

## Cornish Science, Mine experiments, and Robert Were Fox's Penjerrick Letters

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**Abstract:** In 2019 a collection of letters from the nineteenth-century natural philosopher Robert Were Fox was discovered in his home at Penjerrick in Cornwall. Fox came to the attention of scientific audiences for experimentally establishing that temperature increases with depth beneath the Earth's surface and later secured fame for his magnetic dipping needle, developed to measure terrestrial magnetic phenomena. The newly uncovered Penjerrick letters constitute a valuable archival discovery with important historical ramifications for our understanding of Fox's work and its place within nineteenth-century science. As well as highlighting the central role of networking in promoting provincial science, the letters reveal the prominence of the Cornish mine as a site of experiment within British scientific culture. These venues presented Fox with unique spaces in which to scrutinize nature, but such philosophical investigations were unverifiable within a laboratory and appeared susceptible to inaccuracies arising from the working conditions of this uncontrollable environment. Nevertheless, the Cornish mine was crucial to the development of Fox's dipping needle, which became the premier device for making magnetic observations at sea in the 1840s. In this article, I demonstrate the epistemologically problematic nature of the mine as an experimental space that was to take on a central role in the world-wide magnetic survey, that historians have described as the 'Magnetic Crusade'.

**Key Words:** Cornwall, Science, Mine, Experiment, Nineteenth Century, Robert Were Fox, Faraday, natural philosophy, Magnetic Crusade.

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Just outside of Falmouth in Cornwall, surrounded by dense tropical growth, is Penjerrick. Since the present house's construction in 1935, this has been home to the descendants of the nineteenth-century natural philosopher Robert Were Fox (1789-1877). **(Figure 1)** In 2019 his great granddaughter, Rachel Morin, and her gardener, Hilary Watson, discovered a mysterious

package at Penjerrick, containing five letters from Fox to local MPs Charles Lemon (1784-1868) and Davies Gilbert (1767-1839), as well as a stereogram of the Cornishman himself. **(Figure 2)** A specialist in geology and terrestrial magnetism, Fox first came to the attention of European scientific audiences for experimentally establishing that temperature increases with depth beneath the Earth's surface, using Cornwall's deep mines to measure differences in subterranean heat.<sup>i</sup> In the 1820s, Fox surmised that the Earth's interior was a place of high temperature, appearing to confirm French mathematician Joseph Fourier's assertions that the Earth's present stability was the result of gradual cooling and that its interior was a place of great heat. However, it was for his magnetic dipping needle, developed to measure the dip and intensity of the Earth's magnetic field, that Fox secured his greatest reputation. This was to play a leading role in the British Magnetic Scheme or what, in 1979, historian John Cawood termed the 'Magnetic Crusade'.<sup>ii</sup>

The newly uncovered Penjerrick letters constitute a rare and valuable new archival discovery with important historical ramifications for our understanding of nineteenth-century science. Primarily, they show the central role of networking in promoting provincial science in London, to national audiences. Lemon and Gilbert, the latter of whom served as President of the Royal Society from 1827 until 1830, were invaluable patrons for Fox as he looked to secure his Cornish science attention with metropolitan elites. The role of social networks in nineteenth-century provincial-metropolitan exchanges of scientific knowledge has been a productive area of analysis for historians. For instance, James Ryan's study of chemist and science writer Robert Hunt's (1807-1887) development of early photographic procedures showed the significance of local and national philosophical societies, as well as correspondence with the celebrated astronomer John Herschel, in disseminating experimental knowledge, produced in Cornwall, to broader audiences.<sup>iii</sup>

The letters found at Penjerrick enhance our understanding of these processes of communicating, and securing attention for, provincial science. In particular, they show the importance of local MPs in the movement of philosophical knowledge from the regional to the national. MPs like Lemon and Gilbert, being present both in their constituencies and at Westminster, were central to regional communities as well as the elite political and scientific networks of the capital. They were, therefore, the ideal facilitators in communicating knowledge of nature attained from around the British Isles, such as in Cornwall, to London. These political networks provided the ideal channels of scientific communication. What also becomes apparent is that, once brought to the attention of MPs, there were comparatively few places to which politicians could go for verifying new experimental results and theoretical assertions: notably to the Royal Society and to Michael Faraday at the Royal Institution. Securing approval at these influential venues was crucial for aspiring natural philosophers, like Fox, to build authority, but they could also prove harsh places of metropolitan scrutiny for provincial knowledge.<sup>iv</sup>

What made this dissemination of Fox's philosophical work even more difficult was the ambiguous nature of his primary experimental location. The Penjerrick letters reveal the prominent place of the mine as a site of experiment within British scientific culture. As past historical studies have shown, eighteenth- and nineteenth-century natural philosophers often considered that subterranean scientific investigations could be of value, with underground caves and mines taking on increasingly Romantic connotations during the 1820s and 1830s.

While gentlemen geologists appropriated coal mines as places of study, mathematicians also found these venues of use, such as George Biddell Airy and William Whewell's attempts to measure the Earth's density in Dolcoath Mine, at Camborne, between 1826 and 1828.<sup>v</sup> This was a space which provided exclusive philosophical opportunities for scrutinizing natural phenomena, but was also of troubling epistemological value, being uncontrollable and incomparable to similar experiments conducted in laboratories. What emerges from this, as Jenny Bulstrode has demonstrated, is the central role of the Cornish mine in the development of Fox's dipping needle, which became the premier device for making observations at sea.<sup>vi</sup> Considering the importance of this instrument for Britain's global magnetic survey, its origins in the depths of Cornwall's mines provides an example of how localized, provincial knowledge and apparatus were mobilized in a scientific investigation of unprecedented scale. Under the direction of Edward Sabine, this mapping of terrestrial magnetic phenomena was to become the most eminent philosophical project of the 1840s, representing a revolutionary intervention of the British state into scientific research.

