Introducing Geophysics at the British Geological Survey, 1920s-1950s

A thesis submitted by Xiaoyu Liu,

of University College London (UCL),

for the degree of Ph.D.

March 2024

Declaration

I, Xiaoyu Liu, confirm that the work presented in my thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Xiaoyu Liu

March 2024

Abstract

This dissertation investigates several key projects in the history of the British Geological Survey between the 1920s and 1950s that marked the introduction of geophysical techniques in its surveying and mapping work. Historians have indicated a general agreement that, in the early twentieth century, the importance of physics and physical methods transformed many other disciplines, including geology. Illustrative and plausible accounts of the transformation, however, are scarce in the literature about history of geology. This dissertation responds to the scarcity and examines the general agreement by asking: what the transformation was like if geology was infused with physics, what could have driven or obstructed it, and how could it have been embedded in an existing context – in the case of the British Geological Survey, its field work.

The British Geological Survey provides a good case study because it represents a traditional imagination of geological work in the field, and thus any emerging sign of geophysics would be noticeable. This dissertation tracks the Geological Survey's introduction of geophysics by highlighting its first purchase of geophysical apparatus in 1920s, its wartime projects, its post-war expansion of staff and agenda, and its success in airborne magnetic surveys in 1950s. Most sources that support this dissertation come from the government, especially the Geological Survey Board, because these papers

clearly outline relevant projects and their rationale, and because they were accessible in a rather reliable time span against lockdowns.

This dissertation shows that, for the British Geological Survey, the introduction of geophysics was not only an addition to existing methodology, but also a sign of the survey being ready to explore beyond practical functions. It allowed an increased variety of topics that hallmarked a transition to a geoscience research institution.

Impact Statement

My research contributes to the academic literature on the History of Geology and Earth Sciences, especially that focused on the early twentieth century. As is illustrated in Chapter 1, this thesis is about a time period that is relatively less covered by historians. This thesis investigates and provides more information on a time that bred major advances in geology. Plus, the originality of this thesis lies in the analysis of unpublished sources which have been surprisingly unused: the Department of Scientific and Industrial Research papers at the National Archives as well as the British Geological Survey archives. I hope that this thesis will demonstrate the value of these archives and encourage increasing consultation with them.

In addition, this thesis enriches the literature on the History of the British Geological Survey. As Britain's leading research institution in geosciences and geoinformation, the Geological Survey has an outstanding record of serving the development of science, economics, and environment of the country. There are numerous stories in its history awaiting to be written. With the 250th anniversary of the British Geological Survey approaching, this thesis shows a good example to explore its past and to celebrate its heritage.

Furthermore, with its roots in fieldwork, geology has always been a spatial endeavour. As this research project progressed, it became of interest how earth science and technology adapted to field conditions. Although the scope of this thesis is limited due to the accessibility of sources, this work is a good example of understanding the use of techniques in the field and of explaining how such usage could shape a discipline, and I hope it will encourage more literature on this topic.

Finally, this thesis will improve understanding of geology and geologists for non-academic audiences. As I became aware when I was doing my research, the staff at the British Geological Survey nowadays have expressed a major concern that there has been a decline in the number of school students in the United Kingdom who choose geology as their subject, and the decline results from misunderstandings of the content of geology as a subject and of the work of geologists as a profession. With the Geological Survey as an example, my thesis investigates the variety of geological research and the ability for geology to meet political and social demands in different eras, and I hope it will help with public engagement with earth sciences and inspire the next generation of geologists.

Acknowledgements

I would like to express my gratitude to my supervisor Professor Jon Agar, who guided my research project with insightful advice, constructive feedback and, above all, exceptional patience.

I would like to thank my examiner Professor Charlotte Sleigh, not only for offering valuable correction advice for my thesis, but also for all the support in my teaching and career development.

Thanks are also due to all my colleagues in the department who have shown kind interest in my research and given warm encouragement during my PhD course, including Dr Cristiano Turbil, Professor Carina Fearnley, Professor Brian Balmer, Scott Keir, Catherine Lucas, Mengxi Zhang, and Ms Susan Walsh for her timely administrative aid. I would also like to thank Dr Robert Naylor at Manchester - my external examiner, Dr Alexandra Rose at Science Museum, Dr Daniella McCahey at Texas Tech, Andrew Morrison at the British Geological Survey Archives, and Han Jiang at Leicester.

Finally, I would like to express my deepest gratitude to my parents, Yingjun Liu and Yining Zhang, without whose care, encouragement and understanding, not only would this research project never have been completed, but I would not be the person I am today.

Table of Contents

Chapter 1: Introduction

What is geology? According to a public survey in 2021, when asked this question, most people would respond with something about rocks. If asked what a geologist does, most people who have studied geology answer with the broad role of a geologist and note several subdisciplines. For those who had never studied geology, a geologist “studies rocks,” “looks at rocks,” and “looks at/licks/analyses rocks.”[1] One of the particularly negative perceptions of geology reads: “Studying rocks feels old fashioned, and maybe a little like stamp collecting. Is there anything new to discover with rocks?”[2] Researchers who conducted the survey lament the ignorance of the interdisciplinary character and attraction of geology, and observe that the results were “disheartening” but “understandable,” for geology “that struggles to coherently define itself will in turn struggle to communicate its appeal and importance.”[3]

---

[1] Steven Leslie Rogers et al., '“you Just Look at Rocks, and Have Beards” Perceptions of Geology from the UK: A Qualitative Analysis from an Online Survey', 2023, *Earth ArXiv*, https://doi.org/10.31223/X5MD4N.

[2] Rogers et al., '“you Just Look at Rocks, and Have Beards” Perceptions of Geology from the UK: A Qualitative Analysis from an Online Survey'.

[3] Rogers et al., '“you Just Look at Rocks, and Have Beards” Perceptions of Geology from the UK: A Qualitative Analysis from an Online Survey'.

The same incoherence can be found in views about geology's past. On the one hand, people easily take geology as an old-fashioned study of rocks, perhaps influenced by stories of Victorian geologists and natural historians. On the other hand, modern geologists claim that they are "not fully 'outdoorsy'", that they "work in an interdisciplinary manner," and they do not need to work "in the extractive industry" or "curate and collect rocks."[4]

It is curious what happened between the two perceptions: in the long development of the discipline, what made geologists less outdoorsy, less focused on rocks, and less "stamp collecting" – and more like physicists?

Starting with the question above, this thesis explores how one major British geological body responded to the rise of geophysics in the first half of the twentieth century, during which period traditional geological institutions made efforts to catch up with the innovative trends that were brought into the discipline either by industry or were driven by a need for new kinds of information. This thesis hopes to help us answer the broader question: what was the influence of geophysics onto geology?

---

[4] Rogers et al., '"you Just Look at Rocks, and Have Beards" Perceptions of Geology from the UK: A Qualitative Analysis from an Online Survey'.

1.1 Debates, Revolution, and the Rise of Geophysics

In academic literature, a consensus exists that a major change in studies of the earth occurred in the twentieth century. The unsettled question is what the change actually was, or, to be more specific, how did the changes play out in specific places and contexts.

Writings on history of geology seem to prove that geology developed through debating opinions on various topics. There are a lot of such debates that have marked significant progress in people's knowledge about the earth. As historian of geology David Oldroyd has recounted, to begin with, many of the early debates were about dating, such as those in the nineteenth century trying to determine the ages of certain fossils and strata.[5] Other debates dealt with the influence of momentous catastrophes, the formation of granite, or the mechanism of mass extinctions.[6] Sometimes the debates are quite specific to place and context, such as the one between Bailey Willis and Robert T. Hill in

[5] David R. Oldroyd, T*hinking about the Earth: A History of Ideas in Geology* (London: Athlone, 1996), 313. The complete list includes Great Devonian Controversy (Rudwick 1985), Controversy in Victorian Geology (Secord 1986), and The Highlands Controversy (Oldroyd 1990).

[6] Oldroyd, *Thinking about the Earth: A History of Ideas in Geology*, 313. Oldroyd's list goes on to include Great Geological Controversies (Hallam 1983), Controversies in Modern Geology (Muller et al. 1991), Granite Controversy (Read 1957), and The Mass-Extinction Debates (Glen 1994).

the early years of seismology over the geological stability of southern California, as Susan Hough's new book examines.[7]

Some of these are long-existing controversies that took decades to settle down. When it came to the twentieth century, continental drift became a major geological focus. The development and confirmation of continental drift hypotheses led to a whole series of discoveries that let to plate tectonics, and the emergence of plate tectonics is generally regarded as a revolution in geosciences. Detailed accounts of the revolution can be found in the memoirs of its participants such as Kenneth J. Hsü and Henry William Menard.[8] There is no lack of incisive remarks regarding the development of the revolution in geosciences in these books. For example, Hsü remarks that the revolution had a theoretical and a practical aspect, with the theoretical one manifested in Frederick J. Vine and Drummond Matthews's paper on the expanding seafloor around ocean ridges, and the practical one conducted by the deep-sea

---

[7] Susan Hough, *The Great Quake Debate: The Crusader,* the Skeptic, and the Rise of Modern Seismology (Seattle: University of Washington Press, 2020).

[8] Kenneth Jinghwa Hsü, C*hallenger at Sea: A Ship That Revolutionized Earth Science* (Princeton: Princeton University Press, 2014). Henry William Menard, *The Ocean of Truth: A Personal History of Global Tectonics* (Princeton University Press, 2014). Reminiscences of the development of plate tectonics can also be found in *The Road to Jaramillo: Critical Years of the Revolution in Earth Science* (Glen 1982).

expeditions of ship Glomar Challenger through 1960s and 1970s.[9] He also suggests that a division had begun to take shape "between continental geology and marine geophysics", which can be quite crucial if we want to understand the definition of geology. Geologists, he describes, were mostly those who were concerned with stratigraphy, while geophysicists looked more broadly to develop their new theories based on evidence from ocean ridges, coasts, and assorted forms of islands.[10] Throughout the book, he himself can be regarded as an example of an earth scientist who had deeply believed in material proof and refused to accept continental drift due to its temporary lack of rock evidence in his early career, and who later appreciated the way geophysicists collected and analysed deep-sea samples to test their theories. Thereby, the verification of continental drift was revolutionary not because it created a new type of geologists, but because it created a way to hold the geologists and geophysicists in the earth science community together so that such a community would not split.[11]

On the other hand, Menard puts his version of the history into the theoretical frame of Robert K. Merton's multiple discoveries, and indicates that there indeed had been a number of independent discoveries regarding the crust due to the wide variety and availability of geophysical instruments and

---

[9] Hsü, *Challenger at Sea: A Ship That Revolutionized Earth Science*, xviii-xix.
[10] Hsü, *Challenger at Sea: A Ship That Revolutionized Earth Science*, xix.
[11] Hsü, *Challenger at Sea: A Ship That Revolutionized Earth Science*, xix.

techniques.[12] Furthermore, Menard comments that the achievement of successfully explaining a discovery could be more important than the discovery itself, especially when there was a theory to be confirmed. In other words, the importance of a geologists' achievement do not necessarily come from a discovery, but can also come from a plausible explanation of previous findings. In this way, marine geophysicists had no difference from continent geologists. They both were eager to find evidence in the field, no matter if it was on land or deep in the sea, and thus were surpassed by their laboratory colleagues who preferred "manipulating a finite data set".[13]

Yet the word "revolution" means something particular for historians of science, after all. When they take the terminology "revolution" seriously, it is inevitable that historians of earth science attempt to connect it with Thomas Kuhn's idea about the development of science. An elaboration of the continental drift as a revolution in earth sciences can be found in Henry R. Frankel's four-volume monumental work on the subject, *The Continental Drift Controversy* (2012).[14]

---

[12] Menard, *The Ocean of Truth: A Personal History of Global Tectonics*, 296.
[13] Menard, *The Ocean of Truth: A Personal History of Global Tectonics*, 297.
[14] Henry R. Frankel, *The Continental Drift Controversy* (Cambridge: Cambridge University Press, 2012). These volumes give a detailed account of the discussion over continental drift from 1910s when Frank Taylor and Alfred Wegener respectively raised the hypotheses to late 1960s when plate tectonics was proposed and combined continental drift with seafloor spreading. Most relevant to the thesis here is the first volume, where Frankel puts a lot of effort to map the reception of continental drift through 1920s-

Frankel confirms that a scientific revolution in earth sciences had happened by the 1970s, and suggests that a division between continental geologists and marine geophysicists was healed during those years by two complementary methods: fault plane research which led to plate tectonics and land-based paleomagnetic analysis.[15] But key to Frankel's most up-to-date account of the controversy over continental drift are termed several "research strategies", which, as he contends, had spread through the controversy and supplied a framework to describe this evolution in geosciences.[16] A summary of these three research strategies are as follows:

> During the controversy three general types of research strategies were employed, *improving* types used to *increase* the problem-solving effectiveness of solutions and theory, *attacking* types used to *decrease* the problem-solving effectiveness of competing solutions or theories, and *comparing* types by which the problem-solving effectiveness of the preferred solution or theory is argued to be *superior* to the competition.[17]

1950s around the world. Volume 2 is also partially relevant regarding its content about post-war geomagnetism research.

[15] Henry R. Frankel, *The Continental Drift Controversy* Volume 1: Wegener and the Early Debate (Cambridge: Cambridge University Press, 2012), https://doi.org/10.1017/9780511842368, xxi.

[16] Frankel, *The Continental Drift Controversy* Volume 1: Wegener and the Early Debate, 18.

[17] Frankel, *The Continental Drift Controversy* Volume 1: Wegener and the

Frankel further indicates that key to the three research strategies is removing difficulties for supportive theories (and meanwhile showing difficulties of competing ones).[18] The ultimate end of the "improving" strategy is to raise up a new, difficulty-free solution to the controversy, like Arthur Holmes proposing mantle convection to explain continental drift in order to avoid the difficulty – lack of mechanism – in Alfred Wegener's earlier theories.[19] Frankel spends comparatively fewer lines explaining the research strategies "attacking" and "comparing", which may arouse curiosity, but what he has described is already enough to remind readers of Kuhn's elucidation that schools compete to become the model for good research in a domain, and that anomalies, which are not surprising in normal research, lead to the loss of confidence in the paradigm and the appeal for a new one.[20] Difficulties and earth scientists' efforts to overcome them thus act as anomalies and have their consequences.

