was to act as chorus to the naturalisation of the new.

In front of the Compass Observatory stood the other half of the Admiralty's technical department: a domestic space, workshop, and, in just a few years, a museum to developments in compass construction. The house, was, like the Observatory, built to purpose but for a cost of about £500 to the wooden Observatory's £100. A substantial brick building of about 36 feet by 25 with an elevation of about 24 feet, a slate roof and a total of eight rooms, the house was built to include living quarters for the Observatory's keeper, an instrument room, an office, and optician's workroom.[928] By the time of Hunt's visit, six years later, it also featured

[923] Airy,1896,p.158.
[924] Waring,2014,p.72.
[925] Pomian,1990,p.10.
[926] Airy,[1842-1847],**CUL**/RGO/6/342.
[927] Parliament,1841c,p.8.
[928] Draft Leases,[10/1843],**LMA**/E/MW/C/1609/2/1

an established museum of magnetic navigation. Here, instruments, in Hunt's words, became 'instrumental relics'. They were imbued with a quasi-religious value, to carry out a purpose. Hunt described how one exhibit, 'a plain small bar of steel in a rough wooden case', was, 'to the mariner who loves his craft and its heroes,' of 'interest greater than the most perfect of nautical inventions'. This 'morsel of iron', this disarticulated, divided instrument, had belonged to the heroic navigator Captain Cook 'a seaman who achieved great ends with humble means and from humble beginnings'.[929] Wood and iron were offered up to evoke an origin myth. They ceased to be components of a tool of navigation and became themselves tools in the construction of social memory. The brick house was not meant as a museum, according to the intended room plan, but it rapidly emerged as one. There was a balance here. The Observatory worked by the denial of time and of space, but it did so, in part, by making the house a museum, a space where time could be rebuilt, and memory forged.

As with the Observatory, the exhibits of the museum revealed an intense preoccupation with materials. From Cook's 'morsel of iron', through a chunk of a first-rate's hull that exposed the mixture of iron and wood employed in contemporary construction, to a bowl of copper, 'for stilling the irritability (so to speak) of the magnetic needle', displays pulled instruments apart and demanded attention to the material relation between the ship and the compass. Iron, obsessively excluded from the Observatory, ran through the exhibits, *à grains fins*. Both Observatory and house rested on brick and timber foundations, and enclosing the area 'good and substantial' brick and wood fences. Johnson made sure to amend the draft lease with an iron condition: no verandah, greenhouse or fence of ferrous material was to encroach within 100 yards of the Observatory. Solicitor to the Admiralty, Mr William Froggatt Robson wrote requiring 'there should never hereafter be any Foundry or Manufactory of Iron or Blacksmith or Ironmongers shops within 200 yards of the premises.'[930] Yet, in the agreed lease, the eastern perimeter, the frontage in the direction of the Woolwich Academy, was to be fixed with an iron railing and iron gate of uniform pattern and height,[931] while any party who might take lease of the land at either side of the road was obliged to enclose their plots next to the road with the same uniform iron work.[932] Just as iron ran through the exhibits of the museum in counterpoint to the solitary needle in the sequestered Observatory, so it traced the boundaries of contact with the world. Through withdrawal and difference, the Observatory and Museum had defined iron as a worldly pollutant. Now this iron border performed an act of enclosure, and marked Woolwich as worldly representative.

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[929]Hunt,1850,p.415.
[930] Robson:Lyddon,[12/10/1843],**LMA**/E/MW/C/1609/8.
[931] Draft Leases,[13/02/1844],**LMA**/E/MW/C/1609/1; Draft Leases,[n.d.],**LMA**/E/MW/C/1609/2/2
[932] Lyddon:Robson,[14/11/1843],**LMA**/E/MW/C/1609/9/2.

Chapter seven: Cornwall, Jamaica

What lay beyond the Woolwich pale? Scrubland Hutton had long since quarried and built on; a gun range, once marsh now cleared and drained. Further afield a town moor, fiercely embattled; a river with iron steamers and beacons torn down. An inundated county all leats, pumps and tribute. Ice flows, and cane rows, and the bondage of bodies driven far underground. Labour extraction and plantations were not universal principles. They were fundamentally contingent and situated systems, different in their forms as in their consequences, and imposed for different interests, not out of practical necessity or natural law. Yet the systems discussed in this thesis have all shared a common reference point in the needle and were imagined in common within the compass of the regulatory centre: the Observatory. If, despite resistance and wrecking, labour extraction and plantations have appeared to possess a universal character, it is because the alignment of empire, war, economy, science and industry in the age of revolution and reform was forged with so many bonds. If they appeared to be natural kinds it is because the manufactured union of nautical science with the physics of the earth presented a capitalist cosmology.[933] A globe remanufactured in the shape of British capital interests. The Compass Observatory was the child of this union. The idea for it birthed in the appointment of two representatives for two halves of the spherical projection of a capitalist world system. Speaking for nautical science: The Admiralty Standard Compass; and for the physics of the earth: a particular magnetic intensity instrument developed in Cornish mines and dubbed the Fox-type dip circle. What lay beyond the Woolwich pale were needles.

The peroration of this thesis is concerned with the Fox-type, trialed and adopted together with the Admiralty Standard Compass, as a microcosm that materially encompasses the scope of the thesis as a whole. First mentioned in chapter one, this instrument was designed by the Cornish mining industrialist and steam-engine entrepreneur Robert Were Fox. This concluding chapter shows how, in its own time, Fox's design was understood as an argument, which characterized the earth as a steam engine, and the global as a Cornish mine: it was the microcosm both of this physics of metal and of the labour extraction it proposed. To understand the response of Fox's contemporaries, this chapter looks first to the witness of his close friend, enslaver Henry de la Beche, introduced in chapter one for his survey of Jamaica, and in chapter four for his role leading the Admiralty Coal Enquiry between 1845 and 1850. The analysis begins where the thesis began, in Cornwall, and with Cornwall, Jamaica. It ends with the price of iron. The engines of Taylor's global Cornish System were made in the Neath

933 Sahlins,1988,pp.1-51; Cardwell,1971,89-120

Abbey ironworks and steam manufactory, owned by the Fox family (Figure 7.1).[934] "Partem pro toto", as with the needle so with the system: to this day 'Neath' remains a byword for the most extractive labour practices in South Wales, such that to be driven down by a regime is to be 'under Neath'.[935] The Babbage principle was not just Cornish, it was a Fox-type, and its relation to the Admiralty Standard Compass was pivotal.

Figure 7.1: One of two surviving blast furnaces at Neath Abbey, South Wales, dating from the Fox-family purchase in 1793. They are set against a rock face for ease of charging, and, at just over 51 and 63 feet tall respectively, are two of the highest masonry blast furnaces ever constructed. Between them stood a Boulton & Watt blowing engine, in front: the casting houses. In nearly a century of operations, the works buried the eponymous monastery in industrial waste; 2024 will mark a century of attempts to excavate it. Neath Abbey ironworks, 1975, photograph taken by John Cornwell, © Amgueddfa Cymru - National Museum Wales.

934 Ince,2001,pp.54-5

935 With thanks to Eoin Phillips for this information, 27/08/2019, The Maypole, Cambridge.

§1: Fox and friend.

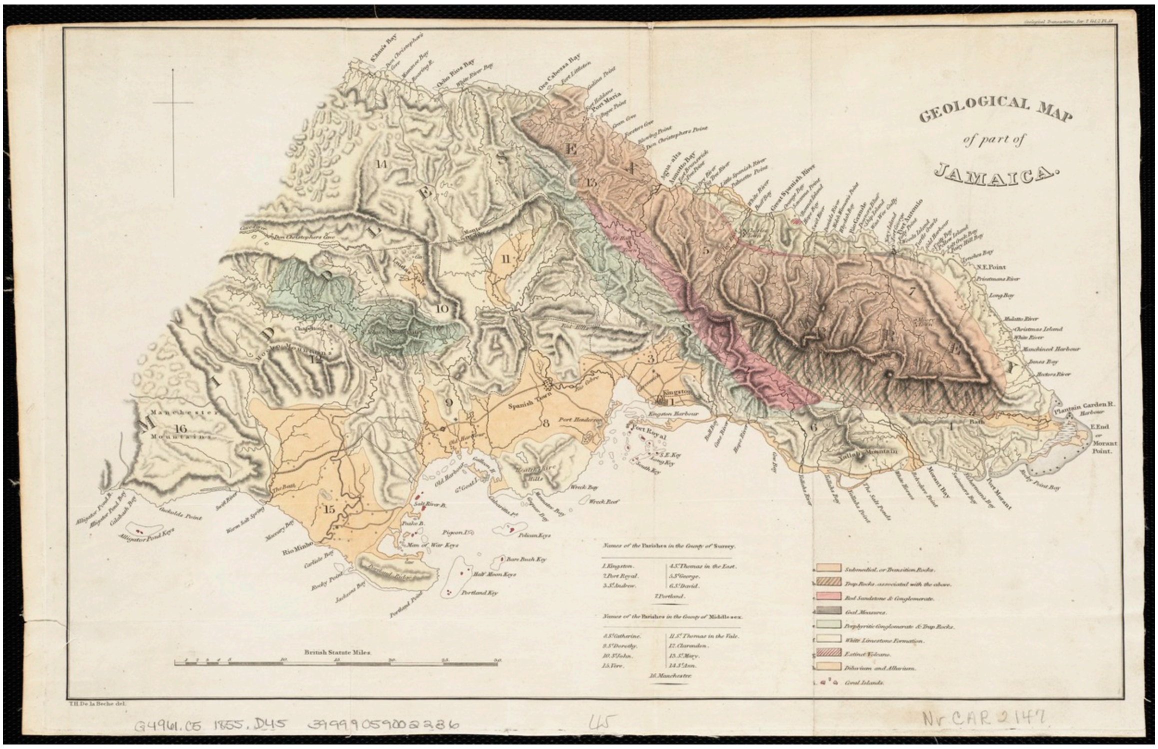

Figure 7.2: De la Beche, Henry, 1827, Geological map of part of Jamaica, surveyed by De la Beche in 1824, *Transactions of the Geological Society London*, Vol.2, Plate 18.