Along with papers at the National Archives at Kew and Cambridge University Library, the Royal Society's Library currently holds most of Fox's surviving correspondence.<sup>vii</sup> This rich archival collection consists of letters between Fox and some of the leading scientific authorities of the mid nineteenth century, including Charles Wheatstone, Henry De la Beche, and Mary Somerville. Here there is much discussion of Fox's dipping needle, particularly in terms of securing sales and commissions for new instruments. This new cache of letters contributes to this archive, throwing fresh light on how Fox's theoretical work and experimental inquiries shaped the design of his magnetic dipping needle during the 1820s and 1830s. Given that the Royal Society was a central organ for securing government funding for this project and for acquiring magnetic instruments with which to conduct it, Fox's dipping needles were immensely important for the development of nineteenth-century British science and the relationship between the government and scientific practitioners. Fox's dipping needle, as a solution to the challenge of making reliable magnetic measurements onboard ships, was crucial to the magnetic scheme's claims to accurately map the Earth's magnetism.

**Figure 1:** Penjerrick garden, full of dense tropical growth planted in the 1830s and 1840s and itself a testing site for Fox's magnetic dipping needles (Author's image, 2020).

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The earliest of the Penjerrick letters dates from 1827 and provides an image of the industrial Cornwall in which Fox lived and worked, surrounded by steam power and engineering innovation. Written to Gilbert in the same year that he became President of the Royal Society, Fox here discusses steam engines and questions of coal economy. Having received a copy of Gilbert's Royal Society paper on the steam engine, Fox recalled his own earlier experiments on high pressure steam. He had been 'convinced by many experiments on vapour, which I made in 1812, that its density, when in contact with the liquid producing it, increased nearly in

proportion to its elasticity, and that the advantages of using high pressure steam, is almost entirely mechanical'.<sup>viii</sup>

Fox had considerable industrial interests. As the son of Robert Were Fox senior (1754-1818), he was part of a devout Quaker family with commercial ventures that spanned ship-brokering, copper mining, tin-smelting, and foundry work.<sup>ix</sup> Indeed, the Foxs were hugely influential in Falmouth, with Robert Were Fox junior's grandfather, George Croker Fox (1727-1781), establishing the port's leading shipping insurance company in 1762. Like his father and grandfather, Fox junior's business dealings put him at the very centre of west Cornwall's industrial and commercial expansion during the early nineteenth century. His second brother, Charles Fox (1797-1878), was similarly engaged in scientific research, as well as being a partner in the family shipping business and General Manager of Perran Iron Foundry at Perranarworthal, which manufactured machinery and engine castings for local mines. In addition to owning smelting works in South Wales at Neath Abbey, the Fox family was at the absolute centre of Cornwall's industrial revolution.<sup>x</sup>

Beyond these commercial and industrial interests, Robert Were Fox took careful note of local engineering innovations, delighting in a working engine which Cornish engineer Goldsworthy Gurney (1793-1875) had designed for steam locomotion. Fox reported to Gilbert that 'it bids fair to answer for many purposes at least, as it combines lightness with strength in a superior degree, & must I conceive, be economical as it respects fuel'.<sup>xi</sup> Gurney used this engine to drive his steam-powered road carriage that would, in 1829, complete the journey from London to Bath, before going into commercial operation, albeit briefly. Likewise, at St Katherine's Docks in London, Fox had witnessed 'the application of the principle of how tubes infused metal for generating steam, but the engine was not working. The fire was not advantageously applied, being by the side of, & not under the iron case, which contained the fused metal & tubes'.<sup>xii</sup> Fox thought this a troublesome arrangement, given the thickness of the metal between the fire and water, which was detrimental to the 'transmission of heat' and would make it hard to sustain a uniform temperature. He also speculated to Gilbert that the tubes for the fused metal would soon wear out at high temperatures. Having grown up amid the steam engines of West Cornwall's intensive mining industry, it was hard for Fox to resist scrutinizing a new apparatus.

**Figure 2:** The stereogram of Robert Were Fox found at Penjerrick (Author's image, 2020).

It was not just steam engines that occupied Fox's attention. His letters also demonstrate how the mine itself had become a site of experimentation. Fox later recalled that he had collaborated with engineer Joel Lean in 1815, performing 'some enquiries relative to the temperature of mines at different depths, with the express view of proving the existence of a progressive increase of temperature under the earth's surface'.<sup>xiii</sup> This use of the mine as a laboratory space is a constant theme through the Penjerrick letters. Thanks to his connections with local mine captains, such as John Rule at Dolcoath, Thomas Lean at Wheal Abraham, and William Teague at Treskerby, Fox secured privileged access to these underground sites, transforming what were nominally places of labour into experimental spaces.<sup>xiv</sup>

After fifteen years of subterranean temperature measurements, Fox was eager to explain how metalliferous veins formed. It was his belief that these mineral seams, which in Cornwall

were so rich in tin and copper ore, were the result of underground electric currents. This electrical action was, he speculated, the product of subterranean heat acting on saline water which lay deep beneath the Earth's surface. In turn, the electrical currents produced caused a chemical action on the saline water, causing it to deposit its dissolved minerals in veins of metalliferous ore. To prove this theory, Fox was determined to show that electrical currents could be sustained through rock deep beneath ground and, if possible, to actually identify naturally occurring electrical action. For both, the Cornish mine provided an invaluable site of experiment.<sup>xv</sup>

**Figure 3:** Fox's arrangement to measure the existence and direction of electrical currents within a mine, published in the BAAS's report of its 1834 meeting in Edinburgh (Author's image, 2020).