Early Debate, 18-19.

[18] Frankel, *The Continental Drift Controversy* Volume 1: Wegener and the Early Debate, 19-21.

[19] Frankel, *The Continental Drift Controversy* Volume 1: Wegener and the Early Debate, 19-20.

[20] Thomas Nickles, 'Scientific Revolutions', in *The Stanford Encyclopedia of Philosophy* (Winter 2017 Edition), ed. Edward N. Zalta (Stanford: The Metaphysics Research Lab, Center for the Study of Language and Information, Stanford University, n.d.), https://plato.stanford.edu/archives/win2017/entries/scientific-revolutions.

In all of this, instrumental technique choice is important. One should notice that Frankel, in the introduction to the last volume, alludes to the fact that computer had played an important role in earth sciences during the revolution, and there are several casual mentions of computer in the volume. Although he has not elucidated the claim in detail, it is reasonable to suppose that critical techniques play an equally important role in every phase of the revolution. Here techniques include not only computing which had been important in processing data and leading to the plate model, but also ones such as radioactive dating and astatic magnetometers, which had been widely applied to provide cogent evidence for geological changes in earlier phases.

The revolution or any type of change within earth science is also suggested in terminology. Scientists who study the earth and historians of science have invented or adopted several terms to refer to all or part of the studies of the earth: geology, geophysics and geochemistry, geoscience, earth sciences, and so on. Some terms may be young, such as earth sciences, which usually follows “modern” or “contemporary” as an indication of a new subject booming in the twentieth century. Others have longer traditions, such as geology and geophysics, which, as Naomi Oreskes and Ronald Doel outline, had respectively developed distinctive characteristics by the late eighteenth century, that geophysicists generally “spent little time in the field”, while geologists “tried to elucidate earth history primarily from physical evidence contained in the rock record”, which is to be found (or at least sourced) in the field; that the geophysical tradition emphasises mathematics, while the geological tradition prioritise observations; that the former is deductive in logical character, and the latter inductive.[21]

Nevertheless, by the time the term "earth sciences" became widely used, the methodology of the new subject had decisively turned to the geophysical side. A number of possible reasons for the turn are mentioned here: the expansion of the range of geophysical research objects, the substantiated plate tectonics theory and its irrefutable geophysical evidences, the invention and application of physical and chemical techniques and instruments, and "an abstract epistemological belief in the primacy of physics and chemistry", which is regarded by Oreskes and Doel as the crucial one.[22] The trend is described here to be "the depersonalization of geology",[23] and an extended description of the trend can be found in Oreskes' book *The Rejection of Continental Drift: Theory and Method in American Earth Science* (1999). In a relevant chapter of the book, the explanation begins with admitting that traditionally geology was a "personal" science, that required seeing, touching, and travelling by

[21] Naomi Oreskes and Ronald Doel, 'The Physics and Chemistry of the Earth', in *The Cambridge History of Science: Volume 5: The Modern Physical and Mathematical Sciences*, ed. Mary Jo Nye, vol. 5, The Cambridge History of Science (Cambridge: Cambridge University Press, 2002), 538, https://doi.org/10.1017/CHOL9780521571999.030.

[22] Oreskes and Doel, 'The Physics and Chemistry of the Earth', 539,

[23] Oreskes and Doel, 'The Physics and Chemistry of the Earth', 545.

oneself.[24] But in early twentieth-century America key developments put the traditional kind of geology in trouble. First, as the community of American geologists grew, scientists and their research institutions were scattered all around North America, and it became impractical to gather everyone together at a field site to witness and settle a debate. Second, with the increasing complexity of geological problems, an attempt to solve even one of them required not visiting single field sites, but evidence from various places in many field seasons. And third, while such impracticality had challenged even the most stubbornly empirical geologists, geophysical data collected by instruments proved itself to be reliable with the help of contemporary ideas that the earth itself was really the greatest laboratory in the world operated by nature, and that earth scientists' task was to collect results from the laboratory. If earth science was only about collecting results, then it did not matter whether they were collected directly by hand or through instruments.[25]

As Oreskes notes, the rise of laboratory work in geology was a branch of prevailing faith in quantified data – in measurement – that had swept across scientific disciplines by the early twentieth century in North America. This is

---

[24] Naomi Oreskes, *The Rejection of Continental Drift: Theory and Method in American Earth Science* (New York: Oxford University Press, 1999), 298.
[25] Oreskes, *The Rejection of Continental Drift: Theory and Method in American Earth Science*, 298-300. More discussions on the "nature laboratory" will follow in section "Place, Field Work, and the Meaning of Faraway Explorations" of this chapter.

not a surprising finding, but one may also find the details in the episode quite revealing as well as interesting, such as that more students were admitted into geosciences programmes with a background in mathematics, that students were no longer encouraged to "map a quadrangle" and wait for a theory to emerge from the work, and even that geologist stopped wearing "boots, jeans and flannel shirts" at conferences as if they were working in the field.[26]

1.2 The Ocean Turn and the Making of Earth Sciences

Apart from literature that focuses on explorations generally, it should be noted that, in recent years, research on history of ocean science is trending as a crossover of several perspectives which have been examined in this chapter. Historians like Donald B. Freeman and Paul Butel, started to write histories which focus on oceans.[27] Their histories pay more attention to the oceans as a location and market for trades and migration, as a method of transportation and communication, and as a stage for power competition. This historiography has been labelled the "oceanic turn" referring to increasing

---

[26] Oreskes, *The Rejection of Continental Drift: Theory and Method in American Earth Science*, 288-291.

[27] Donald B Freeman, *The Pacific* (London & New York: Routledge, 2013). Paul Butel, *The Atlantic* (London & New York: Routledge, 2002).

acknowledgement on the interaction between oceans and human beings.[28] Lately historians of science have added an aspect of the oceans' role in human history: as the object of scientific explorations. This allows historians to explore human involvement in the vertical dimension of oceans: the deep sea. Helen M. Rozwadowski's book on imagining the deep sea is relatively early among these works.[29] Instead of another case study on the importance of the sea as a place to science, Rozwadowski makes a fascinating argument about the importance of science to the sea, that, although mariners, travellers, and those who made use of resources had gained some knowledge about the sea (one can find examples of the knowledge in any general history of oceans as mentioned above), becoming an object of scientific study was "a cultural redefinition of the sea as a destination and a location with new meaning for the Western world".[30] The redefinition did not only inherit the knowledge which people had gained from living and trading experience, but also created a culture symbol that was intertwined with the political interests of transoceanic powers (here referring to Britain and the United States), and was

---

[28] Antony Adler, *Neptune's Laboratory: Fantasy, Fear, and Science at Sea* (Cambridge & London: Harvard University Press, 2019), 6.

[29] Helen M. Rozwadowski, *Fathoming the Ocean: The Discovery and Exploration of the Deep Sea* (Cambridge & London: Harvard University Press, 2005).

[30] Rozwadowski, *Fathoming the Ocean: The Discovery and Exploration of the Deep Sea*, 214.

infiltrated into daily life with the claim of deeper sea.[31] Nevertheless, the book concentrates on the emergence of deep sea exploration around the mid-nineteenth century. Although Rozwadowski foresees the participation of biological and physical scientists in the years to come, this is primarily a prehistory of the booming years of oceanography.

Rozwadowski recently attempted to further illustrate the culture of oceanic inquiries, but the book looks more similar to general histories of oceans that keep a balance between the economics and politics of oceans, as well as science.[32] If someone is expecting the scientific culture of oceans after the nineteenth century, this can be found in other works on the history of oceans. Antony Adler's history of deep-sea explorations is based on both literature on science and field and that on imagination of technology.[33] For example, he comes back to the resonating theme of the division between laboratory and field, and investigates whether it can shed light on history of oceanography. Drawing attention to the rather contemporary period, Adler argues that the division between laboratory and field in oceanography is blurring, especially after data collected from the field became calculable on computer since the

---

[31] Rozwadowski, *Fathoming the Ocean: The Discovery and Exploration of the Deep Sea*, 214-217.

[32] Helen M. Rozwadowski, *Vast Expanses: A History of the Oceans* (London: Reaktion Books, 2018).

[33] Adler, *Neptune's Laboratory: Fantasy, Fear, and Science at Sea*, 7-8.

second half of last century.[34] Another notable recent work on history of science in oceans is Oreskes' work on funding and knowledge, which supposedly cover a long period between mid- and late-twentieth century.[35] Curiously, these works on the history of oceanic science leave the early twentieth century blank again.

With all the geology-related sciences taken into consideration, the evolution from geology to modern earth science is particularly worthy of investigation. Being a case to illustrate how a new, comprehensive discipline came into being, the formation of modern earth science will shed light on people's understanding of interdisciplinarity. The formation of modern earth science is undoubtedly a process of interdisciplinisation. It is apparent that a number of existing disciplines combined to become earth science, such as meteorology, petrology, and oceanography, as mentioned in this chapter. However, studies on interdisciplinarity hardly touch the territory of earth sciences.

---

[34] Adler, *Neptune's Laboratory: Fantasy, Fear, and Science at Sea*, 160-161. Adler's example is tracking the movement of animals in oceans. As previous sections in this chapter have shown, there were other kinds of data which could support the argument.

[35] Naomi Oreskes, *Science on a Mission: How Military Funding Shaped What We Do and Don't Know about the Ocean* (Chicago & London: University of Chicago Press, 2021).

Gabriel Gohau gives one of the few accounts of geosciences as inter-discipline in his history of geology.[36] This account is focused on geology in the narrow sense, but acknowledges that the interaction between various branches is the most important element within the discipline.[37] For example, the evidence that helped geology to tackle the mystery of extinction at the end of the Mesozoic came from several sub-disciplines. First, uninterrupted sedimentations in Northern Italy, in Denmark, and on the bottom of the Atlantic prove that there was a biological gap between the Mesozoic and Cenozoic. Second, geochemistry test results showed that such sedimentations contained an unusually high amount of iridium, which is seldom produced naturally on earth, and which is regarded as strong evidence for the extra-terrestrial explanation that the extinction was caused by impacting comets or meteorites.[38] Thereby, Gohau successfully presents an example, one that is not the well-known continental drift debate, to show the cooperation between sub-branches of science to answer a question partly within geology.

Perhaps because the idea of interdisciplinarity first came from studies on the intertwining between science and humanities, cases like Gohau's which focus on a single natural science are rare. Even those that contain "earth sciences"

---

[36] Gabriel Gohau, *A History of Geology* (New Brunswick & London: Rutgers University Press, 1990).

[37] Gohau, *A History of Geology*, 215.

[38] Gohau, *A History of Geology*, 215-216.

in the title actually deal with the comparably marginal environmental science, which is relatively farther from the centre of earth science as a natural science, but is closer to studies on humans. Victor R. Baker argues that interdisciplinarity is an inherent characteristic of earth sciences by the case of studies of floods.[39] Surely there is hydraulic engineering, but, as Baker argues, even this single aspect involves an interdisciplinarity in epistemology, by referring to the rock types, local climate, “and even regional tectonic history” of a flooded alluvial fan.[40] In addition, Baker raises the idea of interdisciplinarity in methodology by analysing what he and Kochel calls “paleoflood hydrology”, which extends beyond “the physics-based hydrological tradition” by examining past flood events historically.[41] With history of floods in mind, Baker starts to approach the humanities side of interdisciplinarity, and he also predicts the possibility that flood studies will become more transdisciplinary, such as through their involvement with policy, education, and public understanding.[42]

---

[39] Victor R. Baker, ‘Interdisciplinarity and the Earth Sciences: Transcending Limitations of the Knowledge Paradigm’, in *The Oxford Handbook of Interdisciplinarity*, ed. Robert Frodeman (Oxford: Oxford University Press, 2017), 10.1093/oxfordhb/9780198733522.013.8.

[40] Baker, ‘Interdisciplinarity and the Earth Sciences: Transcending Limitations of the Knowledge Paradigm’, 9.

[41] Baker, ‘Interdisciplinarity and the Earth Sciences: Transcending Limitations of the Knowledge Paradigm’, 10.

[42] Baker, ‘Interdisciplinarity and the Earth Sciences: Transcending Limitations

In these cases, one can see how several sub-branches within a new discipline interact with each other to solve problems. However, simply telling the stories of branches does not touch the nature of interdisciplinarity. With the accumulation of narratives as a prerequisite, studies on interdisciplinarity should lead to answers to epistemological questions such as whether there are different roles for branches of varied importance, how certain branches can meet together, and, as is in the case of geology, which was evolving tremendously in early twentieth century, and indeed what defines a discipline.

It is unsure yet what geology has become; yet, it is sure that geology nowadays isn't a simple combination of all the relevant branches together. As Eric Mills comments on history of oceanography, "Trying to define the history of oceanography is akin to finding the cat behind the grin; the closer one looks, the more one sees the grin and the less the cat."[43] Although Mills' opinion has led Adler to simply define "marine sciences" and "oceanography" as "a broad range of practices deployed to gain a better understanding of the aquatic environment",[44] this may not necessarily apply to earth science in the same way. While it would be handy to define both "earth science" and "geology" as "a broad range of practices deployed to gain a better

of the Knowledge Paradigm', 12-13.

[43] E. L. Mills, 'Editorial What Is History of Oceanography', *History of Oceanography*, no. 2 (1990): 2.

[44] Adler, *Neptune's Laboratory: Fantasy, Fear, and Science at Sea*, 15.

understanding of the earth environment," such as simple definition carelessly ignores the fact that earth sciences has been a selective process over geology only lately, and that it largely preserves the original methods and professional characteristics of geology. The key to understanding changes that had happened to geology in early twentieth century is not to clarify what the term really meant, but what geological institutions have worked out in their research agenda.