Henry De la Beche came from an ancient Cornish family, responsible for establishing some of Britain's first Caribbean plantations in the early decades of the seventeenth century. One ancestor, James Guthrie, negotiated the Maroon War settlement of 1739, mentioned in chapter two. Another, his grandfather Thomas Beach, was appointed Attorney General and Chief Justice of Jamaica in 1766. Under Beach's jurisdiction, the longstanding Cornish system of delineating Jamaican land patents using a miner's dial was further formalised and made statute. Indeed, De la Beche's family were considered one of the most significant in Jamaican plantation history.[936]

In 1823, after four years of travelling and geologising supported by the income of his enslaver inheritance, De la Beche was elected a Fellow of the Royal Society. That same year, concerned by declining revenue from his plantations and growing instability in Jamaica, he made the voyage out to visit his estates. Within twelve months of his arrival he had made the first formal survey of Eastern Jamaica (Figure 7.2). Presented in 1825, his map followed closely on the publication of Taylor's 1824 edition of Humboldt's survey of South American mining.[937]

[936] Chubb,2010,p.12; Jamaica,1802,p.141
[937] Taylor,1824,p.i

As mentioned in chapter one, Taylor's selected translations were devoted to making a direct and explicit parallel between the mines of Cornwall and those of Mexico, where he was then engaged in establishing the Cornish system, using engines made at Fox's Neath Abbey works.[938] De la Beche's work, published just a year later, compared the Jamaican geological formations with those described by Humboldt in Mexico. In each, claims for geological analogy were a gloss for the direct transposition of a system of high-capital labour extraction. Here geological survey was not driven by a crude quest for coal, but rather by the relation between human labour and land that motivated an argument connecting survey with capital investment.[939] At the same time as compiling this geological survey, De la Beche made a human survey: a survey of the labour of enslaved Africans and his investment in the human capital of the plantation.[940]

On his return to Britain, in the second half of the 1820s, De la Beche determined to make the Ordnance Survey of England and Wales, then under construction, the basis for a geological survey of each county, just as he had done for Jamaica. Embarking on the task at his own expense, using the income from his Jamaican plantations to support himself, he began with the mining districts of Devon and Cornwall. In 1831, at the same moment parliament debated whether enslavers should be compensated for the abolition of enslavement, De la Beche decided to apply to the government proposing he complete his geological survey for a fee. The close of the year saw a major revolt on Jamaica, dubbed the Christmas uprising. Its brutal suppression was enacted through the murder of some 500 African people, the majority in 'various forms of judicial executions'. The vast cost of the assessed property damage was reported in 1832, contributing significantly to accelerating emancipation and enslaver compensation. In the same year the government decided to compensate De la Beche for the human lives he claimed as property, it also decided to pay for his personal surveying enterprise, and appointed him 'to affix geological colours to the maps of Devonshire and positions of Somerset, Dorset and Cornwall.'[941] It was through the application of this visual language that De la Beche met Fox,[942] who would come to be a close friend of the contract geologist and enslaver.

As mentioned in chapter one, in 1812, aged just twenty-three, Fox had been awarded a joint patent for improvements to the steam engine. Three years later he extended his experiments on heat-engines to interest in the possibility of 'internal heat' in the earth's core, and at the

[938] Ince,2001,pp.54-5
[939] Porter,1973,pp.320-343.
[940] Chubb,2010,p.13-20; De la Beche,1825.
[941] Chubb,2010,p.24.
[942] Rudwick,1976,p.156.

same moment began to toy with the idea of electrical prospecting.[943] This line of research led to his proposition that the earth's layers were formed through the interaction of electricity and magnetism, a relation proven, Fox claimed, by the native internal heat of the earth. Electromagnetism in the service of industrial geology thus became his introduction to the question of central heat, described in chapter one. Critics, however, challenged Fox that his observations could not separate heat that was native to the Earth from that which was the waste output of human labour and mechanical work. Fox's expertise derived from his privileged access to Cornish mines, then some of the deepest in the world. But these Cornish mines had been the locus of steam power in Britain since the early eighteenth century precisely because, reaching far below the waterline, they required constant pumping and labour to remain active.[944] Fox's research attracted bitter criticism from rivals such as Helston medic, Matthew Moyle,[945] and even supporters of his findings expressed strong reservations. Geologist and physician John Forbes, with whom chapter one opened, questioned whether 'in the case of miners, who are very imperfectly clothed, [heat radiation] may be greater than in many other classes of men.'[946] As for Christie in chapter four, heat had dangerously plebeian associations. It was with these debates in mind, ranging from polite doubt to overt hostility, that in 1837, De la Beche passed his stay in Cornish pub, The White Hart, St Austell, sketching a parody periodical, *The Mining Chronicle,* for his close friend Fox.[947]

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943 McConnell,1986b,p.37
944 see Chapter one.
945 Moyle,1822,pp.308-10.
946 Forbes,1822b,p.198-9
947 Sharpe&McCartney,1998,p.38,no.377

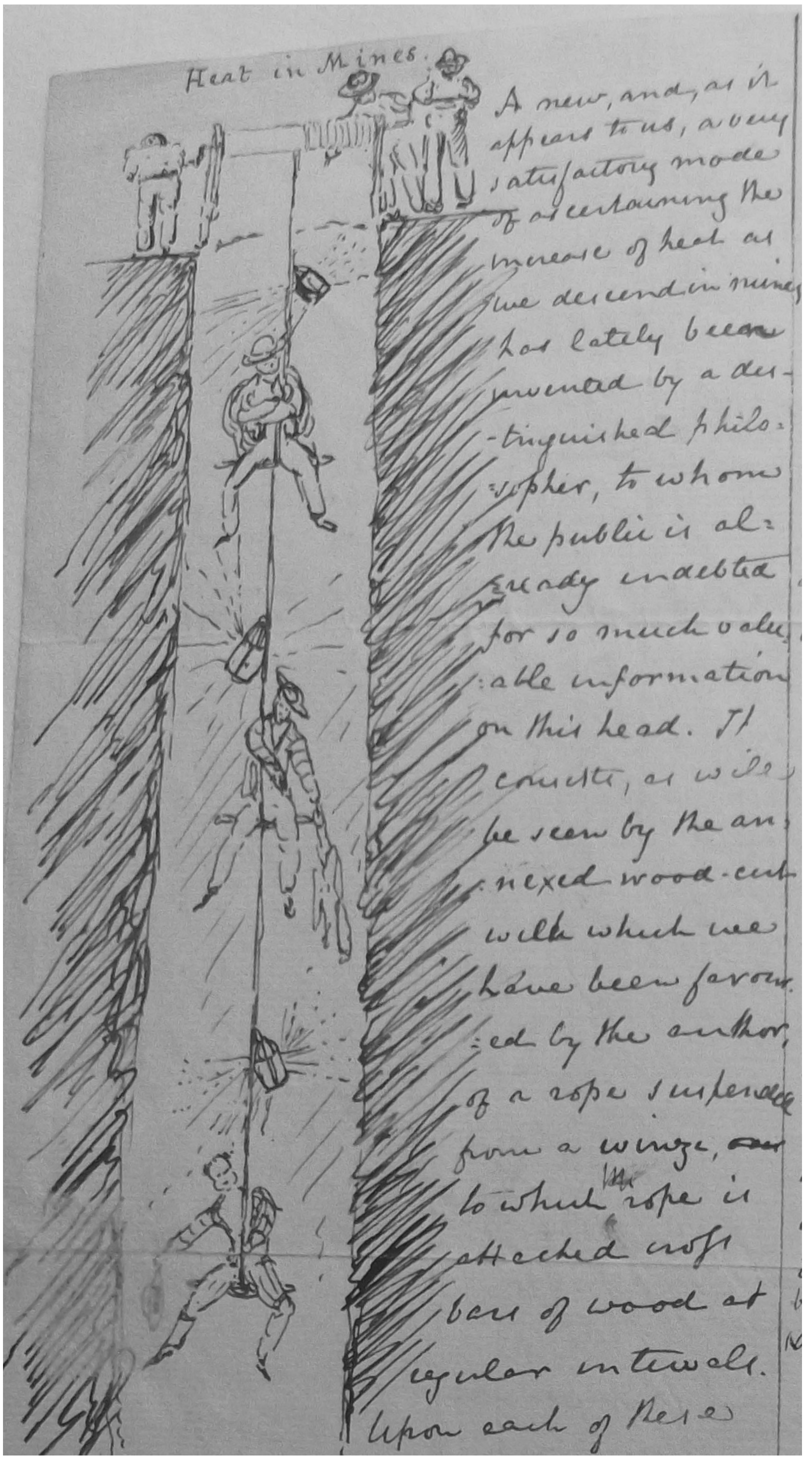

Figure 7.3: 'Heat in Mines'

'A new, and very satisfactory mode of ascertaining the increase of heat as we descend in mines has lately been invented by a distinguished philosopher to whom the public is already indebted for so much valuable information on this head. It consists of a rope suspended from a winze to which rope is attached cross-bars of wood at regular intervals. Upon each of these cross-bars a miner is placed, each miner being clothed in the same manner. The miners are then each drawn down the shaft, and they are told that when they feel they have too much clothing on, they are to take as much off as will render them comfortable. By these means it is found that the heat in mines gradually increases with depth, as the lower miners gradually deprive themselves of all clothing while those at the top of the line retain their clothes with great pertinacity.'