Among the Penjerrick letter, Fox's earliest to Charles Lemon, dated 30<sup>th</sup> March 1830, provides an account his subterranean experiments 'on the electricity of copper veins with a galvanometer' performed in Huel Jewel, Dolcoath, and Tresavean mines. He explained how he fastened 'Slips of sheet copper two feet long, & 3 inches wide ... to different parts of the veins, and an electrical communication was established between two of these & the galvanometer, by copper wire coated with sealing wax. The distance of the copper slips from each other was generally less than 20 or 30 fathoms. – The deviation of the needle was in some cases considerable, its oscillations extending over more than half the circle, in others, the action was comparatively slight'.<sup>xvi</sup> These were encouraging results. By incorporating a mineral vein within an electrical circuit, connected to a galvanometer, Fox claimed to have shown how a current could be sustained through the vein itself. Fox published his findings in the Royal Society's *Philosophical Transactions* in 1830 and presented them to the Edinburgh meeting of the British Association for the Advancement of Science (BAAS) in 1834.<sup>xvii</sup> (**Figure 3**)

Fox also wanted to determine the direction in which these subterranean electrical currents operated, suspecting that they might be governed by the Earth's magnetic field. (**Figure 4**) To do this, he constructed an apparatus for ascertaining the character, in terms of direction and strength, of terrestrial magnetism within a mine. As early as 1830, Fox reported to Lemon that he had 'made some experiments in mines with the magnetic needle ... seven inches long, suspended through a glass tube, by very fine untwisted silk. I found a considerable increase of intensity in the mines; for instance at Tresavean'.<sup>xviii</sup> Effectively, this device was a very primitive dipping needle. Fox's later instrument, so important to Britain's global magnetic survey, secured a reputation for robustness, which was essential to use at sea, far from highly disciplined observatories. It is significant that Fox developed and employed his original apparatus within the equally challenging environment of the Cornish mine. Dipping needles were traditionally delicate devices, but had to be refashioned for use in mines and on ships.

**Figure 4:** Fox's drawing showing the direction of subterranean electric currents (Author's image, 2020).

These mine experiments contributed to a broader series of experiments that Fox conducted throughout 1830 on terrestrial magnetism at the surface of the Earth which he published the following year in *Philosophical Transactions*. Taking two needles, one

possessing a strong northern pole and the other in which the south pole was predominant, Fox suspended each of these with silk in two identical slate boxes, mounted on bricks, and employed an eight-inch-long magnetic bar to control the needles's movement from below. Over the course of a year, Fox measured the direction of force of the needles with their opposing polarizations. Generally, he found that the yearly mean magnetic movement was equal between the two poles, but that the intensity of this force varied over time.<sup>xix</sup> Fox therefore thought it 'most reasonable to refer the phenomena of the earth's magnetism to the urgency of electrical currents existing under its surface, as well as above it'.<sup>xx</sup> During the subsequent winter, Fox took advantage of a particularly beautiful display of the Aurora Borealis at Falmouth to provide further results on the movements of magnetised needles. This striking natural marvel 'sent up streams of red and white light' that coincided with unusual magnetic activity from the suspended needles. At 7pm on evenings when these streams occurred, both needles rested at 0°. By dusk, however, the north ends of the needles moved east, producing an easterly variation of 1° 15', before returning west. At 10pm they were back at 0°. Fox reported a similar display on most nights on which the Aurora Borealis was visible, attributing this movement to 'electrical phenomenon'.<sup>xxi</sup> Fox delivered an account of his observations to the Royal Society in March 1831 and this was published in the institution's prestigious *Philosophical Transactions* soon after. Along with his earlier Royal Society publication on mineral veins, this marked a considerable coup for the Cornish natural philosopher, which was as much the product of Fox's careful networking with allies such as Gilbert, as to his own experimental skill.

This central place of the mine in Fox's work characterized what was a distinctly Cornish approach to natural philosophy, in which the county's rich industrial resources were mobilized in the study of the natural sciences. Indeed, Cornwall had a booming scientific culture during the first half of the nineteenth century, in which Fox, Lemon, and Gilbert were all prominent figures. Most obviously, this expanding scientific tradition took shape in a series of philosophical societies throughout the county. Established in 1814 at Penzance, the Cornwall Geological Society was only the second British geological society, following the Geological Society of London in 1807, although it attracted few members from industry, remaining a largely gentrified organization.<sup>xxii</sup> The foundation of the Cornwall Philosophical Society in 1818 represented the region's second scientific society. Originally meeting in the County Library at Truro, with the intention to cultivate knowledge of geology, mining, engineering, and agriculture, it soon specialized in natural history and antiquarianism, becoming the Royal Institution of Cornwall in 1821. Again, this was a socially elite organization, with Charles Lemon serving as president between 1818 and 1830.<sup>xxiii</sup> But it was the Cornwall Polytechnic Society that Fox was to be most influential, helping his three children, Anna Maria, Barclay, and Caroline, to found the Falmouth-based institution in 1833. Intended to promote mining knowledge and be accessible to broader social groups than Cornwall's existing philosophical societies, the Fox family canvassed local subscribers to finance prizes for 'clever workmen', especially those at the Perran Foundry, 'who were constantly bringing models and inventions' to their employer.<sup>xxiv</sup> With a little encouragement from Fox, both Lemon and Gilbert were eager supporters of this industrially focused society.