1.3 Research Institutions in Geosciences

Apart from interpretations of the general epistemological change in earth science in early twentieth century, there are also accounts of the development of specific research institutions, and a reappearing focus is the Geophysical Laboratory of the Carnegie Institution of Washington. John W. Servos traces the beginning of the laboratory, especially how the import of physical and chemical techniques into geosciences had shaped "geophysics" here and also influenced science in America. In this account of the opening years of the laboratory, Servos observes that geophysical experiments in the laboratory appeared relatively late, while the research agenda had once emphasised geochemistry and petrology.[45] On the other hand, the concept of a

---

[45] John W. Servos, 'To Explore the Borderland: The Foundation of the Geophysical Laboratory of the Carnegie Institution of Washington', *Historical*

geophysical laboratory had existed long before the laboratory was established, and it was mathematically-trained scientists such as George F. Becker in the U.S. Geological Survey who had seriously contemplated the demand for a geophysical laboratory as early as the 1890s.[46] Thus, geophysical research had to begin a competition mainly with geochemistry over laboratory resources. The competition is well-presented in detail, and it reflects the budget, personnel, and management in the early years of the Geophysical Laboratory.

Servos is aware that the narrative displays plenty of personal characteristics of leading geologists involved, which may seem implausible. His solution to the narrative problem is to conclude that the early design of the laboratory was stimulated by American geologists' expectations, who were eager to recreate the prototype of experimental methods in geology that have been dated back to the late nineteenth century. These stimuli are, as Servos lists, "the theoretical studies of British physicists", "the laboratories of continental petrographers", and "the international specialty of physical chemistry".[47] He then elucidates these stimuli, but one may suppose that these could have

---

Studies in the Physical Sciences 14, no. 1 (1983): 147–85, https://doi.org/10.2307/27757528, 149-150.

[46] Servos, 'To Explore the Borderland: The Foundation of the Geophysical Laboratory of the Carnegie Institution of Washington', 156-157.

[47] Servos, 'To Explore the Borderland: The Foundation of the Geophysical Laboratory of the Carnegie Institution of Washington', 179.

been interpreted more plausibly if combined with his mentions of American geologists' visits to the British and continental geophysicists or institutions prior to the establishment of the Geophysical Laboratory, such as Charles R. Van Hise's visit to Europe and his correspondence with Lord Kelvin.[48] Moreover, it could be a better way to illustrate how the Geophysical Laboratory changed the discipline of geology and even changed science in America, if Servos managed to put the development of the laboratory in the context of the development of earth studies.

The same episode was revisited by H. S. Yoder Jr. in his book chapter,[49] along with other contributors who each examine a certain period or aspect of the Geophysical Laboratory of the Carnegie Institution of Washington. In the same book, Gregory A. Good then focuses on Louis Agricola Bauer, founder of the Department of International Research in Terrestrial Magnetism of the laboratory, who raised the status of terrestrial magnetism and thus connected the laboratory with international geophysics studies.[50] Good traces the

---

[48] Servos, 'To Explore the Borderland: The Foundation of the Geophysical Laboratory of the Carnegie Institution of Washington', 169.

[49] H. S. Yoder Jr., 'Development and Promotion of the Initial Scientific Program for the Geophysical Laboratory', in *History of Geophysics: Volume 5–The Earth, the Heavens and the Carnegie Institution of Washington*, ed. Gregory A. Good (American Geophysical Union, 1994), 21–28, https://doi-org.libproxy.ucl.ac.uk/10.1029/HG005p0021.

[50] Gregory A. Good, 'Vision of a Global Physics: The Carnegie Institution and the First World Magnetic Survey', in *History of Geophysics: Volume 5–The*

Department's magnetic surveys both on land and at sea. In the limited space within a short chapter, he manages to mention some notable themes that could trigger further reflections over the surveys, such as the interaction between colonial countries and local scientists and governments (as was the case in Africa),[51] the role of key instruments in field explorations (as was the case of the deck house of ship *Carnegie*),[52] and the continuity of geomagnetism surveys and studies (as Good refers to the laboratory's later surveys through 1930s and 1940s and its sponsorship of Sydney Chapman and Julius Bartels' classical work on geomagnetism).[53]

An English counterpart of such work is Carol A. Williams' *Madingley Rise and Early Geophysics at Cambridge* (2010).[54] As its name suggests, the book is a detailed narrative of history of the Department of Geodesy and Geophysics at University of Cambridge, although not strictly "early" since she covers as long as a century from before its establishment to 1980 when it merged into the

---

Earth, the Heavens and the Carnegie Institution of Washington, ed. Gregory A. Good (American Geophysical Union, 1994), https://doi-org.libproxy.ucl.ac.uk/10.1029/HG005p0021, 29.

[51] Good, 'Vision of a Global Physics: The Carnegie Institution and the First World Magnetic Survey', 32.

[52] Good, 'Vision of a Global Physics: The Carnegie Institution and the First World Magnetic Survey', 33-34.

[53] Good, 'Vision of a Global Physics: The Carnegie Institution and the First World Magnetic Survey', 35.

[54] Carol Williams, *Madingley Rise and Early Geophysics at Cambridge* (Antique Collectors' Club, 2010).

Department of Earth Sciences. The time span makes it ideal to learn about the same period which concerns this thesis, while also contrasting with this thesis by focusing on an academic institution. As Williams' book shows, geophysics in Cambridge was born under significant influence of mathematical and physical studies at that time. Hugh Newall, a main supporter of the establishment of geophysical studies in Cambridge, started his career there as demonstrator in experimental physics. Gerald Lenox-Conyngham, first head of School of Geodesy and later Department of Geodesy and Geophysics, started his career at the Survey of India measuring the longitude, latitude, and azimuth for map production. His later measurement of gravity with colleague Sidney Burrard in the high mountains joined the global effort on the subject and allowed him to be part of a network of geophysicists.[55]

It is fair to say that Williams' history of the Department provides mostly a blow-by-blow factual account. Having said so, Williams' book helps us find out what could have been the subject of geophysics in an early 20th century English university: apart from measuring gravity that has been mentioned above, research in the Department of Geodesy and Geophysics explored, to name a few areas of research, seismic waves, geothermal sources, geomagnetic

---

[55] Also see Edward Crisp Bullard, 'Gerald Ponsonby Lenox-Conyngham, 1866-1956', *Biographical Memoirs of Fellows of the Royal Society* 3 (1 January 1997): 129–40, https://doi.org/10.1098/rsbm.1957.0009.

fields and electro-magnetic properties of sediments, and, ultimately, the earth's interior.[56] The history of Cambridge's Department of Geodesy and Geophysics also resonates with themes in recent historiography of science, such as the oceanic turn and studies of transnational and international science. For example, the promotion of a geophysical institution was not only an academic concern, but was also supported by the National Hydrographic Office, and was under a pressure that nearby European nations had established their own counterparts.[57]

1.4 Politics, Organisation, and the Context of Expeditions

To better understand the context where geology was involved with political issues, we should now return to Oreskes and Doel's chapter. Apart from tracing the advance of geophysics or geochemistry as part of a discipline, Oreskes and Doel presents another approach in the second half of the chapter, that is, to relate the disciplinary progress with institutional development. They suggest that the ascendance of geophysics was mainly shaped by the second industrial revolution, perhaps as a result of increasing demand for oil, and was demanded by the "military patrons during the World

---

[56] Williams, *Madingley Rise and Early Geophysics at Cambridge*, 190-193.
[57] Williams, *Madingley Rise and Early Geophysics at Cambridge*, 48-50.

War II and the Cold War".[58] Furthermore, they argue that funding from these military patrons not only aided the production of knowledge in these subjects, but also decisively changed the academic approach to them, including university graduate programmes, technical practices, and job markets in the discipline.[59] As Oreskes and Doel outline:

> Petroleum companies funded research in stratigraphy, sedimentology, and paleontology; mining companies paid for studies in petrology, mineralogy, and crystallography. Industrial funding of both geological and geophysical research remained strong into the mid-twentieth century; what tipped the balance in favor of geophysics was national security. By midcentury, industrial support was overtaken by military funding, and new areas of geophysical research – for example, paleomagnetics – were stimulated above all by their relevance to national security concerns.[60]

Specific cases that are referred to in Oreskes and Doel's chapter. For example, W. Maurice Ewing started his career by investigating seismic refraction under the support of oil industry and established the Lamont Geological Observatory at Columbia University relying on navy funding.[61] Similarly, almost each military technique was linked with one or more subjects

---

[58] Oreskes and Doel, 'The Physics and Chemistry of the Earth', 552.
[59] Oreskes and Doel, 'The Physics and Chemistry of the Earth', 552.
[60] Oreskes and Doel, 'The Physics and Chemistry of the Earth', 553.
[61] Oreskes and Doel, 'The Physics and Chemistry of the Earth', 553.

in earth science: submarines with geophysics and oceanography, land-based missile guidance with solid earth geophysics, airborne weaponry with meteorology.[62]

Doel discusses earth sciences in the Cold War in his chapter, which is very revealing on the general influence of politics on earth science. Although the title shows some confusion about the definition of earth science, it touches some critical cases in the development of post-war earth science.[63] To illustrate how military funding shaped geophysical knowledge, Ewing's Lamont Geological Observatory again serves as an instructive example. As

---

[62] Oreskes and Doel, 'The Physics and Chemistry of the Earth', 554.

[63] Ronald E. Doel, 'Constituting the Postwar Earth Sciences: The Military's Influence on the Environmental Sciences in the USA after 1945', *Social Studies of Science* 33, no. 5 (2003): 635–66. The confusion lies in the division between earth sciences and environmental sciences: the title of the paper suggests that environmental sciences are equal to earth sciences, or at least are a major part of the latter. However, the paper starts with a suggestion that the birth of modern environmental sciences in the U.S. were partly attributed to the development of earth sciences, because earth scientists were interested in the physical environment on the earth. However, for most scientists to be examined or merely mentioned in this thesis, they were interested the phenomena and mechanism regarding the earth itself, and what they investigated must have been far from modern environment sciences, which concerned the relationship between human beings and the earth. As Doel mentions as the other reason for the birth of environment sciences, it was closer to public perception of environmental crises caused by nuclear fallout and excessive pesticide, and was in this sense a biological and ecological problem, instead of an earth science problem.

Doel observes, Ewing had expected that Lamont could have become “a well-rounded oceanographic institution with divisions of biology” by capitalising on “Lamont’s ocean-going capability, its extensive deep-sea core library, and AEC-funded water-sampling programs”, and he had managed to approach Rockefeller Foundation for support. However, with Lamont’s deep involvement with military programmes in the study of the spread of radioactivity from atomic tests, ocean circulation, and short-range ballistic missile tests, marine biologists “found it difficult to integrate into the culture and community of Lamont”, and the effort of Ewing to focus on the ecosystems of the oceans pitifully failed.[64] Another example is the Marine Laboratory at the University of Miami under F. G. Walton Smith’s leadership, which originally kept “a balance between biological, chemical, and physical approaches to tropical marine research”, but turned heavily to the physical oceanography of submarines due to the navy’s financial influence.[65] Moreover, Doel argues that there was indeed differences between the community shaped by military funding and the other. He suggests that universities which were supported by industrial funds, like Stanford University, maintained more of “the geologic tradition”, and were able to claim their geology programme emphasised the “integration of the traditional areal and historical aspects of the solid earth and its biological

---

[64] Doel, ‘Constituting the Postwar Earth Sciences: The Military’s Influence on the Environmental Sciences in the USA after 1945’, 641-643.
[65] Doel, ‘Constituting the Postwar Earth Sciences: The Military’s Influence on the Environmental Sciences in the USA after 1945’, 643-644.

inhabitants", with physical and chemical aspects relatively marginal. Those earth scientists who had long been associated with the military, as Doel declares, even produced "deep suspicions" about ecology and biological oceanography, which was "deemed irrelevant to utilitarian and operational aims".[66]

1.5 Place, Field Work, and the Meaning of Explorations

There is a huge literature on the relationship between places and science published since the 1990s, the so-called 'spatial turn' in the historiography of science. Since then, the still increasing literature attempts to cover more subjects in science, and to illustrate more ways that science is/was influenced by places.

There is no doubt that one of the classics regarding this question is David Livingstone's attempt of "Putting Science in Its Place", where a number of spatial factors that can influence science are listed and given analysed.[67] The starting point, and the factor which is most relevant to geological explorations, is the site where science practices are conducted. As Livingstone describes, a

---

[66] Doel, 'Constituting the Postwar Earth Sciences: The Military's Influence on the Environmental Sciences in the USA after 1945', 652.

[67] David N. Livingstone, *Putting Science in Its Place: Geographies of Scientific Knowledge* (Chicago: University of Chicago press, 2010).

site of science is where “the disposition of equipment and other accoutrements regulates human behaviour in one way or another”.[68] It is where the sites themselves “restrain or promote certain interactions”, students socialise “into their respective scientific communities”, and practitioners realise the “core values, convictions, and conventions of their tradition of inquiry”.[69] When it comes to field operations, the site is significant primarily because it provides the most plausible way to gain credibility for a study, based on an ancient logic that seeing is believing.[70]

Another aspect of field operation is that field is a place where social life becomes different from the normal. Various groups meet together in the field: amateurs and professionals, women and men, commercial and national identity and scientific identity, conductor of a field operation as the knowledgeable in his/her subject and as a learner from the local.[71] Although “learning from the local” sounds like the methodology of cultural anthropology or ethnology, one can also assume that this is equally normal for natural scientists. Not only do they learn particular techniques and experience from

---

68 Livingstone, *Putting Science in Its Place: Geographies of Scientific Knowledge*, 18.
69 Livingstone, *Putting Science in Its Place: Geographies of Scientific Knowledge*, 18-19.
70 Livingstone, *Putting Science in Its Place: Geographies of Scientific Knowledge*, 41.
71 Livingstone, *Putting Science in Its Place: Geographies of Scientific Knowledge*, 42-44, 47.

local people, but they benefit from the field operation itself as well, and the field is surely characteristic to its local context.

Being different from the normal is a key feature of field work, and this exactly supports Vanessa Heggie's argument, that the activity of scientific exploration itself is a science, instead of merely a means to science.[72] Heggie quickly mentions the fact that history of geophysical sciences has been largely dealing with crucial sites in national competitions,[73] which this chapter also illustrates. Apart from this, and apart from noting the fact that there has been relatively less literature on explorations in the twentieth century, Heggie firstly argues that exploration will provide historians of science with a new approach to understand field work.[74] The case here that support the new approach is a 1911 study of metabolism, exercise and nutrition on British "Terra Nova" expedition. Briefly speaking, the experiment was aimed to find the best balance of nutrition to absorb when a human body maintained a certain level of metabolism, and was conducted by controlling the taken-in nutrition of each participant, who was also the conductor of it. Heggie observes that such a significant experiment had long been ignored because historians of science preferred to overlook sources regarding exploration itself, let alone even more

[72] Vanessa Heggie, 'Why Isn't Exploration a Science?', Isis 105, no. 2 (2014): 318–34.