De la Beche, Henry, 02/02/1837, The Mining Chronicle, St.Austell, MS 710/124, Royal Society.

The first caricature showed Fox's miners as the thermally sensitive component of his philosophical apparatus, who registered heat by degrees of undress (Figure 7.3). In 1830s Britain, the notion of the human body as an unusually responsive instrument was common, particularly among adherents of the new 'reflex' physiology. Significantly, notions of the sensitive human instrument were bound up with ideas of animal magnetism.[948] The joke targeted both Fox and his critics, the latter for what they seemed to believe, and the former for what he seemed to be doing. Yet De la Beche's satire was also grounded in a labour fetish of land to which he himself subscribed, evident in his first surveys of Jamaica. In later publications, the same diagonal shading that marked the walls of the mineshaft in his caricature would become his formal visual language, used to indicate 'the increase of temperature of the crust of the globe inwards.'[949]

Fox had 'long been impressed with the analogy mineral veins seem to present to some voltaic combinations.'[950] In 1814, the same year his friend and client John Taylor described the Cornish System to Ricardo's Geological Society of London, Fox helped found the Royal Geological Society of Cornwall. From its inception, the London Society served as a forum for leading theorists and authors on political economy.[951] Fox's Cornish Society was to be directly modelled on this, but with the explicit aim of fostering the allied advance of mining and science.[952] In January 1819, United States president James Monroe, who had negotiated the Louisiana Purchase under Jefferson, appointed Fox consul to the United States of America for the port of Falmouth.[953] While a continuation of his father's role as consul 1794-1812 and again 1815-1818, the Fox-family Falmouth consulate was unusual in that it saw a British subject and Cornish industrialist and shipping agent directly advising the American government on foreign tariffs.[954] That same year, Fox's long-held views took on a cosmological confidence, and he presented to the Cornish Geological Society his opinion on the intimate connection between heat, electricity and magnetism as operative forces in the dynamic processes of the earth.[955]

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[948] Winter,1998,pp.37-8
[949] De la Beche,1853,p.18,Fig.12
[950] Fox,1838,p.166
[951] Wise&Smith,1989a,pp.278-80; Wise&Smith,1989b,pp.424-34
[952] Naylor,2010,p.64
[953] Monroe,[1819], in Preston,2001,p.748.
[954] Kennedy,1990,p.185.
[955] Fox,1822,p.447

Initially offered 'merely as a suggestion', by 1828 Fox declared it 'highly probable' that electricity was the 'primary exciting cause of the high temperature of the earth.' His evidence was 'the prevalent direction of the principal metallic veins, nearly at right angles to the magnetic meridian.'[956] Writing to Faraday in 1838, Fox's suggestive associations had become concrete conclusions:

> the veins, as well as the laminae, are always perpendicular to the voltaic currents… These facts have a decided bearing on very important geological phenomena.[957]

De la Beche titled his second caricature of the *Chronicle*, (Figure 7.4), "Copper Bottom", and in this single deft gesture encapsulated not only how the mine itself was made into hull-sheathing and sound financial investment, but also the very material of electromagnetic instrumentation. In this Copper Bottom the thermal principle of the first cartoon (Figure 7.3) was developed to show Fox's 'voltaic combinations' in all their valence: miners, unionised in the assemblage of the instrument, responding to the electro-magnetic action as if they themselves were the needle. As already noted, far from peculiar to the enslaver, what De la Beche caricatured was the serious response of Fox and his peers. The steam-engineer's electromagnetic geology was undermined by the views of contemporaries such as Moyle, who, drawing on a medical preoccupation with miners' fatigue-wasted bodies, diagnosed deep heat as human.[958] Heat as waste from work threatened the conceptual mechanisation of the earth, and drove Fox and his like-minded peers to seek out a way of dividing the two.[959]

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[956] Fox,1828,pp.324-5
[957] Fox,[1838], in James,1993,p.518
[958] Moyle,1822,pp.404-437
[959] Fox,1822,pp.14-28;Forbes,1822b,pp.159-217

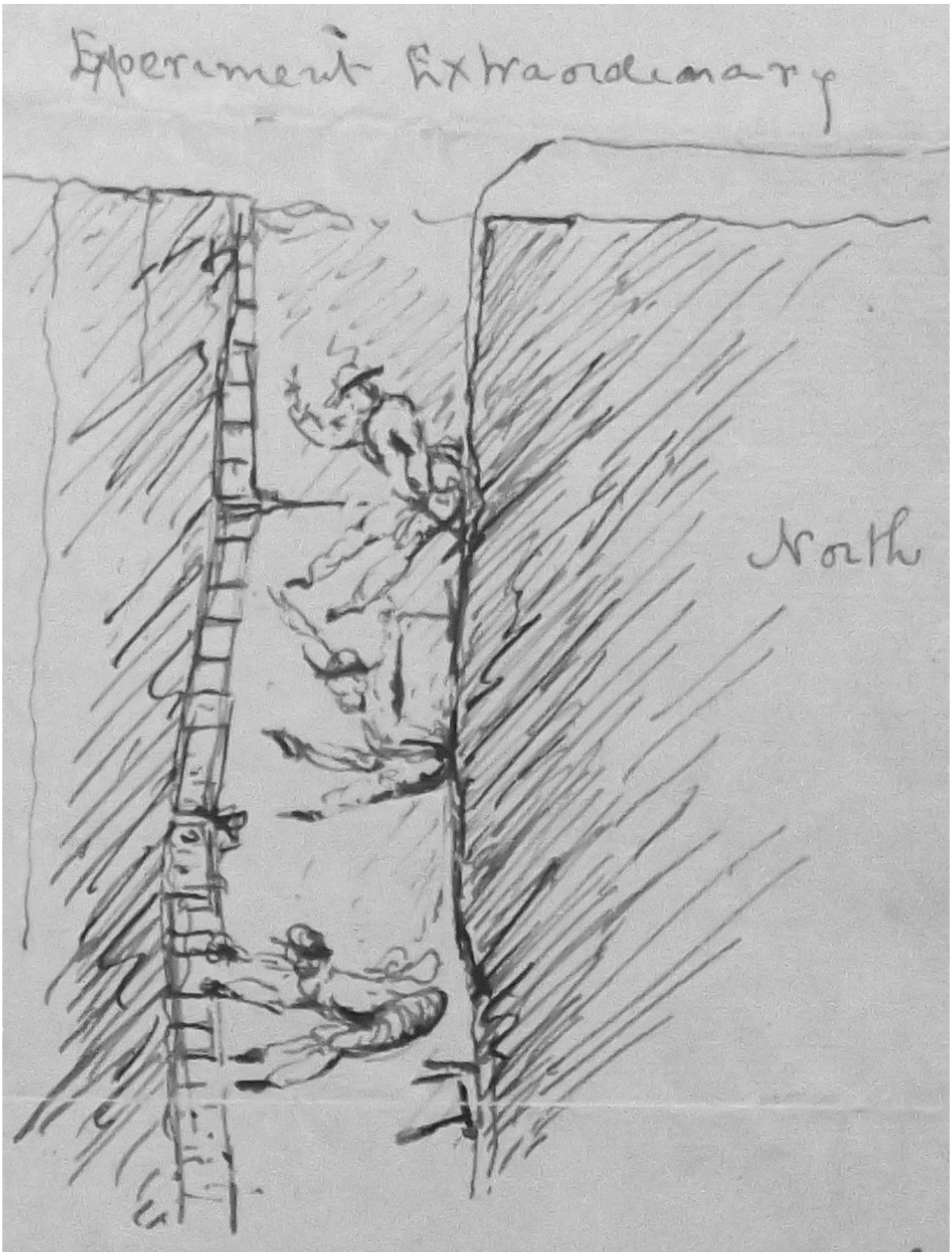

Figure 7.4: 'Experiment Extraordinary'
'On Wednesday last as a gentleman well known to the scientific public was experimenting on the electro-magnetic action of Copper Bottom North Lode, this action became so strongly developed in a shaft through which one of the experimenting wires passed, and down which three miners were descending at the time, as to draw the latter suddenly, by polarity to the north wall of the shaft.'
De la Beche, Henry, 02/02/1837, The Mining Chronicle, St.Austell, MS 710/124, Royal Society.