In April 1834 Fox wrote again to Charles Lemon, thanking him for his account of Faraday's investigations into electrical action and providing details of a paper on magnetic

attraction he had recently submitted to the *Philosophical Magazine*. Here he had ‘shown by the appearance of the filaments of pulverised load stone [iron filings], that the divergency of the magnetic elements, at the extremities of magnetic poles, alter on the approach of another magnet, - the laws of the magnetic forces changing at the same time’.<sup>xxv</sup> Fox manoeuvred two small magnets, altering the respective magnetic force of each through contact with the other. What appears initially as rather trivial manipulations of the character of magnets, in fact reflected a growing complexity in Fox’s conception of the behaviour of magnetic phenomena. **(Figure 5)**

**Figure 5:** Fox’s sketch of his manipulations of the force of two magnets (Author’s image, 2020).

Yet at stake here was much more than candid magnetic observations. As much as detailing his subterranean experiments, the Penjerrick letters represent Fox’s efforts to build a consensus and secure credibility for his work. Above all, it was Michael Faraday’s attention that Fox wanted to arouse. In his 1830 letter to Lemon, Fox wondered if his mine experiments on terrestrial magnetic phenomena would not be of interest to Faraday. Hoping that Lemon would raise his investigations with London’s foremost experimentalist, he was keen ‘to know whether any of my views might obtain the sanction of such an authority, or if not, I might have the benefit of his corrections. I cannot but feel very diffident on the subject of my opinions, till I am more acquainted with the ... conclusions of this Philosopher. Perhaps thou wilt have the kindness to mention my experiments to him, if a suitable opportunity should occur’.<sup>xxvi</sup>

Fox’s coercing of Lemon paid dividends, with the Cornish philosopher’s work piquing Faraday’s curiosity. On 12<sup>th</sup> January 1832, during his Bakerian Lecture at the Royal Society, Faraday invoked Fox’s work on the subterranean movement of electrical currents through copper veins in relation to his own recent observation of electromagnetic induction. He speculated that these trials might contribute to an enhanced understanding of electromagnetic phenomena and informed his august audience that ‘Mr. Fox of Falmouth has obtained some highly important results respecting the electricity of metalliferous veins in the mines of Cornwall’. Faraday had examined Fox’s 1830 *Philosophical Transactions* paper on mineral veins to see if any of the Cornish philosopher’s results related to electromagnetic induction. ‘When parallel veins running east and west were compared’, observed Faraday, ‘the general tendency of the electricity *in the wires* was from north to south; when comparison was made between parts towards the surface and at some depth, the current of electricity in the wires was from above downwards’.<sup>xxvii</sup> In conceiving of the Earth as a giant magnet, Fox had measured the movement of electric currents through veins to determine the direction of the Earth’s magnetic pole, in the same way that passing electricity through a wire suspended over a magnet revealed the direction of the magnet’s pole. Nevertheless, Faraday refused to be drawn on his opinion of Fox’s work, maintaining that there was no discernible relation between electromagnetism and the direction of underground electrical currents running through the Earth.

Yet Faraday remained unconvinced by Fox’s experiments. Charles Lemon forwarded his 1834 letter from Fox to the London experimentalist, requesting Faraday’s opinion on the existence of subterranean electrical currents.<sup>xxviii</sup> Faraday responded in late April, expressing doubts over Fox’s description of these proposed currents as an ‘Electric agent’, this constituting

a vague claim. ‘It is easy to imagine forces with certain directions as a kind of abstract notion of electricity but that is saying little’, reflected Faraday. Without discovering the cause of a force, in this case that acting on Fox’s magnetic needles as described in his Royal Society paper on the Aurora Borealis, there was no reason to suppose it was an ‘Electric agent’, any more than any other force. Nevertheless, Faraday confirmed that Fox’s experiments were of certain value and hoped they continued, with the Cornishman’s unprecedented access to the deepest mines in the country revealing much new knowledge of nature.<sup>xxix</sup> These were experiments that could not be conducted within a laboratory: Fox produced observations that could neither be verified nor rejected from Faraday’s laboratory at the Royal Institution.

Two things become very clear from Lemon and Faraday’s discussion of Fox’s letter. The first is that while Fox’s experiments had produced genuinely interesting results, he had not yet successfully connected his observations to credible explanations. Attributing the deflections of magnetic needles to subterranean electric currents, the existence of which was suggested through his metalliferous vein experiments, was still unsubstantiated. What is more telling, however, is that for all Fox’s growing credentials, the credibility of his claims largely rested on Faraday’s interpretation. Fox might impart scientific knowledge to local gentry and politicians in Cornwall, like Lemon, but they in turn looked to Faraday for philosophical guidance. The Penjerrick correspondence did not occur in isolation, but was part of an extensive communications network, linking Fox to elite London natural philosophers.