[73] Heggie, 'Why Isn't Exploration a Science?', 320.

[74] Heggie, 'Why Isn't Exploration a Science?', 321.

sources that could outline the logic of such explorations.[75] Furthermore, Heggie argues that the ignorance of field work in general and expeditions and explorations in particular lies in a stereotype that science should be laboratory-based, or a hierarchy of scientific practices and sites where collecting is always on the lowest level.[76]

Heggie's argument leaves her audience to reflect on the relationship between laboratory and field science. Indeed, if one carefully examines the place of science, one will be sure to notice that laboratory and field are two equally important sites for science. As Livingstone describes the differences between the two that, in every discipline including geology, field people believe that the credibility of a study is "to some degree, a matter of locality", while theorists and experimenters prefer to deduce their findings "from the laws of physics and their operation in laboratory-based experiments on force, solids, and fluids".[77] Another early attempt to examine the division between laboratory and field is Robert Kohler's series of publications on the topic. Kohler gives a detailed account of how the division between laboratory and field was blurred by the concept of the earth as a natural laboratory.[78] For biology, which is the

---

[75] Heggie, 'Why Isn't Exploration a Science?', 322-324.

[76] Heggie, 'Why Isn't Exploration a Science?', 321-322, 328-329.

[77] Livingstone, *Putting Science in Its Place: Geographies of Scientific Knowledge*, 41-42.

[78] Robert E. Kohler, *Landscapes and Labscapes: Exploring the Lab-Field Border in Biology* (Chicago & London: University of Chicago Press, 2002).

discipline that is the focus in his book, he coins the term “natural laboratory” to underline a tension over credibility between the two kinds of methodology. Although the conventional logic was seeing as believing and supported field science, the credibility of field biology was once weakened by the dominance of modern laboratories by the beginning of twentieth century.[79] Completely different from that within geosciences, Kohler images field work at a disadvantage compared to laboratory work at the beginning of the interactions in his book. The idea of the natural laboratory helped field biology to survive, instead of highlighting the advantage of laboratories.

Among branches of biosciences, the idea of the natural laboratory is particularly clear in ecology. As Kohler suggests, it was on Bear Island that Charles Elton “first perceived his theory of animal communities”. Bear Island was an ideal “place to see these patterns because very few kinds of animals and plants live there” so that “it was easier to lump species unambiguously into metabolic categories than it would have been in more complex ecosystems”.[80] In ecology, field work shows some degree of irreplaceability, though one may wonder whether there are other disciplines where field work can be irreplaceable.

---

[79] Kohler, *Landscapes and Labscapes: Exploring the Lab-Field Border in Biology*, 192.

[80] Kohler, *Landscapes and Labscapes: Exploring the Lab-Field Border in Biology*, 195.

For historians of geology, the relationship between laboratory and field science is also a branch that requires considerable attention, as the development of geology in the twentieth century was apparently promoted by laboratory techniques such as radioactive dating, while it bears a long tradition of field work. In a similar way to biology, geological field and laboratories are closely connected. Geological samples are picked up from the field and brought to the laboratory to be examined. Different field work in geology may have different aims; for example, a short excursion may be focused on enriching the rock collection, while an international expedition may bring back samples that are more likely to be thoroughly examined with laboratory equipment. On the other hand, equipment may not always stay indoors. They are used as tools to measure and examine the properties of specific points in the field to enhance the understanding of massive geological structures. In some cases, laboratory tools are not used to conduct experiments at all, but for determining mapping data, which is again essentially field-based.

In recent years, historians of science have also focused on explorations in other aspects. Michael S. Reidy, Gary Kroll and Erik M. Conway have written a significant book over the subject.[81] It provides a general view of history of human explorations, although based particularly on history of Western

---

[81] Michael S. Reidy, Gary R. Kroll, and Erik M. Conway, *Exploration and Science: Social Impact and Interaction* (Santa Barbara: ABC-CLIO, 2007).

science. Authors of the book show that, over the last five hundred years, explorations in the Western context have long been intertwined with the development of capitalism, representative governments, and, of course, colonisation, and that explorations were motivated by cultural and social forces, as well as the demand for personal and national identity.[82] The book's own arguments on explorations are not particularly revealing, but it is informative and useful, if one need some basic facts and contexts in history of explorations.

James R. Ryan and Simon Naylor confirm that the first years of the twentieth century were a watershed for explorations, and refer to commentators' testimony that those years "marked the end of an unalloyed era of discovery": an age of explorer heroes pursuing knowledge and filling blanks on the map.[83] However, Ryan and Naylor notice that the lament for the end of conventional explorations reflects an unfair exclusion of professionalised and institutionalised science as a justified aim of explorations, and they argue that both scientific explorations and heroic explorations span the Victorian era into the twentieth century. One of their supportive cases is Nicola J. Thomas and

---

[82] Reidy, Kroll, and Conway, *Exploration and Science: Social Impact and Interaction*, xi.

[83] James R. Ryan and Simon Naylor, 'Exploration and the Twentieth Century', in *New Spaces of Exploration: Geographies of Discovery in the Twentieth Century*, ed. Simon Naylor and James R Ryan (London & New York: I. B. Tauris, 2010), 9-10.

Jude Hill's research on the Royal Geological Society, which shows that the cultures and practices of exploration changed little in the early twentieth century.[84] On the other hand, Ryan and Naylor argue that what distinguished the twentieth century from previous times was a wider range of explorations, such as research projects in hydrology, oceanography, and space science. Unfortunately, Ryan and Naylor's interpretation jumps from the establishment of the International Council for the Exploration of the Sea in 1902 to U.S. Navy sponsored projects driven by the Cold War, and leaves the long inter-war years only to a single line that says that the period "saw developments" in earth science.[85] The book that they edited also show the tendency to ignore this time period.

In this chapter, we have reviewed various ways to tell the differences between studies about the earth and to define geophysics, especially as an emerging subject in the twentieth century. Inheriting a different tradition from field geology, geophysics took on a physical perspective and aimed to describe geological objects and phenomena with mathematical methods. Nevertheless, most existing literature on the twentieth century geophysics prefers to analyse it as an updated version of geology, equipped with new laboratories, instruments, and objects – even the word "geophysics" is not widely used in the literature. Indeed, developments in physics and chemistry in the twentieth

---

[84] Ryan and Naylor, 'Exploration and the Twentieth Century', 11.

[85] Ryan and Naylor, 'Exploration and the Twentieth Century', 15.

century largely enabled new ways to explore the earth, such as through seismological waves, radioactive decays and, in this thesis, gravitational and magnetic measurements. Like existing literature, this thesis is a story of geology with a step towards geophysics as well. On the other hand, though, this thesis shows awareness that geophysics had its own tradition long before it was regarded an addition to geology in the twentieth century. Thus, the changes that happened to geology in the twentieth century, essentially, did not lie in the location (such as from land surface to deep sea) or organisation (such as from individuals in the field to laboratories), but was about geologists' rediscovery of geophysics by the means of new instruments.

As a result of the change which is summarised above and will be illustrated in this thesis, the scale expansion of geology becomes explainable. On the other hand, with the equipment of geophysics, geology was now able to get involved in more subjects that could have been regarded as its subdisciplines but remained their respective independent names: oceanography, hydrology, and even part of urban planning and construction. Arthur Holmes' textbook *Principles of Physical Geology* in the 1940s might be a good example to show how research on phenomena such as rivers, volcanoes, soils, and others could all be placed under the term "physical geology." On the other hand, the expansion meant that geology became more useful in domestic contexts. First of all, geologists' good understanding of multiple geological factors would solve specialised problems in industry and governance. Moreover, the ability to solve problems allowed geologists to play a role not only in producing maps for reference but in consulting and even conducting their own projects as well.

At this stage, geophysics enlarged the scale of geology in a similar way to the case of meteorology which is discussed by Fiona Williamson and Vladimir Janković. They explore the role of meteorology in nation-building, noting how it became a tool for state power and governance, with a focus on Asian countries. As it collected climate data and aimed to provide people with accurate weather forecasts, meteorology helped states manage agricultural production, plan infrastructure construction and mitigate the effects of natural disasters. Thus, it became crucial for economic stability and growth.

Williamson and Janković continue to argue that the development of meteorological networks allowed nations to control their territories, ensuring better resource management and national security, and that, in this way, the development of meteorology was not only a scientific and technological process, but also political. It became a way that a nation could control its land and people, in the sense of “controlling” the weather. This control had been important for both the colonisers and later independent new nations in Asian.[86]

---

[86] Fiona Williamson and Janković, ‘A Question of Scale: Making Meteorological Knowledge and Nation in Imperial Asia’, *History of Meteorology* 9 (2020): 1–9.

The British Geological Survey's introduction of geophysics was no less important in an economic sense, and, in this sense, it also represented state motivations either to compete and win or to defend and develop territory. As this thesis mainly discuss domestic issues within the British Isles, there may be less sense of national security, compared to Williamson and Jankovic's, but readers will find the resonating theme of energy and mining equally crucial to the country, especially when put in context.

As I discuss the introduction of geophysical methods at the British Geological Survey, this thesis expects to find out what was at stake during their introduction: what was regarded as "new" and what this meant to the historical actors in this thesis – the answer varied for different actors. First of all, every party involved – Survey geologists, government staff, and third-party collaborators – all agreed that there were new instruments, and these instruments embodied the geophysics that would be introduced to mapping. Besides, we will see that geologists were ready to take on a new role as time went by: they were ready to generate knowledge instead of merely collecting data with their new instruments and expertise. On the other hand, their administrative colleagues might have felt reservations that the novelty in the Survey's role were not real, or at least not necessary. We will now see in the following stories how different groups justified their arguments, and how, despite once being intermittent, geophysics became part of the Geological Survey's activities.

1.6 Method and Roadmap

To answer the question I posed at the beginning, and that the literature review above has paved the way but not yet cleared, this thesis investigates the work of the Geological Survey chronologically during the 1920s to the 1950s. The Geological Survey acted as the official surveying institution in Great Britain and is now a leading research institution in the United Kingdom. It provides a good case study to investigate how the meaning of “geology” changed over time, and how the change influenced the institution’s work.

At the beginning of the research project, the plan was to look into documents and correspondence of important geologists who were relevant to the change. By reading these papers, it was planned, this thesis would explore what geologists thought about and did with respect to the change, how they viewed their own discipline, and how they reacted to the innovations in technique and ideas. The early version of the research proposal also included a network of several key surveyors and geologists, which would clearly show how the universities, industry, and the Survey itself, were connected through the decades. The personal papers in question were located in some university and institution archives, including Cambridge, Durham, and the British Geological Survey Archives.

This plan was severely interrupted by the COVID-19 pandemic, during which almost every archive closed as a result of lockdown. For about half of the project, only online archives were accessible, which were apparently inadequate for the research. Some archives reopened only at a very late point of the research period, while others did so even later when the writing-up period almost ended as well.

The National Archives, which was among the first to offer restricted opening and access as lockdowns weakened, became the main and only relatively stable source of archives during this unusual time, and the research plan had to adapt itself to avoid inaccessible primary sources and to complete on time. As a result, most archives used in this thesis came from, and had to come from, the National Archives. Fortunately, the Geological Survey Board, as the administrative body in the government dedicated to review the Survey's work, had a lot to investigate. Unfortunately, due to the monotony of sources, it is impossible to always have a full timeline of a case study – sometimes even the critical pieces of the puzzle can be missing. Even case studies were selected to make the project work during lockdowns; otherwise chapters in this thesis would have a different focus.

This is Chapter 1 of this thesis, which clarifies the research questions, literature, and structure.

Chapter 2 continues to provide a better understanding of the context of the Geological Survey. Firstly, it will tell more about the Geological Survey Board and its governmental department, the Department of Scientific and Industrial Research, to justify the choice of primary sources and to set a keynote for the interaction between the Survey and its board. Secondly, it will take the centennial celebration and report in 1935, to provide a general picture of the role of the Geological Survey in the early twentieth century, or at least the role it was expected to have.

Chapter 3 is focused on the acquisition and application of a Eötvös gravity torsion balance, as the Geological Survey's very early, if not the first, attempt to apply geophysical techniques in its work. It analyses the motivation behind the application and the result of application.

Chapter 4 is a brief review of the Geological Survey's work during the Second World War. It was an interruption for the geophysical agenda that the Survey might have wanted to pursue further, and the chapter contains no concrete examples to show that the Survey had pushed any initiative in geophysics at that time. Having said so, the Geological Survey inevitably got involved with some unfamiliar subdisciplines of earth sciences in its contribution to war effort. Furthermore, the connection with atomic projects demonstrates an important deepening of the linkages between geology and physics.

Chapter 5 follows with the Geological Survey's plan for its post-war organisation. Firstly, Bailey, who was Director by the end of the war, was keen to recruit students from any relevant subject into the Survey so that it would have enough staff to continue and complete it mapping programme. Secondly, a study on the drilling programme suggests that, although there had been chances for geophysical research, the Survey's ability to conduct it was still immature.

Chapter 6 is focused on the Geological Survey's airborne magnetic survey, which was arguably the first successful geophysical project of the Geological Survey. It draws attention to the fact that the proposal of the project showed an unanimity between the government and the Survey about the Survey's job, and the change of the Survey's role in data processing during the project.

Chapter 7, as an epilogue, reviews the Geological Survey's effort to expand its expertise in physics and how this might be interpreted to understand the place of the Survey in the global development of earth sciences at that time.

The final chapter is a general conclusion of this thesis about the change in geophysical methods itself and its implications for the Geological Survey.