Fox mobilised his close relations with mining captains to collect observations across Cornwall in mines of varying depth and mineral content but was frustrated by 'considerable diversity in the temperature of different mines, and even of different parts of the same mines at equal depths.'[960] With inconclusive results, he then undertook observations in 'stopped mines,' abandoned shafts where engines no longer pumped water out or men in. Fox knew such dead mines became cold, but the phenomenon that appeared, superficially, to undermine his heat gradient was a powerful argument for the steam cosmology. As noted, engines made Cornish mines workable by pumping out the water well below the water table. When the engine stopped, the mine rapidly filled and, like a boiler without fuel, cooled. Though he had looked for one form of clarity from observations in stopped mines, Fox took the 'discordant and inconclusive' results as an opportunity to showcase the engine character of the earth. He expanded his observations to include springs filling the mines compared with standing water, and took these results, with his own theories of the geological process, as 'strongly' corroborative of his claims to native heat.[961] In the course of this, Fox modified his experimental practice by using giant 'four feet long' thermometers 'buried three feet deep in a hole in the rock.'[962] The rigour of his efforts to measure mineral rather than meteorological temperature distinguished Fox, and, as chapter one noted, saw his observations taken up on the continent by influential mathematician Joseph Fourier.[963] Fox's temperature observations included notes of the number of men, candles and engines present, as well as the intensity of the work or the power of the engine. The final tabulated results of Fox's observations displayed the numerical expression of heat against depth. As in the particular Cornish character of the Neptunist-Plutonist debate described in chapter one, Fox used attention to the heat of men, engines, and labour, to demonstrate that the earth itself must be an enormous heat engine.

In January 1834, Faraday asked Fox whether 'when your instrument now at Mr Watkins is complete will you let it stand upon our table some Friday Evening for the observation of our members at the [Royal Institution] Meeting?'[964] Fox used this opening to communicate his steam cosmology, and learned that, far from exceptional, the view had long been widely

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[960] Fox,1828,p.313,p.320
[961] Fox,1828,p.323
[962] Fox,1828,p.319
[963] Lawrence,1974,p.265,n.20; Fox,1821,pp.78-81; Arago,1821,pp.81-2; Fourier,1821,pp.82-5.
[964] Faraday,[1834], in James,1993,p.163

considered common sense, though hard to positively prove due to the complexity of the system.[965]

§2: five years to gain an 'Our'

Fox's dipping needle design was drawn directly from his experiments into the impact of temperature on magnetic observations.[966] His experimental apparatus developed, bringing the structure of the mine into immediate correspondence with the basic principles of existing dip circle designs: a magnetised needle, suspended within a circle-box, balanced along a horizontal axis free to move as much as possible without obstruction and friction. His experiment was to vary the thermal conditions of the circle-box by varying its container. One container was made of layers of Cornish copper with a hollow structure designed to carry water at temperatures determined by the experimenter, just as in James Watt's 1815 patent for boiler-heated garden-houses described in chapter one. Another container was made of wood, and a third used slate. According to Fox's own account, in Cornish geology slate deposits known as *killas* rested on granite,[967] the extraction and export of which was a major industry for Cornwall. Fox's slate container rested on a warmed granite base, which heat could be supplemented with further hot water. The artificial climate was then insulated by use of a blanket thrown over the container, and into each container Fox placed a thermometer.[968] At the British Association meeting in June 1832 Fox's thermal investigations were reported on with enthusiasm and admiration by his fellow Association members,[969] and a few months later in October he published the description of his experimental apparatus in *The London and Edinburgh Philosophical Magazine*,[970] edited by the Association's instigator, David Brewster. In the same journal early the following year, he published a map and accompanying description of the relation between granite and the *killas* in the region, bounded by the Redruth Road to Falmouth and Helford Harbour, and centred on Fox's Penjerrick garden (Figure 7.5).

[965] Davy,1807,pp.3-17; Faraday,[1834], in James,1993,p.178,pp.194-5
[966] Fox,1832a,pp.311-315
[967] Fox,1833,pp.326-7.
[968] Fox,1832a,pp.311-2
[969] British Association,1833,p.401.
[970] Fox,1832a,pp.310-15.

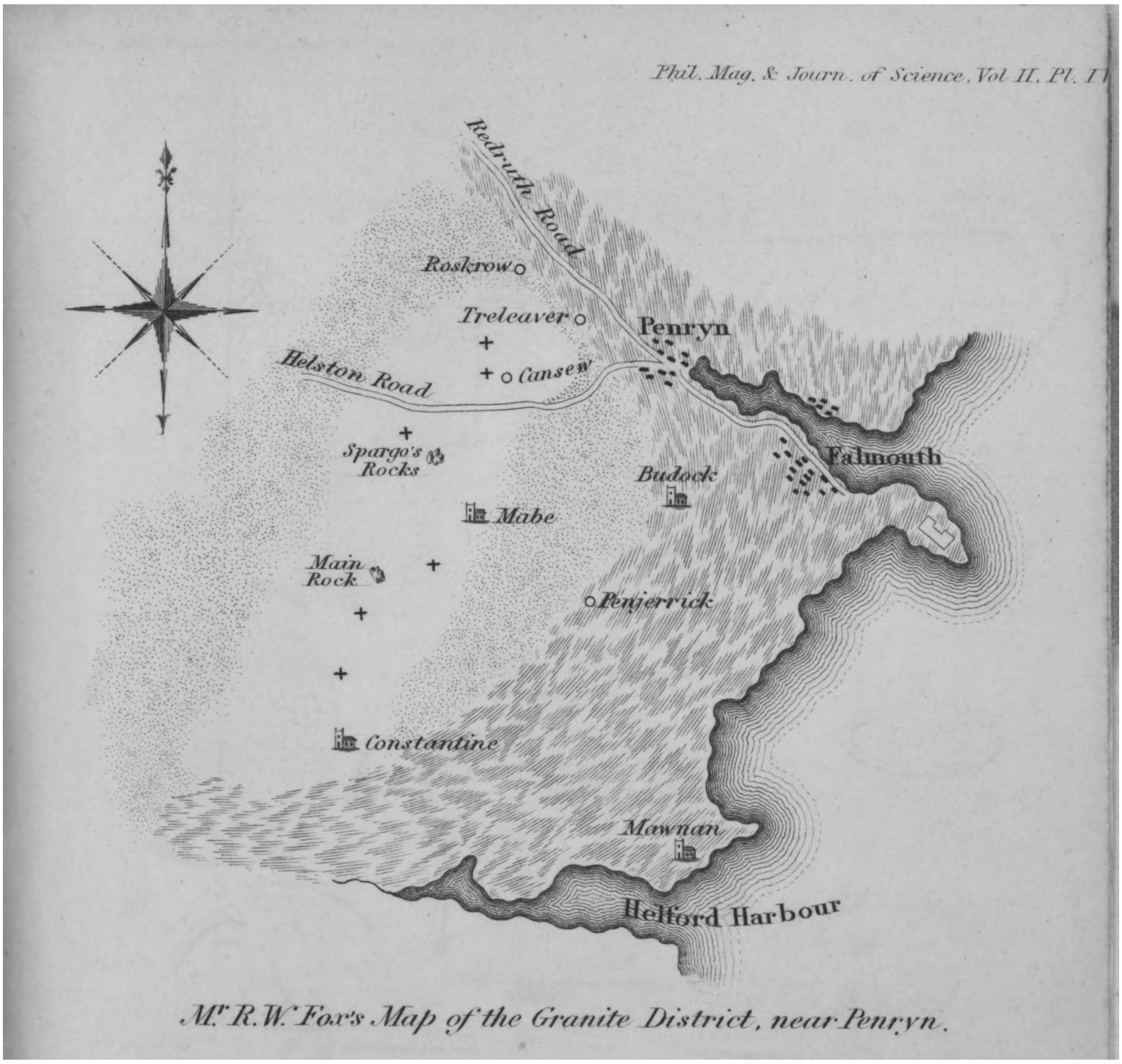

Figure 7.5: Fox, Robert Were, 1833, A geological sketch of a portion of the granite district near Penryn referred to in the preceding paper, *The London and Edinburgh Philosophical Magazine and Journal of Science*, Vol.2, Iss.11, May, Pl. IV.

Since the early nineteenth century, Fox and his children had cultivated this garden with plants 'the gardeners about London would scarcely believe' (Figure 7.6).[971] Penjerrick then became the centre for demonstrating his dip circle design, and Admiralty Officers gave exotics in exchange for training in its use.[972] An advertisement in De la Beche's *Chronicle* for 'an engineer well skilled in the use of the solid carbonic acid engine[,] wanted by the British-Irish-American-Australian-Polynesian-mining association,'[973] satirised the familiarly global shape of the industrial Cornish vision, but Penjerrick grew the seeds of this vision. Fox's

[971] Loundon,1836,p.370.
[972] Westley,2013; Fox,1833,pp.326-7; Fox:unnamed,[26/08/1870],**CUL**:MS.Add.9942/14; Fox:Evans,[n.d.?1872],**CUL**/MS.Add.9942/16; Fox,(Barclay),[5/04/1842],[4/10/1836], in Brett,1979,p.265,p.98.
[973] De la Beche,[02/02/1837],**RS**/MS/710/124.

experimental apparatus was a controlled microcosm of the Cornish mine, his final design calibrated in a verdant theatre of its economic dominion.