Fox was, in fact, struggling with a much bigger question of credibility with audiences beyond Cornwall, as demonstrated by the Royal Society’s archives. In June 1832, the terrestrial magnetism specialist Samuel Christie delivered a devastating review of a paper Fox had submitted for publication in *Philosophical Transactions*. Examining the effects of temperature variation on a magnetic needle and its implications for the study of terrestrial magnetism, which Gilbert had read at a Royal Society meeting in May, Fox detailed his experiments to ‘discover the cause of the irregularities in the indications of the intensity of terrestrial magnetism given by the vibrating magnetic needle’ when suspended in a box around which water of different temperatures was circulated.<sup>xxx</sup> Fox had found that when heat was applied equally on all sides of the box, the needle’s vibrations remained constant, but when he applied heat to only one part of the box, the oscillations became irregular. He supposed that temperature inequalities within the box produced currents of air that interfered with a magnetic needle’s movements. Fox supplemented these observations with fresh results from deep mine experiments. He had not found ‘any increase of magnetic intensity at the depth of 1000 or 1200 feet below the level of the sea; but if any thing, rather the reverse; but, on the whole, the discrepancy in the results was so great, that no dependence can be placed on them as establishing a general fact of this importance’.<sup>xxxi</sup>

Christie rejected this work completely with a scathing critique. He left little doubt that the treatise was far below the standards expected for a Royal Society publication, with Fox’s style ‘so discursive, and the subjects to which the author, in different parts of it refers, so various, that it is difficult to say what is the precise object of the communication’.<sup>xxxii</sup> Fox claimed ‘opinions and views, as new’ which were well known, revealing him to be poorly acquainted with the subject of terrestrial magnetism: this alone prevented its publication in *Philosophical Transactions*. Christie noted that the Royal Society of Edinburgh had published a paper in 1824 showing that the varied action of the sun’s rays on the planet, between tropical



and polar regions, effectively converted the earth into a ‘vast magnetic apparatus’.<sup>xxxiii</sup> He had himself written an article in the *Philosophical Transactions* in 1827 that experimentally demonstrated how the sun determined the daily variation of a needle in London. The Cornishman therefore appeared profoundly naive and ignorant of broader scholarship. Christie also regretted that Fox had a tendency to contradict himself. At the start of one paragraph, for instance, Fox asserted that the cause of terrestrial magnetism must be due to phenomena at the earth’s surface. But by the end of the same paragraph, Fox had concluded ‘that the principal cause of terrestrial magnetism must exist at a great depth in the Earth’.<sup>xxxiv</sup> Fox was clearly muddled, thought Christie. Brutally, Christie concluded that the paper was ‘quite unfit for publication in the Transactions of the Royal Society’.<sup>xxxv</sup> This criticism of Fox’s experiments, produced in the industrial context of the mine, was typical of broader denigration of practical geological expertise which frequently characterized the attitudes of gentlemanly metropolitan elites.<sup>xxxvi</sup> Fox never published with in *Philosophical Transactions* again.

Facing such sustained opposition to his philosophical speculations, Fox continued to canvass support from local allies like Lemon, but few were as valuable to him as Gilbert. Five years after Christie’s rejection, in January 1837, Fox was still advancing his claims to Gilbert, declaring that as he had already established the ‘fact’ of the increase of temperature with depth beneath the Earth’s surface, he was eager to link this to an explanation for ‘the origin of mineral deposits’. He requested that Gilbert secure Fox’s latest paper a reading at the forthcoming anniversary meeting of the Geological Society.<sup>xxxvii</sup> Fox explained his theory in full, referring ‘to the high solvent power of very hot water existing at the bottom of deep fissures, & to its tendency to ascend with any salts, with which it might have been charged through the upper portions of water in the fissures’. This circulation must, Fox supposed, ‘have caused a transference of matter from the lower, towards the upper part of the fissures ... & as the ascending warm water had its temperature reduced, & its solvent powers accordingly diminished, a deposition of some of the substances contained in it, might gradually have taken place’. Fox then returned to the role of ‘electrical excitement’ within this process, which ‘may have been produced by great differences of temperature in different parts of veins; - & in many other ways, the phenomena of mineral veins may have been modified by the circulation of water in the fissures at different degrees of temperature’. Fox was confident that there was much in the character of the mineral veins encountered in mines that would ‘be more & more referred to electro magnetic, or magneto-electric action’.<sup>xxxviii</sup>

As well as continuing to press his own theoretical claims, Fox developed new techniques to help disseminate his theories through his social networks. The big challenge he faced was that experiments conducted within mines were not easy to verify or replicate in metropolitan centres of science like London and Cambridge. Fox resolved this problem by devising a small-scale model to demonstrate how mineral veins formed. Not only could this be transported beyond Cornwall, but it made a compelling source of entertainment for dinner parties at his Penjerrick estate and Falmouth townhouse, Rosehill.

In November 1837, Fox sent a description of this experimental model to Gilbert. He had separated an earthenware vessel into two cells with a layer of moistened clay. In the first cell he put a piece of copper pyrites, connected by a copper wire running through the clay to the second cell, containing a zinc plate submerged in acidulated water.<sup>xxxix</sup> After leaving this for several months, until the liquid inside had evaporated, Fox removed the dried clay which

split on opening. He found the clay ‘to be divided into two portions, nearly parallel to the sides of the wall, & having rather a conchoidal surface’. A dark line ran through the clay, consisting of a layer of laminae. Providing Gilbert with a small drawing, Fox observed that ‘the divided portions of clay g & h, were, like the metallic bodies, in opposite states of electricity, & one of them, consequently, in a more favourable state than the other, to receive the deposition of metal from their solutions’.<sup>xl</sup> **(Figure 6)** Fox confidently informed Gilbert ‘that these experiments amount to proofs of the correctness of the explanations which I have given of the cause of metallic accumulations’.<sup>xlii</sup> In achieving a deposit of metallic matter through the clay, by the action of a weak electric circuit, Fox believed his theory of vein formation well proven.