Chapter 2: Geological Survey and the Department of Scientific and Industrial Research

As is indicated in the introductory chapter, we shall now focus on the application of geophysics in the Geological Survey of Great Britain.[87] This chapter will introduce the nature and history of the Survey, with comments on

---

[87] The Geological Survey has had several official names in its history. In 1845, the Geological Survey separated from the Ordnance Survey when the Geological Survey Act came into effect and provided the Survey an independent organisational framework. At that time, the Survey was referred to as the "Geological Survey of Great Britain and Ireland," or the "Geological Survey of the United Kingdom". In 1905, the Geological Survey of Ireland was handed over to the Department of Agriculture and Technical Instruction for Ireland, and the Survey was renamed "Geological Survey of Great Britain", which is the name that was used in the whole time period that this dissertation covers. In 1984, nevertheless, the Survey was renamed "British Geological Survey", with acronym BGS, and this remains its name nowadays. Such a history can be summarised from all the histories that would be referred to in this chapter, although a short version can be found on BGS' website at https://www.bgs.ac.uk/about-bgs/our-work/our-history/#1905, or even shorter at https://earthwise.bgs.ac.uk/images/b/bc/OriginsofBGS.jpg.
Simply speaking, the "Geological Survey of Great Britain" is a historical name which appears in most of the primary sources in this dissertation, and "British Geological Survey" is its recognised name at the time when this dissertation was written, and in many academic references. As a result, these two names are interchangeable by meaning in this dissertation, and it is possible that the Survey is referred by different names in a single context, especially when original texts from various sources are quoted.

several histories of it, and then focus on the context within which the changes that this dissertation explores happened. It will then relate the context to the governmental administrative system that existed at that time by introducing the Department of Scientific and Industrial Research. Such an introduction will also explain why the DSIR papers are largely used in this dissertation, and why the use is reasonable and important. Finally, this chapter will take the centennial of the Geological Survey of Great Britain in 1935 as an example to provide a glimpse of the mission of the Survey in the early twentieth century, or at least what the Survey thought its mission was, and, of course, what the centennial at such a time tells us about the agenda of the Survey.

2.1 Geological Survey of Great Britain: its Nature and History

The year 1835 marks the official beginning year of the Geological Survey, when Henry Thomas de la Beche undertook a geological survey of the Devon area under the Ordnance Survey and became the first Director of the Ordnance Geological Survey under the Board of Ordnance. The Survey set up a Mining Record Office in 1839, which reflected its main work at that time: collecting and storing mining data. To be specific, such data included mining plans, mapping of the distribution of mines, and mineral production statistics. In 1845, the Geological Survey Act gave the Geological Survey a legal framework so that it became independent from the Ordnance Survey and organised as the Geological Survey of Great Britain and Ireland.

As its early history suggests, the Geological Survey was set up around mining activities and was aimed to provide necessary and useful geological information to support such activities. The large scale of the task to produce a national geological survey required it to be funded by the government, but the Survey was organised regionally. By the early twentieth century, Great Britain was divided into three regions to help deploy personnel and resources of the Geological Survey for its work: Scotland based in Edinburgh, north England based in Leeds, and south England and Wales based in London along with its headquarters. District Geologists were the main actors of field work in these regions. Collecting data for mapping was endless work. Throughout the decades to be covered in this dissertation, geologists of the Geological Survey kept working on a series of 6-inch geological maps, especially those of some areas in Scotland.

While it carried the label "geological," the Geological Survey actually presented geoscientific work in a multidisciplinary way. With its origin in mining and geology, the Geological Survey also had special branches in subjects such as palaeontology and geophysics, and more and more elements such as forestry and underground water were added into their range of investigations. Later chapters will show in better detail that the Geological

Survey was not only a data provider for economic development, as they claimed to be, but also a moderate pioneer in geosciences research. Research is put at even higher priority at the Survey's agenda today.

At the start of Peter Allen's book on the history of the British Geological Survey, he refers to the existing accounts as follows:

> There are five histories of the British Geological Survey (BGS) currently available. The first was written by Sir John Flett, The first hundred years of the Geological Survey of Great Britain. It was a memorial volume to celebrate the centenary of the Survey and contained a full and systematic account of its growth and development. In 1952, Sir Edward Battersby Bailey published The Geological Survey of Great Britain. In the preface he says that he wrote it originally for the British Council, to appear in their series Science in Britain, but the series was discontinued so he published it as a book rather than waste the effort he had put into it. He also covers the period since the Survey was founded in 1835, but he put more emphasis on scientific progress than did Flett. Harry Wilson wrote another full account, Down to Earth, bringing the history up to the sesquicentennial year, 1985. Two other accounts have been published as BGS technical reports only covering recent history. Peter Cook, on his retirement at the end of 1997, published his review if the period he was Director, A history of the British Geological Survey 1990-1997. Finally, in

> 1999, Dennis Hackett, who had been the BGS Secretary since the mid-1980s, compiled Our corporate history: Key events affecting the British Geological Survey, 1967-1998, which contained brief summaries of major events since the formation of the research councils in 1965, including a detailed commentary on the development of the Survey at its site at Keyworth.[88]

Thus, including Allen's own book, there are six books on the general history of the British Geological Survey. Allen's book is focused on the contemporary BGS and squeezes the first one hundred and fifty years of the Survey into a brief introductory chapter, so, like the Cook report and Hackett history that he mentions, it is not very helpful for this dissertation. Thus, this dissertation mainly refers to Flett's, Bailey's and Wilson's works to provide necessary background information about the Geological Survey in history.[89]

While Flett's and Bailey's books provide detailed and useful chronological accounts of the history of the Geological Survey, Wilson's account makes it easier to find the theme that we are looking for: introducing geophysical techniques into the Survey's work. In his book, Wilson contributed a full

---

[88] Peter Allen, *A Geological Survey in Transition*, vol. 1, British Geological Survey Occasional Publication (Keyworth: British Geological Survey, 2003), vii.

[89] Strangely, among these three books, the more years it covers, the smaller the book is.

chapter talking about the Survey's early attempts to use geophysical techniques, although the chapter is brief. As far as Wilson is concerned, the early explorations on geophysics at the Geological Survey was about gravity. In 1774 and long before the formal establishment of the Survey, Nevil Maskelyne had put geophysics (before, of course, the term existed in its modern sense) into geological field work by measuring the deviation of gravity on the mountains in north Perthshire and successfully calculating the density of the earth there. Wilson claims it to be “perhaps the earliest geophysical calculation,”[90] and, although geophysicists had questioned Maskelyne’s calculation mathematically, the Geological Survey rediscovered its significance in early twentieth century. The next attempt was a collaboration between the Survey and the Iron Ore Committee of the Conjoint Scientific Societies in 1917, and the first serious attempt to apply gravity methods in mining took place in the mid-1920s when the Geological Survey sent W. F. P. (William Francis Porter) McLintock and J. (James) Phemister to the Anglo-Persian Oil Company to the witness and test of the Eötvös torsion balance. The Survey then purchased one such torsion balance, and Wilson firmly states that it was “the first geophysical equipment acquired by the Survey.”[91]

---

[90] H. E. Wilson, *Down to Earth: One Hundred and Fifty Years of the British Geological Survey* (Edinburgh & London: Scottish Academic Press, 1985), 152.

[91] Wilson, *Down to Earth: One Hundred and Fifty Years of the British Geological Survey*, 153.

On the other hand, Wilson also notes the difficult side of such geophysical explorations. He noticed that then Assistant Curator of the Museum of Practical Geology, A. F. (Arthur Francis) Hallimond, had conducted a series of experiments with a portable magnetometer during inter-war years, but these experiments did not produce cheerful results and were soon suspended, for the magnetometer was lent to Imperial College for teaching.[92] Another example he mentions was called A. E. (Arthur Ernest) Mourant, who was one of the few geologists who supported Hallimond's experiments, while such experiments were "presumably deemed too esoteric for field geologists."[93] Thus, we infer that in the early decades of the twentieth century, there was still a long way to go for geophysics at the Geological Survey, and we will see how this way finally led to a successful project.

2.2 Department of Scientific and Industrial Research: its Origin, Framework, and Function

The Department of Scientific and Industrial Research existed from 1915 to 1965. It was created under a white paper presented in May 1915 by Arthur Henderson, the then President of the Board of Education, and under the

---

[92] Wilson, *Down to Earth: One Hundred and Fifty Years of the British Geological Survey*, 155.

[93] Wilson, *Down to Earth: One Hundred and Fifty Years of the British Geological Survey*, 155.

pressure to get rid of the dependence of science and industry on German materials and products, since the country had been in war with Germany for months by then (such an origin of the DSIR is a repeated theme in academic papers, and we shall return to it later in this chapter). The legal Order-in-Council to establish the DSIR came into effect in July.

At the beginning, a Committee of the Privy Council acted as the ministerial overseer of the Department.[94] The committed consisted of six members: the Lord President of the Council (who also acted as the President of the committee), the Chancellor of the Exchequer, the Secretary for Scotland, the President of the Board of Trade, the President of the Board of Education, and the Chief Secretary for Ireland, as well as three other Privy Councillors. There was then an Advisory Council to provide expertise for the committee, and it consisted of highly recognised scientists and Fellows of the Royal Society.

The administrative body of the DSIR was added in 1916, when Sir Frank Heath was appointed as the first Permanent Secretary of the Department. During Heath's administration, the Department was responsible to Parliament through the Lord President of the Privy Council, and Heath himself was in

---

[94] A plain introduction of the original structure of the DSIR and its development can be found in Harry Melville, *The Department of Scientific and Industrial Research* (London: George Allen & Unwin Ltd., 1962).

charge of the implementation of policies “formulated by the Advisory Council, and approved by the Committee of the Privy Council”.[95]

Perhaps due to the secrecy that surrounded official papers, the first published accounts of the DSIR did not appear until the 1960s, fifty years after the Department’s establishment. One of these introductions was Harry Work Melville’s, published in 1962 and which aimed to highlight the way this department contributed to the advancement of science through its organisation. As the last Permanent Secretary of the Department, Melville had not yet witnessed the abolishment of the Department by the time his book was published. Such an ignorance of the end of the DSIR story might have induced less critical attitudes on the Department’s history, but it on the other hand manages to keep the whole book in a positive and proud tune, which possibly has made Melville happily include almost everything he knew about the DSIR’s work and makes this book one of the few sources to provide a helpful explanation of the relationship between the Geological Survey and the DSIR.

---

[95] Melville, *The Department of Scientific and Industrial Research*, 27. Melville adds that Heath’ name “will undoubtedly stand out” if there were “a detailed history of the development of DSIR,” and the same is said about William McCormick (ibid, 27-28). Unfortunately, such a history seems not existing yet up till now and the constructive work that Heath had done in the department can only be inferred from historical research on other topics, including this dissertation.

As Melville wrote, by the time the Geological Survey and its Museum of Practical Geology became a branch of the DSIR, the Survey was organised "on a regional basis" with a headquarter in charge of the museum and special branches for all regions, including geophysics.[96] A Director oversaw the whole survey, and the DSIR appointed an advisory Geological Survey Board to provide support, smoothing communications with relevant governmental departments. Among all the activities conducted by the Survey as branch of DSIR, Melville highlights some including:

> To assist its work the Survey has the advantage of powers by legislation, for its officers to enter private land for survey purposed. Even more valuable are provisions under the Mining Industry Act, 1926, the Petroleum (Production) Acts, 1918 and 1934, and the Water Acts, 1945 and 1946, which include obligations upon any persons sinking boreholes or shafts beyond certain shallow depths to report their activities to the Survey (or to DSIR, which for this purpose acts through the Survey) and to provide information about the results and permit inspection of workings and samples from them. Operations of this kind have become increasingly frequent, and in 1960 investigation

[96] Melville, *The Department of Scientific and Industrial Research*, 111.

> of their progress and results occupied almost one-tenth of the whole effort of the Survey staff.[97]

The quotation above describes the relationship between a DSIR board and the organisation it oversaw, and thus it explains why reading the Geological Survey Board papers sheds light on the Geological Survey's work, especially when the full archive of the British Geological Survey has not been available (due to Covid-19 lockdowns, as is mentioned in Chapter 1) during the time when this dissertation was being researched and written. The quotation also explains the close connection to the government that the Geological Survey enjoyed in the early twentieth century. On the other side, though, Geological Survey itself might have felt slightly differently. For example, Flett remembers that the Geological Survey Board was appointed to supervise its important research activities, or, in more detailed words:

> (a) To undertake, within the limits prescribed in the estimates for the year and by the general policy and the programme of work approved from time to time by the Minister, the management of the Survey and Museum so far as concerns all current business, work of survey or report and distribution of personnel.

---

97 Melville, *The Department of Scientific and Industrial Research*, 112.

(b) After consultation with the Director to frame and recommend annually for the approval of the Minister, a programme of work to be undertaken for the coming year and to submit therewith a statement as to the staff arrangements and other provision required for carrying out that programme.

(c) To report upon matters bearing on the functions or work of the Geological Survey or Museum; and

(d) To submit an annual report of the work of the Survey and Museum with such observations as they think fit.[98]

Obviously, as Flett saw it, the Board was involved in the Survey's activities much more often and in detail than Melville thought. Nevertheless, the Board and the Survey enjoyed a good relationship, as Flett remembered, during the chairmanship of the first chairman of the Geological Survey Board, Francis Ogilvie, the Board met "several times a year and considers the programmes and reports on the progress of work submitted by the Director," and, as it promised, kept strong connections with representatives in the Department of Health, Mines, Development Commission and Ministry of Agriculture.[99]

---

[98] John S. (John Smith) Flett, *The First Hundred Years of the Geological Survey of Great Britain, 1835-1935* (London: H. M. Stationery Office, 1937), 173-174.

[99] Flett, *The First Hundred Years of the Geological Survey of Great Britain,*

Unfortunately, available literature cannot provide any more details than above on the general pattern of the communication between the Geological Survey and its supervising board, or between the DSIR. However, case studies on other comparable institutions that used to be branches of the DSIR provide an impression of the way such a supervising system worked. For example, Russell Moseley has a detailed account of how the National Physical Laboratory enjoyed the support of the DSIR during inter-war period.

Moseley claims that the NPL had been in a tension between the Royal Society and the Treasury since its very first day of existence. The Royal Society had always appealed for a larger financial support for the laboratory, while the Treasury insisted that the laboratory should start to support itself as soon as possible. With such a tension, it seemed that the future of the NPL would have been uncertain as the breakout of the First World War took away much of its funding. Hence, Moseley argues that the NPL was somehow saved by the new DSIR, in that:

> The immediate problem of future finance seemed to have been settled, while a significant victory over the salaries of NPL staff augured well for the future. Moreover, the impression that the Royal Society's powers remained intact was strengthened by the DSIR's agreeing to the creation

---

1835-1935, 174.