Figure 7.6: Penjerrick Garden, Falmouth, Cornwall, planted by the Fox family. With thanks to Edward St John Gillin for the photograph.

As already noted the fundamental principle of Fox's design was no different to other dip circles. Unlike its counterparts, however, the Fox-type was exquisitely machined, compact, and heavy, to provide stability in constantly shifting environment (Figure 7.7).[974] In a design feature directly derived from Fox's experiments on boiler construction, first published in 1832,[975] then read out at the British Association meeting later that year,[976] the instrument had a blackened brass back to the face, against which a silvered dial and mercury thermometer stood out prominently, with ivory Centigrade and Fahrenheit scales graduated from 10°F to an ambitious 160°F and centigrade equivalents. This was an instrument that anticipated extreme heat. The thermometer and the needle were the most costly components, the needles of such value that Fox insisted on balancing them himself.[977] The circle-box was

[974] McConnell,1986b,p.30
[975] Fox,1832b,pp.345-7
[976] British Association,1833,pp.272-3.
[977] Fox:Ross,[08/03/1845],**RS**/MS/257/572; Fox,[09/03/1850],**RS**/MS/257/579.

lacquered brass, deep and with a double-glazed window in a tightly machined brass frame. To open, the door and circle-box required prising apart. The circular azimuth base featured a spirit-level, screw feet for a gimbal fitting, a scale and vernier. It allowed for rotation on the stand, the vernier enabling accurate determination of position. Internal rotation nominally enabled errors to be detected by comparing needle positions in different meridians, described as a capacity for self-correction of the needle.[978] The needle sat in agate jewel-cup bearings, which promoted stability over sensitivity and were a significant feature of early nineteenth-century precision miners' dials.[979]

Figure 7.7: Fox-type dip circle made by William Wilton of St Day, Cornwall, who became Fox's maker of choice from 1846 (see Robert Were Fox to James Clark Ross, 20/08/1846, Royal Society MS.257/574; 28/12/1847, Royal Society MS.257/576; 26/02/1848 Royal Society MS.257/577) and would produce the instrument shown here for the Great Exhibition in 1851. Anonymous,1851, *Official Catalogue of the Great Exhibition of the Works of Industry of All Nations 1851*, 4th edition, London, Spicer Brothers, Wholesale Stationers; W.Clowes & Sons, Printers .p.66.No.402. Wh. 6538.1, Whipple Museum.

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978 Fox,1834,p.82
979 McConnell,1986b,p.27

From September 1834, close family friend of the Foxes, naval officer and Arctic veteran John Franklin lobbied Beaufort to take up the design. He further acted as agent to get Fox's instrument on Admiralty expeditions, beginning with 'an Expedition to survey the Euphrates with a view of opening communications by steamer to India through that channel in the Persian Gulf'. This was to win Fox exposure but not payment, with Franklin explaining:

> As the instrument has not yet been in general use I fear that the Government, in these economical times, would not sanction its being purchased at once for the use of the Expedition though they might perhaps sanction its purchase after it had been repeatedly tried, if the report was favourable.[980]

Beaufort was enthusiastic for the instrument but evasive about any formal Admiralty involvement. Significantly, he recommended the Astronomical Society as 'a very proper place for its being sent'.[981] Babbage had helped found this Society in 1820 as part of his campaign to reform Admiralty navigation tables with the Difference Engine,[982] an engine based on division, which, as chapter one detailed, was significantly derived from the Cornish System.

As already noted, Fox had been involved in the British Association from its earliest meetings. Chapter six described how Sabine and Ross annexed Lloyd's magnetic survey of Ireland, launched in 1834 on behalf of the Association. In 1835 Fox ensured his instrument also surveyed Ireland, though he was 'not at that time associated with [their] labours'. He did as Sabine had done, and insinuated himself into the construction of the standard, publishing his results that year, in the pages of the Royal Polytechnic Society of Cornwall journal.[983]

By 1836, Franklin was confident that on the basis of Fox's Irish observations, he could persuade Beaufort to give the Fox-type a formal trial, and 'if any Expedition does go out to the North that Beaufort will yield to my solicitations and allow it to be taken.'[984] Beaufort was then already trialling chronometers with glass balance-springs instead of steel, partly as a precaution against magnetic influence, but primarily to make going rates in precision time-pieces more thermally stable.[985] Fox's expertise and the insulated design of his needle spoke directly to this central concern of heat, a concern which expanded dramatically when the Admiralty took over the domestic packet steamers the following year. As chapter one noted, these were steamers maintained in Fox's foundry. By April 1837 the hydrographer was

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980 Franklin:Fox,[22/09/1834],**LAC**/R3888-0-7-E/3.
981 Franklin:Fox,[6/12/1834],**LAC**/R3888-0-7-E/3.
982 Babbage,1864,p.47,p.474; Ashworth,1994,p.413.
983 Sabine,1839,p.101.
984 Franklin:Fox,[26/03/1836],**LAC**/R3888-0-7-E/3.
985 Bulstrode,2018a; Bulstrode,2018b.

sufficiently convinced to spend '3 hours in admiralty garden trying Friend Fox's new dip^g needle' with Ross, Sabine, and Navy Chaplain and veteran Admiralty Arctic exploration George Fisher, also an advisor on the glass spring chronometer trials.[986] That same year, Franklin was appointed Governor of Van Diemen's Land and sent one of his lieutenants to spend fourteen hours in Fox's Penjerrick garden learning how to use the instrument, before accompanying him to the Australian penal colony.[987] Franklin's predecessor had named one of Van Diemen's Land's counties 'Cornwall' the previous year.[988] Now Franklin was dispatched to take his place presiding over one of the principal foci of the government-subsidized mass emigration of Cornish miners, introduced in chapter one.

In 1839, Sabine published the results of the magnetic survey of the British Isles, incorporating Fox's results,[989] and Beaufort replaced James Clark Ross as Chairman of the Admiralty Compass Committee, so that Ross could take up his latest commission to command a voyage to the Southern and Antarctic regions. The expedition has been understood as the triumph of the British Association's magnetic lobby, but the standards are telling. Ross's dispatches to Sabine overflowed with reports of 'our Committee Compass'[990] and a Fox-type,[991] both of which were on trial; as well as sets of Robinson needles, which Ross described as 'the most beautiful I have ever observed'.[992] This was the synchronization of the standards of the fiscal-military state with the representative of the Cornish System. The expedition departed on 30 September 1839, with instructions to erect a magnetic observatory in Van Diemen's Land,[993] to be part of Sabine's 'great combination, embracing the whole globe in its field of action'.[994] Less than a month earlier, Britain had declared war on China and launched its notorious gunboat diplomacy against the Chinese state's resistance to its lethal opium traffic: a crusade in the evangelism of global free trade. As Ross sailed south, the Committee Compass was immediately declared 'a most admirable steering compass & preferred by all our men to any other in the ship'.[995] The Fox, by contrast, incensed Ross and his fellow officers for well over a month, before, in November, Ross announced

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986 Beaufort,[26/04/1837],**CCC**/STAN/2/72; Roberts,2009,pp.57-72
987 Fox,(Barclay),[8/12/1836] in Brett,1979,p.94
988 Proclamation,1836,p.4.
989 Sabine,1839,p.101.
990 Ross:Sabine,[20/10/1839],**NA**/BJ/3/16
991 Ross:Sabine,[06/10/1839],**NA**/BJ/3/16
992 Ross:Sabine,[27/10/1839],**NA**/BJ/3/16
993 Savours&McConnell,1982,p.531.
994 Sabine:Lloyd,[20/12/1839],**RS**/MS/119/80
995 Ross:Sabine, [20/10/1839],**NA**/BJ/3/16

> Our Fox is doing now most admirably in both ships & much of the abuse I heaped upon him in the early part of the voyage properly belongs to myself for the stupidity of not doing him justice and getting a proper table made.

Now the synchronisation and correspondence of observations on board the two vessels, *Erebus* and *Terror*, were reported as a thing of wonder.[996]

Encouraged by these reports, when the British Association met in Glasgow in August 1840, Compass Committee member and soon to be appointed Director of the Admiralty Compass Observatory Captain Edward Johnson had alluded to the wootz-work of Faraday and Stoddart before recommending all instruments built on 'Mr Fox's plan' be set with native alloy pivots. Thus, through Robinson pivots, all Fox-types would be brought into direct material correspondence with government standards, not least the Admiralty Standard Compass.[997] Ross's expedition arrived in Hobart town that same month, and was welcomed there by Franklin. Immediately the following morning, the two friends began to search for the best location for the magnetic observatory, and 'a party of two hundred convicts were the same afternoon set to work to dig the foundation'. Franklin's wife rejected the proposed name, 'Gauss Villa', considering it too 'skittish', and the observatory, fitted out with the standard instruments specified by Lloyd, and a Fox-type, was dubbed 'Ross Bank'.[998] In December, Sabine composed instructions for magnetic observations on a government-supported expedition to the River Niger, specifying a Fox-type on one vessel, a Robinson dipping needle on the other, and an Admiralty Standard design compass on each.[999] An evangelical instrument of colonial science, the expedition was explicitly concerned with the state of the human trade in the region.[1000] In February the following year, they set out. 29 July 1841, the establishment of Ross Bank and the Antarctic expedition's shipboard observations were reported triumphantly at the British Association meeting in Plymouth.[1001] Just four days before, Robinson had died of chronic bronchitis.[1002] Yet when the Association assembled in Fox's home county of Cornwall, the material linkages had taken on their own momentum.