**Figure 6:** Fox’s own sketch of his clay experiment for modelling the formation of mineral veins below the Earth’s surface (Author’s image, 2020).

**Figure 7:** Fox’s watercolour of his clay samples, probably painted in 1838 (Thanks to Michael Carver for permission to use this image, 2020).

Gilbert had, in fact, already witnessed these clay specimens first hand earlier in the autumn at a dinner party at Rosehill. **(Figure 7)** Fox, however, not only relayed a detailed written account of his model, but expanded his interpretation of the experiment. It seemed to Fox that, from this formation of laminae in the clay, ‘a series of poles may be formed in earthy matter, & accord with the fact of copper, oxide of copper, etc. occurring in insulated portions, on the walls of clay moistened with a solution of salts of that metal; & also completely bear out the explanation I have given ... of the frequent accumulation of ores near contracted portions of veins being due to the formation of secondary or intermediate poles’.<sup>xliii</sup> By examining the direction of the laminae through the clay, Fox believed he could determine ‘the direction of the principal electrical action’ at work on the sample in a similar fashion to how mineral veins in mines revealed the direction of the Earth’s subterranean electric currents.<sup>xliiii</sup> As he concluded, he had already shown ‘from numerous observations made at the bottom of mines ... that the progressive augmentation of temperature in descending into the earth is in a decreasing ratio, a fact perfectly inconsistent with the notion of the conducting power of rocks being the immediate cause of the results which have been observed in mines’.<sup>xliiv</sup> It was not just that Fox hoped Gilbert would spread word of these observations beyond Falmouth, but that these clay samples could themselves be transported for philosophical inspection in London and Paris. As much as correspondence and networking, Fox used these clay models to promote his mine-based knowledge of nature.

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These newly found Fox letters demonstrate, first and foremost, the considerable work that went into the promotion of provincial science with elite scientific audiences. Behind papers to learned institutions and publications in eminent philosophical journals, Fox cultivated relations, both socially and scientifically, through letters, demonstrations, and clay models. The Penjerrick letters show how Fox set out his own philosophical assertions to local allies who might, in turn, circulate these accounts with leading London authorities. His 1834 letter to Lemon, forwarded to Faraday, itself became the subject of philosophical discussion. This

material is, therefore, historically valuable in highlighting the processes of transformation from provincial to metropolitan science. At the centre of this troublesome promotion of knowledge of nature, forged in Cornwall, within the capital was the place of the mine as a physical location for the production of experimental evidence. It is not just that Fox's letters to Gilbert and Lemon show the central role of the mine as a place of experiment within nineteenth-century science but, more importantly, they offer insights on the apparently paradoxical philosophical position of this space.

**Figure 8:** An 1840s' Fox dipping needle, held in Falmouth at the Royal Cornwall Polytechnic Society (Author's image, 2020).

At once, the mine presented Fox with a unique venue in which to scrutinize nature in ways quite impossible in scientific centres like London, Paris, and Edinburgh. Here was a place where he could witness natural phenomena, seemingly, directly. Faraday might claim to represent nature through experimental arrangements in his laboratory at the Royal Institution, but through circuits incorporating mineral veins and the oscillations of magnetic needles below ground, Fox asserted that he observed subterranean electrical currents and terrestrial magnetism directly within the mine. This was, quite literally, science at the coalface. At the same time, however, Fox's philosophical investigations were unverifiable without access to a mine. They seemed highly susceptible to the inaccuracies and errors arising from working within such an uncontrollable, non-laboratory, experimental space. Yet the skills and experiences of Fox's mine experiments, especially with magnetic needles, would help him to develop instruments that were robust and capable of measuring magnetic phenomena around the world. Naval expeditions would carry his dipping needles to the further corners of the globe, from James Clark Ross's surveying of the Southern Hemisphere between 1839 and 1843, to John Franklin's disastrous venture to the Arctic in 1845. **(Figure 8)** But these were instruments fashioned through years of experiences within Cornish mines. The mine was, in this way, both philosophically valuable to Fox, but also made the advancement of his inquiries and securing of consensus extremely difficult.

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<sup>i</sup> On Fox see, J. H. Collins, *A catalogue of the works of Robert Were Fox, F.R.S., &c. Chronologically arranged, with notes and extracts, and a sketch of his life*, (Lake & Lake: Truro, 1878).

<sup>ii</sup> The term 'Magnetic Crusade' originated in North America in the early 1840s and was not generally used to denominate the British magnetic campaign until John Cawood's influential 1979 article. No evidence has been found that it was used in Britain until April 1842 and, even then, it did not become a commonly used category. Examined in, Matthew Goodman, 'From "magnetic fever" to "magnetical insanity": historical geographies of British terrestrial magnetic research, 1833-1857', (University of Glasgow: PhD thesis, 2018), pp. 16-7; also see, John Cawood, 'The Magnetic Crusade: science and politics in early Victorian Britain', *Isis*, Vol. 70, No. 4, (Dec., 1979), pp. 493-518; Christopher Carter,

*Magnetic Fever: global imperialism and empiricism in the nineteenth century*, (American Philosophical Society: Philadelphia, 2009).