> of 111 new posts to replace temporary appointments made during the war.[100]

On the other hand, Moseley observes that the future of the NPL under the administration of the DSIR seemed not totally bright. Richard Glazebrook, then Director of the NPL, had been worried about the item “the arrangements for finance will be those of a Government Department” in the agreement since the very beginning of the intervention of the DSIR, and his worries came true only after a few years of negotiations. Soon after the war, the NPL proposed two peace-time projects, one concerning the establishment of testing centres around the country, and the other concerning “the creation of a centre for testing electrical equipment and installations.”[101] The DSIR rejected both proposals, claiming that a government institution should keep a distance from such “commercial” work.[102] What Moseley is trying to say about the rejections, is that the DSIR had actually seized full control over the NPL,

---

[100] Russell Moseley, ‘Government Science and the Royal Society: The Control of the National Physical Laboratory in the Inter-War Years’, *Notes and Records of the Royal Society of London* 35, no. 2 (1980): 169.

[101] Moseley, ‘Government Science and the Royal Society: The Control of the National Physical Laboratory in the Inter-War Years’, 169.

[102] Moseley, ‘Government Science and the Royal Society: The Control of the National Physical Laboratory in the Inter-War Years’, 169.

despite their agreement which said that the scientific control remained with the Royal Society through the Executive Committee.[103]

The NPL lost more control to the DSIR not long into the 1920s. Moseley argues that the reasons for the loss was "the worsening economic climate of the 1920s" and "the new Director's initial submission to DSIR pressures."[104] The Treasury had also played an important role in the change of balance between the NPL and the DSIR, since it continued to insist that the NPL should be self-supporting and exerted pressure on the DSIR. Thus, with limited choices, the DSIR continued their attempt "to bring science to bear upon industry" and to concentrate on "results which could be obtained today rather than tomorrow."[105]

Moseley's work is not the only one which indicates concerns that the DSIR was intervening in science in such a way as to decrease scientists' autonomy, and, for example, Eric Hutchinson expresses such concerns by drawing attention to attitudes that placed "scientists as an inferior class."[106]

---

[103] Moseley, 'Government Science and the Royal Society: The Control of the National Physical Laboratory in the Inter-War Years', 169.
[104] Moseley, 'Government Science and the Royal Society: The Control of the National Physical Laboratory in the Inter-War Years', 173.
[105] Moseley, 'Government Science and the Royal Society: The Control of the National Physical Laboratory in the Inter-War Years', 173.
[106] Eric Hutchinson, 'Scientists as an Inferior Class: The Early Years of the DSIR', *Minerva* 8, no. 3 (1970): 396–411.

Hutchinson argues that the "discrepancies in responsibility and prestige which still distinguish the administrator from the scientist in the British civil service" date back to the early years of the DSIR, "the earliest association of the government with the administration of science and scientists," and he demonstrates the inferiority by comparing the "economic rewards" received respectively by administrative staff and scientific staff in the Department.[107] The founding senior staff of the Department, including H. Frank Heath, the Secretary, and Ll. S. Lloyd, the Assistant Secretary who respectively earned an annual salary of £1,500 and another on the scale £850-1,000, had little experience or training in science.[108] On the other hand, Hutchinson notes, the research staff in scientific institutions under the DSIR received merely scarce salaries. For example, Glazebrook once warned Heath that two of his best staff at the National Physical Laboratory received merely £200 and £450 each, which had pushed them to find jobs elsewhere.[109] At the Fuel Research Station, only the Chief Engineer would receive a salary as high as the scale £850-1,000, with others received less.[110] With 10 individual cases,

---

[107] Hutchinson, 'Scientists as an Inferior Class: The Early Years of the DSIR', 396.

[108] Hutchinson, 'Scientists as an Inferior Class: The Early Years of the DSIR', 397.

[109] Hutchinson, 'Scientists as an Inferior Class: The Early Years of the DSIR', 401.

[110] Hutchinson, 'Scientists as an Inferior Class: The Early Years of the DSIR', 403-404.

Hutchinson shows in a concluding chart that, with the same entrance age, junior staff in the scientific branch of the DSIR earned about only one third of those in the administrative branch, and senior staff earned about two thirds.[111] Since Henry Tizard, the Secretary after Heath, Secretaries of the DSIR had plenty of research experience, but the economic inferiority of scientific staff in the Department remained unchanged.

What Moseley and Hutchinson criticise in their works respectively might have happened to the Geological Survey as well. The attitude of the Geological Survey Board, as the administrative body of the DSIR, could have influenced the research agenda of the Geological Survey. For example, Flett and Bailey worked with two different board chairmen, and they both suggested that the chairmen’s attitude towards geophysical investigations might have influenced the progress: Flett confirmed that Ogilvie was supportive of geophysical explorations, and, indeed, during his chairmanship the Geological Survey was able to make progress on the subject; Bailey, on the other hand, suspects that then chairman of the Geological Survey Board T. Franklin Sibly was nor very favourable to the geophysical experiments, and such experiments were once suspended during his chairmanship.[112]

---

[111] Hutchinson, ‘Scientists as an Inferior Class: The Early Years of the DSIR’, 408-411.

[112] See Flett, *The First Hundred Years of the Geological Survey of Great Britain, 1835-1935*, 188-189; and Edward Bailey, Geological Survey of Great

As another result of a lack of accessible government papers in most years of the past century, there is an imbalance that most academic papers on this department are focused on its establishment instead of any later stages. References above have indicated such an imbalance and, even nowadays when half a century has passed since the very last day of the Department, the imbalance remains obvious. Of course, research on the origin of the DSIR is no less valuable. As it has been commonly recognised, the origin of the DSIR was the result of the First World War, which reminded the British how much they had relied on German imports and how much their science had stayed separate from industry. Readers can understand this situation better with the help of recent academic papers. For example, Ian Varcoe illustrates the problem in detail:

> Industrial research in Britain, however, was just beginning to emerge. It had only recently begun to impinge on the still persisting tradition of amateurism in British science. In Germany in 1902, 4,000 chemists were employed in industry, 84 per cent. of whom had been trained in a university of a polytechnic; British industry in the same year employed 1,500 chemists, 34 per cent. of whom were similarly qualified. The position in British industry had hardly changed by 1914; furthermore, a large proportion of those chemists who did work in industry were ill-paid

---

Britain (Thomas Murby & Co., 1952), 206.

and were not used on ways which drew upon their scientific knowledge. The number of applied scientists in Great Britain was far smaller than in Germany.[113]

In response to such challenge, as Varcoe continues, there had been efforts to apply science, both its outcomes and its manpower, to industry. Such efforts on the government side could be very focused, such as the Board of Agriculture and Fisheries' assistance in "investigations into crop, animal husbandry and the control of pests," the Local Government Board' inquiries into health, and the Colonial Office's concern "with research in the schools of tropical medicine," and on the industry side a committee under the Board of Trade to analyse the use and the shortage of dyestuffs, which later led to the government "establishing a large dye manufacturing company," where the government allocated grants to "ensure the employment of large numbers of chemists, the provision of well-equipped laboratories and the inclusion of technical experts in the directorate."[114]

Varcoe also gives examples of what scientists could do to mitigate their disadvantages. Some of these efforts had existed prior to the establishment of the DSIR. For example, Varcoe regards Norman Lockyer's British Science

---

[113] Ian Varcoe, 'Scientists, Government and Organised Research in Great Britain 1914–16: The Early History of the DSIR', *Minerva* 8, no. 1 (1970): 193.
[114] Varcoe, 'Scientists, Government and Organised Research in Great Britain 1914–16: The Early History of the DSIR', 196-197.

Guild as one “of the most influential of the organisations” to “draw attention to the importance of science, and to undertake the task of ‘applying scientific methods to public affairs’.”[115] Also important were the Institute of Industry and Science which was founded in 1915 and “proposed a ministry of industry to develop essential industries and to deal with the related problems of research and education,” and the Royal Society’s passionate but limited ability of “directly affecting the government or industry, restricted its committees to questions of a purely scientific nature.”[116] However, dissatisfaction with this inability in turn led to some scientists to work together with the government. Such scientists, notably chemists, who represented the most affected industry at war, discussed approaches to a valid policy, and then were consulted as an advisory team by the Board of Trade and the Board of Education respectively on behalf of the government. It was in 1915, and the consultation was one of the many efforts that shaped the DSIR.

While Varcoe tells his readers much about the roles which industry and science played in the origin of the DSIR, Roy M. MacLeod and E. Kay Andrews focus on the government, especially the prehistory of the white paper that led to the origin of the DSIR. By referring to Melville’s “biographical

---

[115] Varcoe, ‘Scientists, Government and Organised Research in Great Britain 1914–16: The Early History of the DSIR’, 199.

[116] Varcoe, ‘Scientists, Government and Organised Research in Great Britain 1914–16: The Early History of the DSIR’, 199-200.

and autobiographical" book and the conventional factual history of the DSIR in the book, they try to supplement such an account by revealing "important links in the chain of events preceding the birth of the Advisory Council."[117]

MacLeod and Andrews' account explains why William McCormick and Heath are so important in the Melville's history of the DSIR. Before the establishment of the new department, McCormick and Heath had respectively provided advisory studies to the Treasury and to the Board of Education. At the beginning, as MacLeod and Andrews note, the former was "chiefly concerned with the development of the arts and the pure sciences" as they were in 1906, but the latter in 1909 added "higher education in technology and medicine" as well.[118]

The establishment of the DSIR also allows historians of science a better understanding of the difference between fundamental science and applied science. For example, Sabine Clarke notes that the DSIR defined a category of research with particular interest, which was "sufficiently fundamental to affect a range of interests wider than a single trade," and has a "direct bearing

---

117 Roy M. MacLeod and E. Kay Andrews, 'The Origins of the D.S.I.R.: Reflections on Ideas and Men, 1915-1916', *Public Administration*, no. 1 (1970): 24.

118 MacLeod and Andrews, 'The Origins of the D.S.I.R.: Reflections on Ideas and Men, 1915-1916', 25.

on the health, well-being, or the safety or the whole population."[119] In this sense, the Geological Survey and Museum, like the National Physical Laboratory, can be understood as a national institution that conducted 'fundamental research': both the Geological Survey's knowledge and data of rocks and the NPL's research areas such as food preservation, building material research, and fuel prospecting were "sufficiently fundamental". In other words, the DSIR defined 'fundamental science' based on their interest that such research could be necessary to both domestic and industrial life, and this in turn shaped the institutions under its authority.

2.3 The Geological Survey Centennial

Next, to better illustrate the relation between the Geological Survey and the DSIR, this chapter will discuss how the Geological Survey prepared its centennial celebrations. The illustration is written largely based on the Geological Survey Board archival papers, and will show readers how these papers can shed light on the function of the DSIR in the Geological Survey's history, especially during the 1920s-1950s, is the period of the introduction of geophysical techniques. We will see how decisions were made between the

[119] Sabine Clarke, 'Pure Science with a Practical Aim: The Meanings of Fundamental Research in Britain, circa 1916–1950', *Isis* 101, no. 2 (2010): 289-301.

Survey and its administrative bodies and how other departments of the government got involved. From the perspective of the Survey itself, we can also see through this case what its organisation was like and what professional network it had. We will also become familiar with some names that will appear in the geological cases which form the focus of the subsequent chapters.

1935 marked the centennial of the Geological Survey of Great Britain, and the celebration included a reception held in the Royal Geographical Society Hall on 3 July that year. At the reception, three of those sitting on the platform were Frank Heath, then Secretary of the Department of Scientific and Industrial Research, T. F. Sibly, then Chairman of the Geological Survey Board, and John S. Flett, then Director of the Geological Survey and Museum. These names undoubtedly reveal that the Geological Survey and Museum was a branch of the DSIR, and such a relation was enhanced by the work of the Geological Survey Board. We can find an outline of the centennial celebrations in the concluding chapter of Flett's book on the first hundred years of the Geological Survey.

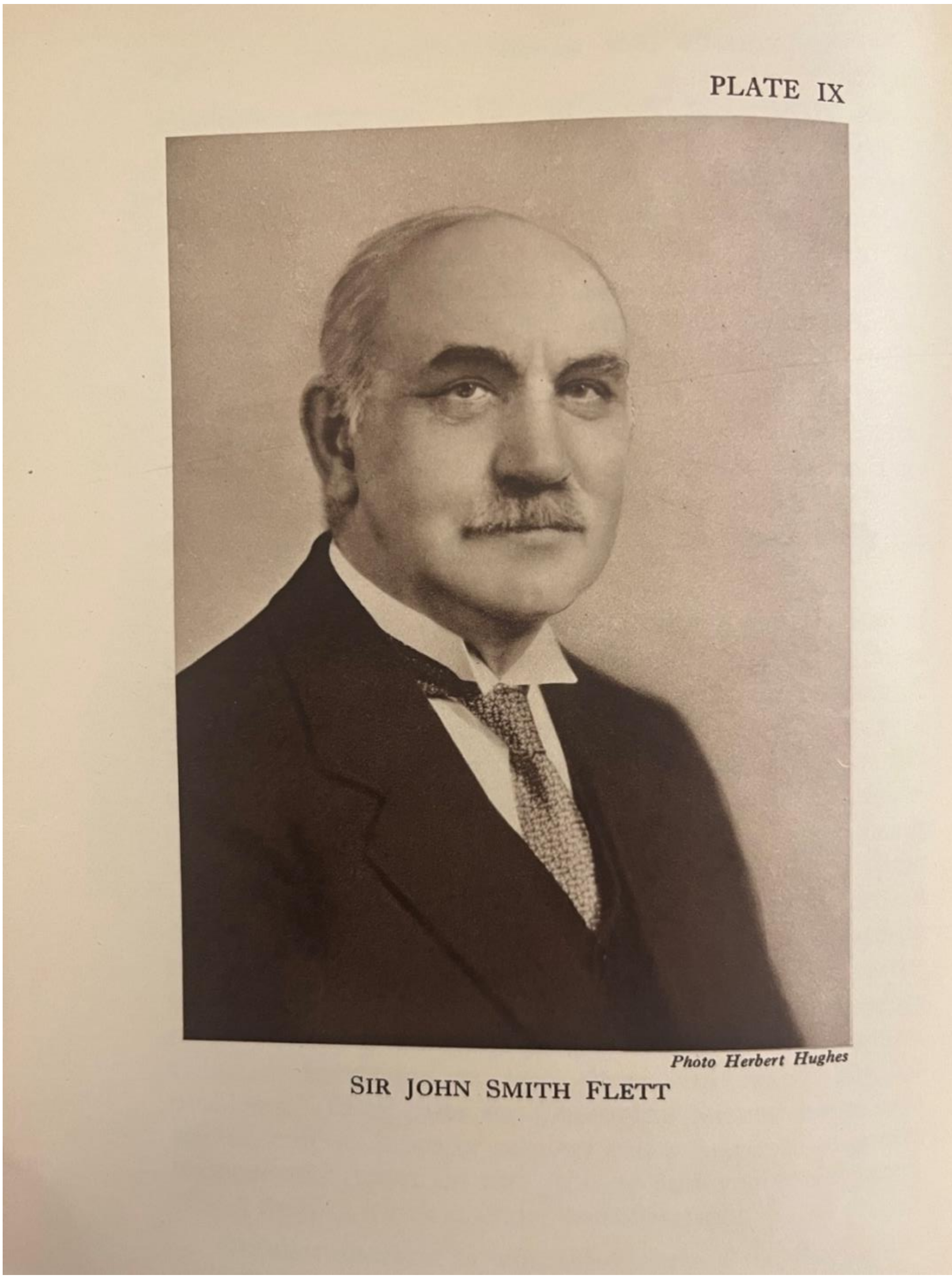


Figure 2.1. John Flett. From: John S. (John Smith) Flett, *The First Hundred Years of the Geological Survey of Great Britain, 1835-1935* (London: H. M. Stationery Office, 1937), 177.