In 1842 China agreed a peace treaty that saw 'the Costs, Ports and Rivers of that Empire laid open' but forbade 'all approach to any part of the Chinese Territories north of Canton'. Within months, in January 1843, an expedition was dispatched to conduct a magnetic survey of the

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[996] Ross:Sabine,[10/11/1839],**CUL**/MS.Add.9942/43,
[997] British Association,1841,p.199.
[998] Savours&McConnell,1982,p.531,p.553,p.558.
[999] Sabine,1841,pp.55-7.
[1000] Gillin,2018,pp.605-26.
[1001] British Association,1842,pp.38-41.
[1002] Stock,1968,p.256.

Chinese territories, as had been done during the hostilities, but this time equipped with a Fox-type. The instrument was much admired by the Chinese political elite, according to Edward Belcher, the author of the survey who described his friend Fox as 'a gentleman to whom our Service and the whole scientific world are deeply indebted'.[1003] Like Belcher, naval officer Owen Stanley also enjoyed the company of Foxes. While at Penjerrick in January the following year, the thirty-three year old newly gazetted Captain described the instrument to Fox's twenty-five year old daughter Caroline as 'his darling child'

> which he said had never before been separated from him during fifty thousand miles of travels. It had sat on his lap across the great desert, sailed in his cabin over the Atlantic, the Pacific, & the Indian oceans & had been his companion in his solitary home on the borders of Siam & on the banks of the Tenasserim River.[1004]

Conclusion

Early in 1845, the Admiralty approved plans for an Arctic expedition with Ross as the immediate choice to command the mission. However, the designated vessels, the *Erebus* and *Terror*, had been altered since they had carried him to Hobart in 1839. As chapter four noted, after directing the Australian Agricultural Company, in which capacity he took over the Newcastle New South Wales coal mines and sought to dominate coal exports to India, the former Arctic explorer William Parry was appointed Admiralty Controller of Steam Machinery. Under his direction the *Erebus* and *Terror* were fitted out at Woolwich's steam manufactory, described in chapter two, with No.2 'Croydon' and No. 6 'Archimedes' 15-ton six-wheeler engines built in 1838-9 by the Rennie firm and re-purposed from London and Croydon railway locomotives. These engines were to power a radical transformation: *Erebus* and *Terror* were the first Royal Navy wooden warships to be converted into screw-driven steam ships. Further, they were supplied with 'patent fuel', a mixture of coal dust and tar formed into bricks under hydraulic pressure, trialled in 1839 by Parry on behalf of the Admiralty.[1005] When the Arctic expedition was mooted in early 1845, Ross had already written to Beaufort declaring the fitting of steamers,

> a measure to which I could not consent if the command were placed in my hands & which alone would be sufficient reason for not wishing to undertake the service as it is proposed at present to carry it forward.[1006]

[1003] Belcher,1848,p.vi,p.2,p.258

[1004] Fox,(Caroline),[27/01/1844],/**CUL**/MS.Add.9942/27.

[1005] Battersby&Carney,2011,pp.200-211.

[1006] Ross,[1844] in Ross,1994,p.275.

Franklin, just recently returned to Britain having disgraced himself in Van Diemen's Land, was appointed instead.[1007]

The expedition departed 19 May 1845. Eight days later, on 12 July 1845, Franklin sent a report to the Admiralty together with sixteen pages for his wife; a cumulative letter he had started the day after the expedition crossed the Arctic Circle. This was the last communication she and the Admiralty ever received from him, as Franklin, along with his entire crew, 129 in all, disappeared into the ice. The gothic horror that the expedition came to represent has often overwhelmed historical interpretation.[1008] But such fatalism was neither the driving ambition nor contemporary understanding of its launch. Rather, this was a test-run of new Admiralty standards in coal and steam,[1009] and its magnetic instrumentation.[1010] Not the cannibalism of the officer and his starving crew, but the cannibalism of a global capitalism. *Erebus* and *Terror* were prototypes for the screw-driven auxiliary steamers which would subsequently become the Admiralty standard.[1011] In the same period, from 1845, the Fox-family Neath Abbey ironworks and steam engine manufactory began to dominate production of the inverted vertical engine most commonly used for powering screw vessels.[1012] In the same year, 1845, De la Beche was appointed to lead the Admiralty Coal Enquiry, an extensive investigation specifically charged with the transformation of a local contingent and vulnerable fossil fuel economy, into an apparently universal juggernaut capable of working in the same way in any place. Franklin may have been transfigured, but as with Robinson the linkages he laid down were already being augmented. Together with the Admiralty Standard Compass, the Fox-type was the Compass Observatory's adjutant in the field, and with it came all the iron and steam 'under Neath'.

[1007] Lambert,2009,pp.137-52
[1008] Craciun,2016.
[1009] Battersby&Carney,2011,pp.200-211.
[1010] Lambert,2009,p.149
[1011] Battersby&Carney,2011,p.211.
[1012] Ince,2001,p.56,p.61

Conclusion: The Mechanics of Enclosure

The enclosure of commons in eighteenth-century Britain was significantly bonded with the violent conquest of land overseas, and the produce of that land cultivated as plantations. Heterogeneous patterns of consumption, formerly shaped by majority subsistence cultivation, local exchange, and household production, were transformed with the gross surplus of plantation commodities, which, in turn, fostered new forms of cultural capital in British politics. 'Improving landlords' sponsored a wave of parliamentary acts for enclosure within Britain, further encouraging the expansion of capitalist agriculture and dispossession and displacement of people.[1013] As chapter two described with respect to the specific advantage of coal over water power, industries able to follow the displaced, profited on their vulnerability as a cheap and plentiful source of flexible labour;[1014] then profited again on the plantation and human trade's burgeoning market for their wares: from textiles to the toy trade in shackles and agricultural implements.[1015] Chapter three considered the transition from the production of such consumer goods to Britain's emergence as a nation dominated by the machine-building industry,[1016] whose products, as chapters two and four described, found their principal markets among American and West Indies enslavers.[1017] The massive surplus profits of the human trade and enslaved labour were not only used to reorganise domestic industry, but also, crucially, the sustaining political and technological machinery. They were bound up with transformations in domestic British production, and as chapter four described, these were bonds enacted and sustained through the changing regulation and architecture of the emergent fiscal-military state.[1018]

By Lord Liverpool's new economic policy of 1817, the mechanism of profiteering on these resources and relations was theorised absent the physical weight of contingency. The exhaustion of land was presented as a natural and inevitable law, the 'law of rent', which necessitated high capital investment and further conquest. The author of this law was financier David Ricardo, introduced in chapter six as a friend and patron of the Mint's chief melter and clerk, Richard Mushet. Ricardo was one of the founding members of the Geological Society of London. The very society where, in 1814, his acquaintance John Taylor described the Cornish mine economy.[1019] As detailed in chapter one, Taylor's account explained the

[1013] Blackburn,2010,pp.509-80; Blackburn,2013,p.268
[1014] Malm,2016a,pp.121-93.
[1015] Beckles,2013,p.91.
[1016] Berg,1982,pp.203-225.
[1017] Sheridan,1989,pp.59-70.
[1018] Beckles,2013,pp.131-142.
[1019] Burt,1977,p.21.

public auction of work, called a 'survey' for the way in which the miner's dial, or surveyor's compass, was used to define the lots. This survey produced intense competition between workers to the profit of the industrialist: an 'open market' within the confines of an underground economy that drove its workers down. Taylor presented a methodology for the extension of this Cornish system into a global metallurgical empire through the export of high-capital machinery: namely Cornish steam. Four years on, with Taylor now Treasurer of the Geological Society, Ricardo published his 'law of rent' that presented Taylor's methodology for extending the Cornish system as natural law driven by necessity. His intention was to present an argument of irrefutable logic, in favour of free trade.

The system of enclosures in place between the seventeenth and later eighteenth centuries had been based on the idea that without a monopoly of the colonial market, domestic and overseas, British manufactures would not sell. The loss of the thirteen colonies following the American revolutionary war was a salutary lesson. In July 1783, an Order in Council decreed free trade between Britain and the new United States, whereby British exports were to be restricted to manufactured goods that could only be paid for in raw materials. As a result, British imports from America became a measure of the power of its exports. These imports increased fifty per cent between 1784 and 1790, and continued to increase, gaining over three times in value between 1792 and 1801.[1020] Under a closed system, British merchants made spectacular profits on purportedly free trade.