<sup>iii</sup> James R. Ryan, ‘Placing early photography: the work of Robert Hunt in mid-nineteenth-century Britain’, *History of Photography*, 41:4, (2017), pp. 343-61; on metropolitan-regional relations scientific exchanges see, Ian Inkster and Jack Morrell (eds.), *Metropolis and Province: Science in British Culture, 1780-1850*, (Routledge: London, 1983).

<sup>iv</sup> This central role of parliamentarians in the cultivation of nineteenth-century science is the focus of a Leverhulme research project at the University of Leeds, ‘The State of Science: governing knowledge of nature in Victorian Britain’, (2020-2023).

<sup>v</sup> Allan Chapman, ‘The Pit and the Pendulum: G. B. Airy and the determination of Gravity’, *Antiquarian Horology* (Autumn, 1993), pp. 70-8; George Biddell Airy, ‘Account of experiments made at Dolcoath Mine, in Cornwall, in 1826, & 1828 for the purpose of determining the density of the earth’, in P. D. Hingley and T. C. Daniel (eds.), *A far off vision: a Cornishman at Greenwich Observatory. ‘Auto-Biographical Notes’ by Edwin Dunkin, F.R.S., F.R.A.S., (1821-1898), with notes on the lives & work of his father, brother and son*, (Royal Institution of Cornwall: Truro, 1999), pp. 173-81; on Romanticism, mines, and geology see, Michael Shortland, ‘Darkness Visible: underground culture in the Golden Age of Geology’, *History of Science*, 32:1, (1994), pp. 1-61, especially 22-30; also see Allen Debus, ‘Re-Framing the Science in Jules Verne’s *Journey to the Center of the Earth*’, *Science Fiction Studies*, Vol. 33, No. 3, (Nov., 2006), pp. 405-20; Svante Lindqvist, ‘The Spectacle of Science: an experiment in 1744 concerning the Aurora Borealis’, *Configurations*, Vol. 1, No. 1, (Winter, 1993), pp. 57-94, 67.

<sup>vi</sup> Jenny Bulstrode, ‘Men, mines, and machines: Robert Were Fox, the dip-circle and the Cornish system’, (Part III Dissertation, History and Philosophy of Science Department, University of Cambridge, 2013); on Fox’s dipping needle see, Goodman, ‘From “magnetic fever” to “magical insanity”’: historical geographies of British terrestrial magnetic research, 1833-1857’; Trevor H. Levere, ‘Magnetic Instruments in the Canadian Arctic Expeditions of Franklin, Lefroy, and Nares’, *Annals of Science*, 43:1, (1986), pp. 57-76.

<sup>vii</sup> For Fox’s surviving archival material, see Royal Society Library, London, MS/710, ‘Robert Were Fox Papers’ and MS/258, ‘Sabine Correspondence, Vol. 2, D-J’; The National Archives, Kew, Sabine Papers, BJ3/19/; Cambridge University Library, Add.9942, ‘Fox Box’.

<sup>viii</sup> Penjerrick Letters, Falmouth (PEN), ‘Robert Were Fox to Davies Gilbert (27<sup>th</sup> Jul., 1827)’, pp. 1-5, 1-2.

<sup>ix</sup> Susan E. Gay, *Old Falmouth: the story of the town from the days of Killigrews to the earliest part of the 19<sup>th</sup> century*, (Headley Brothers: London, 1903), pp. 149-60; P. Payton, (2008, January 03). Fox, Robert Were (1754–1818), merchant and industrial entrepreneur. *Oxford Dictionary of National Biography*. Retrieved 5 Dec. 2019, from <https://www.oxforddnb.com/view/10.1093/ref:odnb/9780198614128.001.0001/odnb-9780198614128-e-42083>; (Anon.), *People from Falmouth*, (Books LLC: 2010); for a business history of the Fox family see, Charles Fox, *On the Brink: the story of G. C. Fox and Company: a Quaker business in Cornwall through eight generations*, (Zuleika: London, 2019), pp. 155-77; the Fox family’s personal and business papers are held at Kresnow Kernow (the Cornwall Centre) in Redruth and the Library of the Royal Polytechnic Society of Cornwall in Falmouth.

<sup>x</sup> On Fox’s industrial works see, Laurence Ince, *Neath Abbey and the Industrial Revolution*, (The History Press Ltd: Stroud, 2001), pp. 29-30; Susie Barson, *The Perran Foundry Perranworthal, Cornwall: an historical report and assessment of a late eighteenth-century iron foundry and steam engine manufactory*, (Historical Analysis & Research Team, Reports and Papers 71. English Heritage, 2002), pp. 10-12.

<sup>xi</sup> PEN, ‘Robert Were Fox to Davies Gilbert (27<sup>th</sup> Jul., 1827)’, pp. 1-5, 2.

<sup>xii</sup> *Ibid.*, p. 3.