The identifications of other attendees show that the Survey was enjoying a good network within the geology discipline, defined in a broad way. By nations and regions, also seated on the platform were A. P. Coleman from the University of Toronto, Edward B. Mathews as Professor of Geology and Mineralogy at Johns Hopkins University, E. de Margerie as former Director of the Geological Survey of Alsace and Lorraine, and W. von Seidlitz who was Director of the Preussische Geologische Landesanstalt.[120] Later at the dinner, the person who responded to Flett's toast was Arthur L. Day, then Director of the Geophysical Laboratory of the Carnegie Institution of Washington.[121]

The centennial was considered an appropriate time to review the Survey's work and plan its future development. The first part of this combined intention was indicated in the celebration activities that the Survey organised, namely a series of excursions that reminded participants of the long tradition of geological explorations in this country. Places for excursions were selected from those particularly important in the history of the Geological Survey, and these excursions were organised by high officers of the Survey. W. W. Watts from Imperial College of Science and Technology and Royal School of Mines

---

[120] Flett, *The First Hundred Years of the Geological Survey of Great Britain, 1835-1935*, 203.
[121] Flett, *The First Hundred Years of the Geological Survey of Great Britain, 1835-1935*, 217.

had given a speech on the reception about the long historical connection between the Geological Survey and the Royal School of Mines, and he also remembered the excursions:

> The Isle of Wight, a pocket edition of later British geology, revealed by the work of Forbes and Bristow, of Strahan and Reid, and recalling Lyell's long-standing classification of the Tertiary Rocks, the Weald, de Lapparent's link with France and Europe, illuminated by the famous memoir of Topley and Foster, the foundation of the "new geography," by Lamplugh and Kitchin, and now by the Weald Committee of the Geologists' Association; South Wales and Bristol, recalling the labours of Logan and Ramsay, Strahan and Thomas, and of Marr, Roberts, Hicks, and Arthur Vaughan; and Edinburgh, rendered classical by Hutton and Playfair and their worthy followers, Peach, Horne, Clough and the Geikies.

While Flett in his memoir records:

> A programme of excursions had been drawn up by the Geological Survey to certain districts of Great Britain which were of exceptional interest to geologists, and on the day after the Celebrations a start was made. Each excursion lasted for a week, and as the weather was very fine the

> programmes were carried out under the most favourable conditions and were much enjoyed by all participants.[122]

Some leaders of these excursions were already established regional geologists. For example, leaders of the Edinburgh and Forth Valley excursion were J. E. (James Ernest) Richey and A. G. (Archibald Gordon) MacGregor. Richey worked in Scotland and had published his research on geology of Ardnamurchan, and his work had earned him a Lyell Medal from Geological Society of London and made him a Fellow of the Royal Society. MacGregor had not yet become a District Geologist, but by 1935 he had already been working in Scotland for about fifteen years.[123]

On the other hand, if we turn to the Department of the Scientific and Industrial Research papers from Flett's book, we find that these excursions might have been the few activities that the Geological Survey was happy to hold and the Department did not intervene. The DSIR papers about the Geological

---

[122] Flett, *The First Hundred Years of the Geological Survey of Great Britain, 1835-1935*, 217.

[123] Some names among participants of these excursions are interesting as well. For example, Dr. J. Phemister in the Edinburgh excursion had conducted the Geological Survey's supposedly very first geophysical tests with gravity one decade earlier, or, in this dissertation, one chapter later; Professor W. J. Pugh from Manchester was at the South Wales and Bristol excursion, and he would be a key figure in the Geological Survey's aeromagnetic survey two decades later, or four chapters later.

Survey's centenary celebrations show us much detail about the process to confirm the celebration programme. These papers also remind us that the Survey had become a sub-branch of the DSIR, instead of an independent organisation, with the Geological Survey Board communicating in between. While technical programmes for regular work were settled and arranged by the Geological Survey itself, as we shall see in later chapters, the DSIR could initiate such administrative agenda as had happened in the preparation of the centenary celebrations.

The preparation started from a letter from Sibly to Frank Smith, then Secretary to the Department of Scientific and Industrial Research. In the letter, Sibly reminded Smith that:

> In June, 1935, the Geological Survey will complete one hundred years of existence, and at about the same time everything should be ready for a formal opening of the new building of the Geological Survey and the Museum of Practical Geology in South Kensington. Some of us have had in mind the desirability of ensuring the adequate celebration of these important occasions. I raised the matter at the last meeting of the Geological Survey Board and the discussions was minuted as follows – [124]

[124] T. Franklin Sibly to Sir Frank Smith, 8th May 1933, DSIR 9/28, National Archives, UK.

As his minute suggests, the “us” he referred to in this letter cannot be the experts of the Geological Survey, but the administrative staff of the GSB. As member of the Board, at least John S. Flett, then Director of the Geological Survey and Museum, should have been active at “the last meeting of the Geological Survey Board” that Sibly mentioned, but we cannot infer how much Flett had been involved in the idea by the time Sibly wrote to Smith, as we will see in later letters that Flett was invited to be present at the centenary preparation meetings only after the DSIR had approved Sibly’s suggestion.

After Sibly’s letter to Smith, the process to approve the suggestion would happen inside the DSIR. In his letter, Sibly noted the steps that he had taken and those that he would like smith to follow up with:

> I have already mentioned this in the course of private conversation with you, and I now write to bring it formally to your notice. If you should decide to ask the Advisory Council to appoint a Committee to consider the whole question and to make any necessary arrangements, I would suggest that it should be a small Committee with power to co-opt additional members, including representatives of such bodies as the Royal Society and the Geological Society.[125]

[125] T. Franklin Sibly to Sir Frank Smith, 8th May 1933, DSIR 9/28.

To summarise, he added: “There will be a great deal to do in the way of preparation, and an early start is very desirable.”[126]

On 10th May 1933, Smith brought Sibly’s minute to the Advisory Council meeting.[127] The Advisory Council agreed that a committee be founded “consisting of Sir Clement Hindley, Dr. Sibly, Dr. Sidgwick and Sir Frank Smith with power to co-opt additional members.”[128] As is mentioned above, Sibly and Smith were both on the DSIR side. Same were Clement Hindley and N. V. (Nevil Vincent) Sidgwick, who were members of the Advisory Council at that time, and neither of them were geologists.[129] In fact, up until this point, no geologist had yet been formally involved in this celebration for the Geological Survey.

Notice of the committee’s very first meeting was, at first, sent to formal members only, that is, Hindley, Sibly, Sidgwick, and Smith on 1st June 1933, about two weeks in advance of the proposed date of the meeting. Flett was

---

[126] T. Franklin Sibly to Sir Frank Smith, 8th May 1933, DSIR 9/28.

[127] The Advisory Council surely had a huge agenda on the meeting, as the “Centenary of the Geological Survey” was listed number 123 on its minute. ‘Extract from Minutes of Meeting held on 10th May 1933,’ DSIR 9/28, National Archives, UK.

[128] ‘Extract from Minutes of Meeting held on 10th May 1933,’ DSIR 9/28.

[129] Henry Thomas Tizard, ‘Nevil Vincent Sidgwick, 1873-1952,’ *Obituary Notices of Fellows of the Royal Society* 9 (1954): 236–258. http://doi.org/10.1098/rsbm.1954.0016.

also invited, but it seemed that his being invitation was only the result of a quick temporary decision by the civil servants of the DSIR. We can find a letter on the same day as other invitations showing this, from G. R. D. Hogg, then Under Secretary to the Department of Scientific and Industrial Research, to Ll. S. Lloyd, then Assistant Secretary to:

> It seems to me that Sir John Flett ought also to be present at this first meeting of the Committee, and I have also prepared a letter to him which you may like to send if you agree that he ought to be invited to come.[130]

On the other hand, Flett should have been aware of the committee even if he was not a member, or, he was supposed to be aware, as Lloyd wrote in the invitation to him: "I think you know that at the last meeting of the Advisory Council a small committee consisting of Sir Clement Hindley, Dr. Sibly, Dr. Sidgwick and the Secretary, with power to co-opt, was appointed to consider arrangements to celebrate the Centenary of the Geological Survey."[131]

Flett accepted the invitation and was present at the meeting. (C. Gilbert) Cullis, who was then Professor of Mining Geology at the Royal School of Mines, was also present, making them the two geologists involved in the preparation of the centennial. The meeting took place at 4.30pm on 14th June

---

[130] G. R. D. Hogg to Lloyd, 1st June 1933. DSIR 9/29, National Archives, UK.
[131] LL. S. Lloyds to J. S. Flett, 1st June 1933. DSIR 9/29, National Archives, UK.

1933, with Hindley absent. The first agenda on the meeting was to co-opt two more geologists as additional members: "Sir Thomas Holland, President of the Geological Society, and Professor P. G. H. Boswell, Secretary of the Society."[132] The committee did not invite them to join immediately, though, and the list of co-opted members was not yet completed. It turned out that the programme of the whole celebrations would be largely changed and simplified after the committee's first two meetings.

The programme changed because linking the event to two concurrent events that interested the committee turned out impossible. One of these events was the International Geological Congress. On the first meeting, the committee discussed the possibility to defer the centenary celebrations to 1936, so that they could hold the next IGC together with the celebrations. As was written in the minute:

> It was the unanimous opinion of the Committee that since the last International Geological Congress held in London had been as long ago as 1888, it was eminently desirable that the next Congress should be in London, that the centenary celebrations afforded a special reason why the next Congress should be held in London, and that there was the further advantage that by combining the celebrations and the Congress,

---

[132] 'Minute of the 1st Meeting held at 16, Old Queen Street, on Wednesday, the 14th June, 1933, at 4.30 p.m.,' DSIR 9/28, National Archives, 1.

> economy in expenditure would be attainable, e.g., such functions as a Government dinner and reception, which would be necessary in connection with the centenary, would serve also in connection with the Congress.[133]

Although combining the IGC sounded like a good idea to promote funding, it could only have added the procedure to get one, as:

> while it would fall to the Government to meet any expenditure in connection with the celebrations of the centenary and the formal opening of the new Museum, and while it was for the Department to take steps to secure the necessary financial authority for this expenditure, the only way to obtain a Government contribution towards expenditure on the International Geological Congress was through the Royal Society, which administered funds made available by the Government for international research activities of this nature.[134]

To achieve this, the committee assigned Flett to approach the President of the Royal Society and to propose an estimate for the expenditure. He and Cullis would also need to approach the IGC in Washington to make sure that

---

[133] 'Minute of the 1st Meeting held at 16, Old Queen Street, on Wednesday, the 14th June, 1933, at 4.30 p.m.,' DSIR 9/29, National Archives, UK, 2.

[134] 'Minute of the 1st Meeting held at 16, Old Queen Street, on Wednesday, the 14th June, 1933, at 4.30 p.m.,' 2.

London got to hold the next congress. However, in September 1933, news came that the IGC had accepted an invitation from Russia to hold the next congress there.[135] The change made Lloyd decide to hold another meeting for the committee. The meeting took place on 11th October 1933. Flett was invited again to join the members of the committee.

Minutes of the meeting shows that the committee had been established by then, although not many issues were discussed among the participants on the meeting. They added A. C. Seward, then member of the Geological Survey Board to the committee and decided that it was time to send invitations to all three co-opted members. Meanwhile, Flett was assigned to prepare a possible programme of the celebrations in detail, including an estimate of the cost. He would write the programme into a memorandum, and the committee would receive the memorandum by 10th November, as they would hold their third meeting on that day.[136]

Between its second and third meetings, the Geological Survey Centenary Committee sent invitations to prospective committee members, or, as they had indicated in earlier papers, "representatives of such bodies as the Royal Society and the Geological Society." Smith signed these invitations and sent

---

[135] Ll. S. Lloyd to T. Franklin Sibly, 20th September 1933. DSIR 9/29, National Archives, UK.

[136] Ll. S. Lloyd to T. Franklin Sibly, 20th September 1933. DSIR 9/29.

them to Thomas Holland, A. C. (Albert Charles) Seward, and P. G. H. (Percy George Hamnall) Boswell. All three were geologists. In the identical invitation letters, Smith promised that it was "not anticipated that a large number of meetings will be required, the main business being to draw up a programme for the proposed Celebrations, to consider the extent of the invitations to be issued and to prepare an estimate of cost."[137] He also asked whether they could join the next meeting at 2.15pm on the 10th of November, and they agreed.

The other simplification of the programme started on the second meeting and was confirmed on the third. On the first meeting, the committee concluded that they would not "combine a formal opening of the new Museum at South Kensington, by (it was hoped) His Majesty The King, with Celebrations of the Centenary."[138] They noted that the reschedule was because such a combination would "not be necessary, or result in any appreciable economy."[139] Instead, the new Museum of Practical Geology would host its

---

137 F. E. Smith to Sir Thomas Holland/Professor A. C. Seward/Professor P. G. H. Boswell, 16th October 1933. DSIR 9/28, National Archives, UK.