With such profits came anxiety to protect this balance against the development of rival manufacturing industries, anxiety seen most strongly in the turn-of-the-century twist debates, described in chapter three, and the shift in regulatory focus that followed the fetish of labour from the manufactured good to the machine. As chapter three detailed, this shift in focus saw the machine-building industry scrutinised by policy-makers for the source of its confidence. Its industrialists were explicit: the global monopoly of machine exports was not threatened by the emigration of artisans or copying of exports, precisely because its machine designs depended on the specific tolerances of a particular kind of fibrous iron: cheap, readily available, and peculiar to Britain, the new kind of iron introduced in chapter two.[1021]

Despite such confidence in an iron hold over the machine-building industry, there persisted a concern over the export of steam engines, where copper was recognised to be the best material for boilers. What followed was a concerted effort, through government contracts and favourable domestic policies, to substitute the copper of engine boilers for iron. Chapter one

[1020] Williams,1944,pp.124-5,p.154.
[1021] Parliament,1824,p.23,pp.112-3.

introduced the mechanism of British capital, whereby close personal relations were used to regulate risk, guarantee contracts, and further set market rates, giving the example of Cornwall's Fox family and their friends Boulton & Watt. Iron became the material means of such interdependence. As chapter four described, by the early 1840s, iron boilers were 'almost universal'. With tolerances, durability, depreciation, and face value all favouring copper, the *Encyclopaedia Britannica* declared

> 'We must look, therefore, for the explanation of the general use of iron to the state of mercantile affairs, and the value of money in the commercial community.'[1022]

Chapters four and six considered the way in which Britain's maintenance of its national boundaries and the peculiarity of its protectionist policies shaped both its concept of the global, and the identity and rights of individuals. Now iron embodied British mercantilist principles, iron defined its borders, its concept of the global, and its individual.

The Walker 'meridional compass', the Admiralty's reference instrument for nearly twenty-five years between 1795 and 1819, was explicitly an instrument of colonial enclosure.[1023] The point of this needle was to rule on 'letters patents', the most powerful of exclusive land titles, hereditary and total. Such patents made endless enclosures: unlimited in time and in what they could take.[1024] The Compass Observatory and its museum were the nationalisation of the Walker reference compass, scaled and centralised as an institution transcending space and time. The Standard Compass was its worldly representative, whose proliferation administered the titles. The magnetic campaign, through weights and measures, remanufactured the world in globalisation's terms, so that the titles held by the Observatory and administered by its Standards were statements of fact with respect to Britain's industrial truth: the fiscal-military state. From the application of the Babbage principle to instrument reform, to Sabine's tour of the quadrilateral trade, each was directly in dialogue with and derived from the miner's dial of the Cornish system and Jamaican plantations. The posited necessity of high capital investment in Ricardo's law premised the export of steam engines as part of the natural law of enclosure: the natural law of imperial rule. As chapter five noted, the Observatory adopted Scoresby and Joule's galvanic battery for calibrating the duty of steam engines to magnetise Standard needles to a uniform power.

The Admiralty Standard Compass remained the Royal Navy's principal compass for over half a century. In that time many foreign navies adopted it, such that,

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[1022] Encyclopaedia Britannica,1842,p.676
[1023] Walker,1794,pp.211-26.
[1024] Higman,2001,p.19.

> From 1855 to 1863, 281 Standard and 388 Binnacle compasses on the Admiralty pattern, as also 246 Liquid Boat's compasses, all manufactured in London, have been examined at the Compass Observatory by official request for the Governments of America, Russia, Austria, Turkey, Portugal, Netherlands & France.[1025]

The Observatory itself would become the longest-running technical department in Admiralty history and one of the oldest Government scientific establishments, preceded only by the Royal Observatory and the Royal Ordnance Factory.[1026]

Mercantilist metal both made the links and maintained the boundaries. This thesis has been centrally concerned with a new kind of iron, born out of African skill in the late-eighteenth century, which would dominate British industrial production in the nineteenth: iron that embodied principles of extreme labour extraction. It was systematically deployed to reorganize production at every level of society within Britain, and to extend this extractive reorganization in the construction of the global. The deliberate deployment of certain materials for their associated systems of production was widespread in the earlier nineteenth century. The same can be said for globalization in new forms of copper coin;[1027] the labour extraction in paper;[1028] or the direct links between such extraction, globalization, and regulatory policy reform, built into glass.[1029] In this period, the very same personnel and institutions introduced in this thesis transformed the design and architecture of the modern world in reforms underwritten by material substitutions. Aspects of the argument presented in this thesis can be seen in each of these materials: such substitutions reinforce the assemblage. But the argument presented here has iron at its core.

Taylor's Cornish System of extractive and globalised labour was built on Fox engines, and the Fox-type instrument, built in the same engine foundries, was appointed the magnetic survey campaign's standard at sea. Invested with Robinson's pivotal parliamentary authority from 1841, the Fox-type was brought into correspondence with established trade, navigation, and scientific standards. The chapters of this thesis have systematically documented and articulated the scope of such historical arguments about material standards, world-wide trade and accumulation in the age of revolution and reform. Within the Cornish System, the survey established a bounded organisation of open market competition that drove down labour costs.[1030] Such cyclopean surveillance and social control was embodied in the

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[1025] Alexander & May,1907-1951,p.34.
[1026] Fanning,1986,p.ix.
[1027] Doty,1990,177-86.
[1028] Schöberlain,2016,pp.730-54.
[1029] Bulstrode,2018a; Bulstrode,2018b.
[1030] see chapter one.

capitalist vision of labour extraction, both in the quadrilateral trade across the Atlantic and at the metropolitan fiscal-military institutions centred on Woolwich.[1031] Cosmologies of manufacture were developed as part of an enterprise to manufacture and model a new set of materials, in textiles, timber and metallurgy.[1032] Britain's leading scientific administrators ensured that the reform of national weights and measures was globally represented in the instrumentation of newly-launched magnetic campaigns of the 1830s and 1840s.[1033] This equipment and these measures were under constant surveillance through the navigational technologies of the fiscal-military state. Reform and co-ordination of standards across the institutions of industry, science and state were directly articulated with a vocal and powerful campaign for free trade.

In 1846, the year after the launch of the Franklin expedition set new standards in Admiralty coal and steam, these efforts came to fruition in the form of the repeal of the Corn Laws. That year saw Fox's twenty-seventh anniversary as United States Consul to Falmouth, just under three decades of supplying information used to fix American tariffs,[1034] over half a century including the tenure of his industrialist father. This conclusion began with enclosures; the inequality and protectionism built into Britain's purportedly free-trade policies with late-eighteenth century America; and the way in which, by the mid-nineteenth, the colonial character of British capital was embodied in the structure and instrumentation of its iron. In 1846 committed mason James K. Polk was elected president of the United States, supported by his vice-president, Dallas Bache's uncle, George Mifflin Dallas.[1035] Coinciding with Britain's Corn Law Repeal, one of Polk and Dallas's first acts was to push through a new set of tariff rates, focused on iron.

Six years on, in 1852, Pennsylvania representative and vocal anti-mason Thaddeus Stevens set out to Congress the relation between the 1846 tariff and land bills then in question. In particular, Stevens sought to explain the impact of allotting enclosures held 'in trust' by the government, 'to railroad companies on the principles of free trade'. Taking the British iron industry as both the most significant and illustrative case, Stevens described these principles as 'a boast… founded on the repeal of the Corn Laws', and 'a lie' that not only concealed the long manufacture of a closed system by which Britain contained its ostensibly open market, but also 'the extraordinary length of interfering with the legislation of other countries'.

[1031] see chapters two and four.
[1032] see chapters three and four.
[1033] see chapter six.
[1034] Kennedy,1990,p.185.
[1035] Introduced in chapter six.

> It must be remembered that the tariff of 1846 was produced by Her Britannic Majesty, after great anxiety, expense, and labour. During the period of its gestation she had an agent, with rooms assigned him in this Capitol, to watch over its progress and facilitate its advent. It was safely delivered by the aid of the celebrated *accoucheur*, Mr Secretary Walker. It is now one of the most celebrated of her numerous offsprings.

The British system, Stevens argued, was 'as highly protective as it ever was' and American railroad companies, whose profits lay in freight and collaboration with Atlantic shipping corporations, annexed land and profited on this drain of wealth, and the driving down of domestic industry and its workers.[1036] The Walker tariff, transformed into state trading standard, shared more than a name with the Walker compass.

Between freight, tariff, and enclosure, Stevens described a post-colonial version of the particular drain of wealth from Ireland set out in chapter four with respect to Johnson's Compass Committee pilot study on the Shannon. Far from incidental context, this compass correction was an argument. The iron steamship *Garryowen* represented the resilience of state administration against wrecking by the colonised of County Clare, mobilised by radical MP Daniel O'Connell's vocal protest. Parallels drawn between Ireland and India were a prominent feature of Irish political discourse in the 1830s through the 1840s,[1037] not least by O'Connell himself.[1038] And for good reason, the same administration would secure the iron bondage of one of the most notorious drains of the mid-nineteenth century: the devastating impact of India's British-imposed railway debt.[1039] The 1846 tariff that concerned Stevens, the articulation of the free trade 'lie', saw the new British iron - intensively remanufactured as chapter two described - now treated as a raw material, and lifted the duty on it.[1040]

Three years on, in January 1849, Bache's colleague Joseph Lovering, the American professor who coined the term 'magnetic crusade' in print, wrote of the campaign

> Suppose every meridian on the earth's surface to be marked by the iron bands of the railroad or the smoke of the steamship, suppose each of its parallels of latitude to be made visible by the fine wires of the telegraph, so that every degree of its area should be bounded, north and south, east and west, by the lines of intelligence - and suppose the Christian spirit to have taken possession of only two or three of the more

[1036] Stevens,1852,pp.1-8.
[1037] Ryder,2006,pp.12-25.
[1038] Collombier-Lakeman,2013,pp.41-54.
[1039] Headrick,1988,pp.276-9; Dutt,1950,pp.353-370.
[1040] Stevens,1852,p.5.