- <sup>xiii</sup> PEN, ‘Robert Were Fox to Davies Gilbert (28<sup>th</sup> Jan., 1837)’, pp. 1-4, 4; also see, Robert Were Fox, *Further Observations on the Temperature of Mines. Communicated to the Royal Geological Society of Cornwall and published in their 3<sup>rd</sup> volume of Transactions*, (T. Vigurs: Penzance, 1827).
- <sup>xiv</sup> Robert Were Fox, ‘On the temperature of mines’, *Transactions of the Royal Geological Society of Cornwall*, 2<sup>nd</sup> Volume, (T. Vigurs: Penzance, 1822), pp. 19-28, 19.
- <sup>xv</sup> For historical geographies of science and territorial themes of analysis see, Jon Agar and Crosbie Smith (eds.), *Making Space for Science: territorial themes in the shaping of knowledge*, (Palgrave Macmillan: Basingstoke, 1998); David N. Livingstone, *Putting Science in its Place: geographies of scientific knowledge*, (University of Chicago Press: Chicago, 2003).
- <sup>xvi</sup> PEN, ‘Robert Were Fox to Charles Lemon (30<sup>th</sup> Mar., 1830)’, pp. 1-5, 1-2.
- <sup>xvii</sup> Robert Were Fox, ‘Account of some experiments on the electricity of the copper vein in Huel Jewel Mine’, in *Report of the Fourth Meeting of the British Association for the Advancement of Science; held at Edinburgh in 1834*, (John Murray: London, 1835), pp. 572-4.
- <sup>xviii</sup> PEN, ‘Robert Were Fox to Charles Lemon (30<sup>th</sup> Mar., 1830)’, pp. 1-5, 2.
- <sup>xix</sup> Robert Were Fox, ‘On the variable intensity of terrestrial magnetism, and the influence of the aurora borealis upon it’, *Philosophical Transactions*, Vol. 121, (1831), pp. 199-207, 199-201.
- <sup>xx</sup> *Ibid.*, p. 201.
- <sup>xxi</sup> *Ibid.*, p. 202.
- <sup>xxii</sup> Simon Naylor, *Regionalizing Science: placing knowledge in Victorian England*, (Pickering & Chatto: London, 2010), pp. 30-1; also see, Simon Naylor, ‘Geological mapping and the geographies of proprietorship in nineteenth-century Cornwall’, in David N. Livingstone and Charles W. J. Withers (eds.), *Geographies of nineteenth-century science*, (University of Chicago Press: Chicago, 2011), pp. 345-70.
- <sup>xxiii</sup> Naylor, *Regionalizing Science*, pp. 31-3.
- <sup>xxiv</sup> W. L. Fox quoted in, Alan Pearson, ‘A study of the Royal Cornwall Polytechnic Society’, (M.A. Thesis: University of Exeter, Sep., 1973), p. 31; on the Polytechnic see, Julie Maxted, ‘Scientific and cultural networks in nineteenth-century Falmouth: the Fox family and the Royal Cornwall Polytechnic Society’, (B.A. Dissertation: University of Exeter, undated), pp. 14-23.
- <sup>xxv</sup> PEN, ‘Robert Were Fox to Charles Lemon (9<sup>th</sup> Apr., 1834)’, pp. 1-2.
- <sup>xxvi</sup> PEN, ‘Robert Were Fox to Charles Lemon (30<sup>th</sup> Mar., 1830)’, pp. 1-5, 4.
- <sup>xxvii</sup> Michael Faraday, *Experimental Researches in Electricity*, (London: Richard and John Edward Taylor, 1839), pp. 54-5.
- <sup>xxviii</sup> PEN, ‘Robert Were Fox to Charles Lemon (9<sup>th</sup> Apr., 1834)’, pp. 1-2.
- <sup>xxix</sup> ‘Letter 712: Michael Faraday to Charles Lemon (25 Apr., 1834)’, in Frank A. J. L. James (ed.), *The Correspondence of Michael Faraday, Vol. 2: 1832-December 1840. Letters 525-1333*, (Institution of Electrical Engineers: London, 1993), p. 178.
- <sup>xxx</sup> Robert Were Fox, ‘On Certain Irregularities in the Magnetic Needle, produced by partial warmth, and the relations which appear to subsist between terrestrial magnetism and the geological structure and thermos-electric Currents of the Earth’, *Proceedings of the Royal Society*, No. 10, 1831-1832, (London, England), pp. 123-5, 123.
- <sup>xxxi</sup> *Ibid.*, p. 124.
- <sup>xxxii</sup> Royal Society Library, London, RR/1/73, Samuel Christie, ‘Report on Mr Fox’s Paper, 27<sup>th</sup> June 1832’, (1832), p. 1.
- <sup>xxxiii</sup> *Ibid.*, pp. 2-3.
- <sup>xxxiv</sup> *Ibid.*, pp. 9-10.
- <sup>xxxv</sup> *Ibid.*, p. 11.

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<sup>xxxvi</sup> On the contrasts between practical and gentlemanly geology see, Martin J. S. Rudwick, *The Great Devonian Controversy: the shaping of scientific knowledge among gentlemanly specialists*, (University of Chicago Press: Chicago, 1985), p. 38.

<sup>xxxvii</sup> PEN, 'Robert Were Fox to Gilbert Davies (28<sup>th</sup> Jan., 1837)', pp. 1-4, 1.

<sup>xxxviii</sup> *Ibid.*, pp. 1-4.

<sup>xxxix</sup> PEN, 'Robert Were Fox to Gilbert Davies (20<sup>th</sup> Nov., 1837)', pp. 1-3, 1.

<sup>xl</sup> *Ibid.*, p. 1.

<sup>xli</sup> *Ibid.*, p. 2.

<sup>xlii</sup> *Ibid.*, p. 2.

<sup>xliii</sup> *Ibid.*, p. 3.

<sup>xliv</sup> *Ibid.*, p. 3.