> powerful nations of the earth, and what ignorance or vice could stand up against the intolerable blaze which would be kindled round every hearth-stone?'[1041]

Lovering's image of a globe bound by powerful nations with combinations of iron bands, fine wires, and lines of intelligence was a vision he knew and reported to be in the making: a vision that presented what was mechanical as natural, and reality to be remanufactured in correspondence with a cosmology of manufacture. Physics as the articulation of God's natural laws gave to capital universal authority, declaring the march of such technocratic extraction a march of necessary and inevitable progress. In turn and in its twisted links, capital gave to physics a true correspondence with the world as it was remanufactured within her iron enclosures.

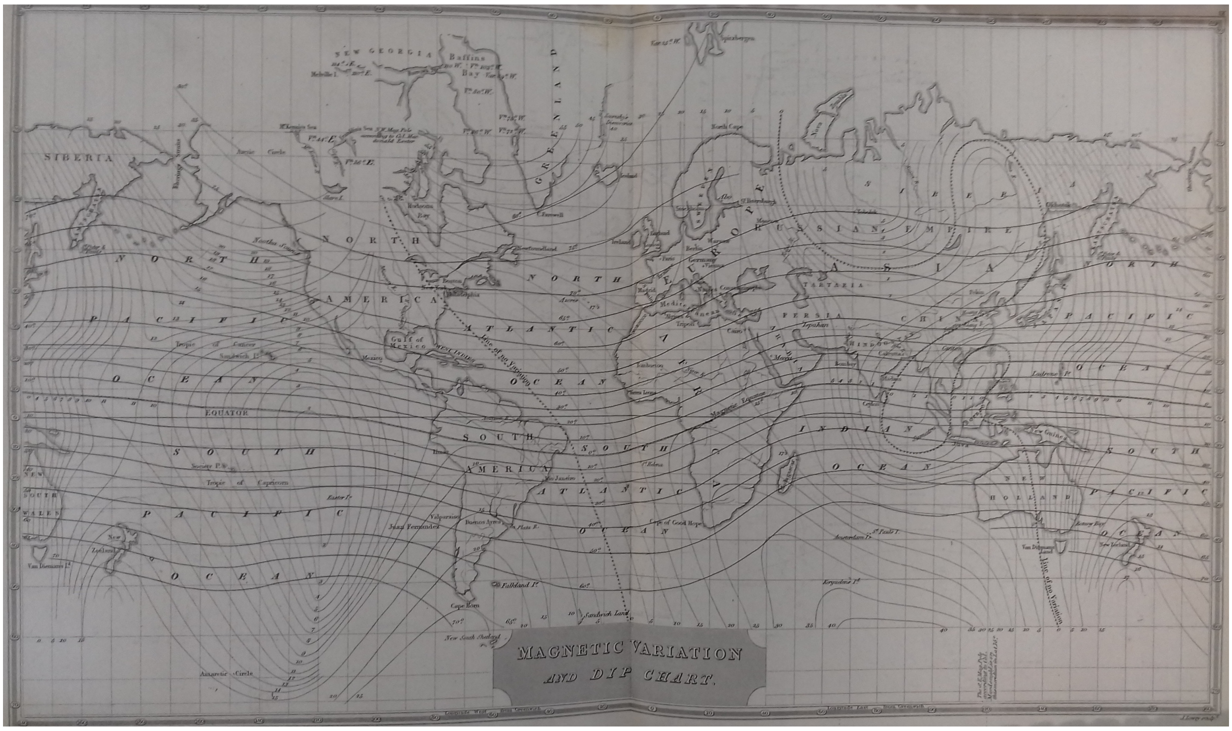

Figure 8.1: Barlow, Peter, 1829, 'magnetism,' *Encyclopaedia Metropolitana* Vol.I, London: Baldwin and Cradock, 735-845.

[1041] Lovering,1849,p.74.

Epilogue: Germinal

Every act of enclosure differs in its form and effects, as incommensurable as the histories and geographies of the cultures on which it trespasses.[1042] But the compass and the dip circle were the instruments of a powerful illusion. In commuting land and labour into quantitative cash relations they projected the fantasy of commensuration. Every reference to the Admiralty Standard was as a reference to one of its precursors - whether the Walker instrument on Jamaica or the miner's dial in Cornwall. These needles, their material components and their derivatives, threaded the Cornish system through every chapter of this thesis, not as a universal principle of extraction but as a widely propagated method of commutation that gave different forms of extraction the illusion of a singular universal principle.

The 'survey' in the Cornish system was the public auction of the right to work land, marked out by the miner's dial. Harnessed to the magnetic campaign, the international extension of the Cornish system became a claim that the geographical problem of induction could be resolved by the auction of this inalienable right. With every reference to the derivatives of the dial, distinct and incommensurable forms of labour extraction were transformed into an imagined continuum. Despite extensive and longstanding efforts to represent such technocratic surveillance technologies as innocuous, the work of the Compass Observatory and its magnetic officers was widely resisted. But such technology did not need to be popular or even effective to weave its fiction.[1043] For all the failure of the instrument to reveal hoped for physical laws, every reference to the needle reinforced the illusion of the global and the commensuration of extraction. As has often been marked in the analysis of governmentality, failure itself even served to screen the machinery of extraction and indirect rule.[1044] Machinery that in the case of the needles, wove a powerful fantasy of commensuration.

The illusion was powerful because its currency was so widely circulated in the repeating character that connected institutions, instruments and materials. The copper bottom of the compass was the basis of the mercantile system, the financial foundation of the mining speculation, the sheathing of the enslaver's hull, and the current carrying wire that bounded the globe. The iron of the needle was the engine, the steamship, the chains and the pale. The design and architecture of the modern world.

[1042] Tuck&Yang,2012.
[1043] Hunt,1850,p.414; Cawood,1979,p.516; Morrell&Thackray,1981,pp.530-1.
[1044] Ferguson,1996,p.xiv,pp.19-23,pp.254-6.

From its inception the aim of this doctoral thesis was to explore the overlap between the substantial extant bodies of scholarship relating to nineteenth century geomagnetic research in Britain. Literatures concerned with Britain's magnetic researches as a geopolitical response and intervention,[1045] were to be brought together with those which considered the novel 'modernity' of this science,[1046] the material basis of its abstractions,[1047] and its relation to the major institutional and societal changes of the nineteenth century.[1048] As the prologue noted, study of these literatures not only highlighted points of overlap, but also the way in which iron, copper, the compass and the Fox-type served as synecdoche for the integration of the canonical concerns. Each chapter made significant original contributions, from innovations in iron production, to field theory, Abolition, and the Walker tariff. But it is in the analytical originality of the thesis as a whole, its interconnectedness and the microcosm of the instrument assemblage, that the germs of a significant overarching contribution lie.

The compass, the dip circle, and their material components are suited to the synecdoche of this thesis precisely because they were designed and deployed by its protagonists to manufacture the myth of commensuration. Analysis of these microcosms then presents an acutely sensitive tool for the historical analysis of this colonial machinery, where analysis enables breaking up the complex into its constituent parts. The title of chapter five drew on David Turnbull's famous portfolio of exhibits, *Maps are territories*, designed, as he put it, to show maps as conventional and embedded in forms of life. The chapter's aim was to exhibit Barlow's researches in their specific form of life: 'The map is the territory, the compass a gun'.[1049] After the enclosure, this expression demands extending: as Eve Tuck and K. Wayne Yang put it: 'Decolonization is not a metaphor'.[1050] From Maxwell's penny and 'money makes the world go round' to the globe bound in iron lines with which this thesis concluded, the exposure of apparent metaphor as material reality has been a driving force for this thesis. The overarching contribution is no more than a seed at this stage, to be further developed in future work. Modern physics is a colonial physics, and its universal claims describe a global capitalism that is racial capitalism. This thesis presents the possibility of material and instrumental synecdoche as the basis for analyses which can begin to unpick these

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[1045] Cannon,1978; Cawood,1977; Cawood,1979; Carter,2009; Dörries,1994; Morrell&Thackray,1981.
[1046] Cunningham,1988; Cunningham&Williams,1993; Kuhn,1976; Miller,1986.
[1047] Cardwell,1971; Gooding,1989; Marsden&Smith,2005; Wise&Smith,1989a,1989b,1990; Smith,1998.
[1048] Barford,2015; Cotter,1979; Craciun,2016; Fanning,1986; Lambert,2009; Levere,1993; May,1987; Winter,1998; Savours&McConnell,1982
[1049] Turnbull,1993.
[1050] Tuck&Yang,2012.

universalising claims. In its germinal efforts this approach began to reach towards histories of protest and insurrection. It offers a future for the history of physics in insurgent energy.

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