138 'Minutes of the Second Meeting held at 16 Old Queen Street on Wednesday, the 11th October 1933, at 5 p.m.,' DSIR 9/29, National Archives, UK, 1-2.

139 'Minutes of the Second Meeting held at 16 Old Queen Street on Wednesday, the 11th October 1933, at 5 p.m.,' DSIR 9/29, 1.

formal opening in October 1934, more than one year before the centenary ceremony.

All members of the Geological Survey Centenary Committee were present at the third meeting, as well as Flett and a small team of geologists. W. F. P. McLintock was in the team. As Curator of the Museum of Practical Geology, he reported to the committee "the successive steps to be taken in connexion with the occupation of the New Museum and gave revised estimates of the time necessary to complete the transfer from Jermyn Street."[140] Basically, his claim was that the relocation of the museum could not complete by October 1934, and the formal opening could not happen even in May 1935, when the centenary celebrations would take place. The committee accepted his suggestion, and simply removed the formal opening of the museum from the centenary celebrations.[141]

The second part of the meeting was a discussion on Flett's draft programme. This programme was an ambitious one, lasting five days plus one more week for excursions. In the programme, Flett expected the first day, which was likely to be a Tuesday, of the celebrations to be filled with:

---

[140] 'Minutes of the Third Meeting of the Committee Held at 2.15 p.m. on Friday, 10th November, 1933,' DSIR 9/29, National Archives, UK, 1.
[141] 'Minutes of the Third Meeting of the Committee Held at 2.15 p.m. on Friday, 10th November, 1933,' DSIR 9/29, 1.

1. Address to Royal Personage by Lord President.

2. Response by the Royal Personage.

3. Statement by Chairman of board or Director.

4. Presentation of Delegates (with addresses etc.) A few remarks by selected foreign delegates.

5. Perambulation of Museum by Royal Personage and Delegates.[142]

Apart from an evening reception with toasts, running buffet, and band. For the second day, he planned:

> 11 a.m. A few short addresses by distinguished persons on Geological in its economic and cultural relations in Imperial Institute Hall, Geographical Society's Hall, or Victoria and Albert Hall.[143]

He also planned many museum visits, where possible venues included Science Museum, Natural History Museum, Victoria and Albert Museum, Imperial Institute, London Museum, Geographical Societies Collection, and

---

[142] 'Tentative Programme of Estimates for Centenary Celebrations, Suggested by the Director, Geological Survey and Museum,' DSIR 9/29, National Archives, UK, 1.

[143] 'Tentative Programme of Estimates for Centenary Celebrations, Suggested by the Director, Geological Survey and Museum,' DSIR 9/29, 1.

the Survey's own one. He also suggested some subjects for the morning addresses, such as:

> Geology and the development of modern ideas on the Universe and the evolution of man.
>
> Geology and agriculture.
>
> Geology and mining.
>
> Geology and public health, engineering and industry.[144]

The day would end up with a government banquet to some delegates and guests. The third day would be filled with afternoon visits to London spots such as:

> Hampton Court
>
> Tower and Mint
>
> British Museum, Bloomsbury
>
> Westminster Abbey, Westminster Hall and L.C.C.
>
> National Physical Laboratory

---

[144] 'Tentative Programme of Estimates for Centenary Celebrations, Suggested by the Director, Geological Survey and Museum,' DSIR 9/29, 2.

Building Research Station[145]

And then end up with another reception. After these, Flett left the fourth day blank, and expected guests to set out for excursions on the fifth day to “classical areas of British Geology,” which might be:

Isle of Wight and Southampton Basin

London and East Anglia

Shropshire and Welsh Border

Devon and Cornwall

Bristol and South Wales

Snowdonia and Anglesey

Oxford and the Cotswolds

East Yorkshire

Edinburgh

[145] ‘Tentative Programme of Estimates for Centenary Celebrations, Suggested by the Director, Geological Survey and Museum,’ DSIR 9/29, 1-2.

Scottish Highlands[146]

Flett brought the tentative programme to an end by estimating the finance needed to be £2,225. Whether the estimate was reliable or not, the committee had realised that the programme would be too long for the celebrations, and they should cut it into as short as two days, excursions excluded. Nevertheless, the committee approve the gist of the programme, and decided that Flett could continue to work on "details and estimates" for a further proposal to be discussed on the next meeting.[147] In the new programme, morning addresses on the second day would reduce into one, and the committee suggested Flett that he invite W. W. Watts to give the address.[148] Days for city visits and rest before excursions are cut off, too.[149] The estimate, on the other hand, rose up to £2,635, as Flett did not realised the costs for personnel such as interpreters.[150]

---

[146] 'Tentative Programme of Estimates for Centenary Celebrations, Suggested by the Director, Geological Survey and Museum,' DSIR 9/29, 3.
[147] 'Minutes of the Third Meeting of the Committee Held at 2.15 p.m. on Friday, 10th November, 1933,' DSIR 9/29, National Archives, UK, 2.
[148] 'Proposed Programme for Centenary Celebrations,' DSIR 9/29, 1. And 'Minutes of the Third Meeting of the Committee Held at 2.15 p.m. on Friday, 10th November, 1933,' DSIR 9/29, 2.
[149] 'Proposed Programme for Centenary Celebrations,' DSIR 9/29.
[150] 'Memorandum on Detailed Arrangements Proposed for the Centenary Celebrations,' DSIR 9/29, National Archives, UK.

It has been worth discussing the detail of these meetings because, as I argue, the change on the programme, especially on the addresses' schedule, reflects a potential disagreement between Flett and the DSIR personnel. When Flett expected a series of speeches on the broad topic "geology and man," he looked like someone who was concerned about the general relationship between science and human life, and whose concern was denied by his government colleagues. Thus, this disagreement also reminds us of Bailey's claim that Sibly had been unwilling to explore geophysical approaches. It might have been true, for Sibly acted in both cases not as an explorer in geology; not even as a supporter, but as a government staff who, perhaps, would rather things be done quickly and predictably.

It took Flett months to produce a further proposal which included a detailed estimate and a list of guest geologists, surveys, and institutions that he would like to invite. As the committee had expected about 1,000 guests on the reception, the list was very long, to include 87 surveys, 120 museums, 12 universities, 32 geological societies, 49 general learned societies, 88 distinguished foreign geologists, and 94 British geologists, as well as officials to be complemented by the DSIR.[151] This list remained mostly unchanged in later meetings, and thus we can see the international network shown on the scene of celebrations that was recorded in Flett's book. In fact, according to

---

[151] 'Memorandum on Detailed Arrangements Proposed for the Centenary Celebrations,' Appendix, DSIR 9/29, National Archives, UK, 1.

existing minutes, there should have been only one more meeting after the third. On the fourth meeting, another group from the Geological Survey was present along with Flett. The meeting settled some details, such as the content of Flett's address as well as Watts' – Flett's on history of the Survey and Watts' "by moving a vote of thanks to the Director" – and changing the excursion point "London and East Anglia" to "London and the Weald."[152] The committee also decided that they should start sending invitations and proposed a memorial volume of publication to be distributed to guest delegates on after the addresses.[153]

In the years when the Geological Survey and the DSIR prepared the centennial celebrations, the Geological Survey Board was also preparing a report. The report was a regular practice that happened every ten years, but this one, completed in 1934, was particularly important to understand the nature and mission of the Geological Survey at that time. Moreover, it not only coincided with the centennial, but also was the only one of such reports in the Geological Survey Board papers to be archived with plenty of papers on its preparations.

---

[152] 'Minutes of the Fourth Meeting of the Committee held at 2.30 p.m. on Wednesday, 20th June 1934,' DSIR 9/29, National Archives, UK, 1.
[153] 'Minutes of the Fourth Meeting of the Committee held at 2.30 p.m. on Wednesday, 20th June 1934,' DSIR 9/29, 2.

2.4 The Geological Survey Centennial Report

The 1934 report was prepared and completed by a special committee assigned by and responsible to the Advisory Council. In governmental correspondence, the committee was referred to as the Geological Survey Committee. According to signatures, the committee consisted of three members: W. C. D. Dampier as Chairman, A. C. Seward, and T. F. Sibly, showing a combination of the Geological Survey Board and the Advisory Council.[154] The report claimed that the committee had nine meetings to prepare the report, and they collected their evidence from a wide range of scientific and administrative personnel, including John Flett, Bernard Smith (Assistant to the Director in England), M. MacGregor (Assistant to the Director in Scotland), W. F. P. McLintock, F. L. Kitchin (Palaeontologist to the Survey), H. H. Thomas (Petrographer to the Survey), P. G. H. Boswell, E. O. Forester-Brown (Mining Engineer), H. Lamworth (Consultant Engineer), O. T. Jones (Woodwardian Professor of Geology, University of Cambridge), and P. J. Wheeldon (Establishment Officer, DSIR).[155] The selection of sources covered internal and external parties and was supposed to lead to plausible recommendations on the scale and direction of the Geological Survey's future

[154] 'Report of the Geological Survey Committee,' National Archives UK, DSIR 9/109, National Archives, UK, 17.

[155] 'Report of the Geological Survey Committee,' DSIR 9/109, 1-2.

projects. All in all, the report would become a useful reference at a time, when:

> the economic situation had made it essential to secure the utmost economy in the administration of the work of the Department of Scientific and Industrial Research consistent with the discharge of its functions. We have accordingly directed our attention to consideration not only of the scale upon which, in our view, the work of the Survey and Museum ought to be conducted under normal circumstances but also to the desirability and practicability of some curtailment in that scale in relation to the present economic situation.[156]

Having said so, the first thing that the report confirmed was that, due to the wide scope that the survey had dealt with and its importance in providing references for economics, the Geological Survey should then be regarded as "a permanent service,"[157] although it had not been expected to last so long at

---

[156] 'Report of the Geological Survey Committee,' DSIR 9/109, 1.

[157] 'Report of the Geological Survey Committee,' DSIR 9/109, 4. As Melville remembers in his valuable book, the Survey was indeed intended to be temporary originally, and at "intervals during its history, and into the early part of the twentieth century, the question was asked, by governments and in Parliament and elsewhere, 'When will the Geological Survey of Great Britain be finished?'"(Melville, *The Department of Scientific and Industrial Research*, 111.) Melville in his book could insist that the answer was no, but his answer explains neither when nor why. Thus, the Geological Survey Board report in 1934 provides an answer that, at least by the time the Geological Survey

the beginning, when it was regarded as simply a facility to store geological data and publish survey records. On the contrary the report committee could now claim that the Geological Survey had played its role in many important areas:

> The primary purpose of the Survey is the collection of data on the geology of Great Britain and the preparation and, as far as possible, publication of geological maps and memoirs which record the results of the survey, and discuss the various economic aspects of the results. …
>
> But this statement gives a wholly inadequate picture of the importance of the Survey's work, which impinges at numerous points on the economic life of the whole country. In addition to its importance in relation to all mining development, and particularly coal-mining, its work is of the greatest value in connection with water supplies, building and engineering problems (including especially sources of building materials and foundations for structures of all kinds) agriculture and forestry, and town-planning. Some 1000 enquiries per annum are received and answered. The Survey Office is in fact a "bureau of reference" on the Economic Geology of Great Britain.

---

celebrated its one hundred years' birthday, it had been certain to be a permanent establishment.

In a later section, the report returned to the permanency of the Geological Survey, arguing that the Survey existed in an era when

> Geological science was in its infancy, or at most, adolescence, and when sufficient experience had not been gained to show the economic value of geological information in relation to many human requirements. But geology is not a static science. Year by year new developments occur which lead to revision, often radical revision, of former views. Moreover human activities, of which mining operations and well sinking are the most obvious but by no means the only examples, furnish almost daily information which throw fresh light on geological problem. The result is that geological maps and sections can never be final. Periodical revision is essential. Hence the work of the Survey can never be concluded. The Geological Survey must be viewed as a permanent organisation.
>
> Incidentally, the growing complexity of geological science and the ever increasing demand for more detailed information account for an inevitable slowing down of the rate at which a staff of given size can survey a given area.[158]

Speaking somewhat proudly, the report acknowledged that the Geological Survey, together with the information that it processed, played an

---

[158] 'Report of the Geological Survey Committee,' DSIR 9/109, 11-12.

irreplaceable role in the economic development of the country. The longevity of the Survey was based on the fact that both the information it should provide and the science it used were expanding or changing eternally. Among all such information, the most important and unique was mapping, which had been the focus of the Survey's work in the past decade, "particularly in connexion with the 6'' survey of coalfields, the acceleration of which was the primary object of the expansion of staff in 1921."[159] It also stated that the completion of the 6-inch maps of the whole England would take another fifteen to twenty years – it would remain a big task for the Survey in many years to come.

Finally, the report discussed the potential of geophysical work, which I will summarise and which provides a link to the subsequent case studies. According to the general histories of the Geological Survey that have been referred to at the beginning of this chapter, in 1920s-1930s, the geophysical work was only an immature attempt, if any, and was far from any real success. The 1934 report noticed these attempts and gathered evidence "both in favour of and against the use of these methods in the normal work of the Survey."[160] As it turned out,

> Some years ago the Survey undertook a series of investigations into the application of geophysical methods, especially the gravitational method,

159 'Report of the Geological Survey Committee,' DSIR 9/109, 5.

160 'Report of the Geological Survey Committee,' DSIR 9/109, 14.

> to the solution of geological problems, but for the time being such work has been abandoned in favour of more urgent requirements.

The comments above suggest that geophysical work, although existing, has always lied at the margin of the Survey's work, although it was exciting as part of the contemporary progress in surveying technology. Hence, the report committee recommended that they

> recognised the importance of their application to geological research and are satisfied that the Survey cannot afford to neglect them altogether. The question of the extent to which they should be used by the Survey is however difficult. It is also a matter for consideration whether, on such occasions as it may be considered desirable to apply a geophysical method or methods to the solution of a particular geological problem, the more satisfactory and economical procedure would be to employ outside experts or to utilise members of the Survey staff. The latter course would involve the continuous employment in the Survey of at least one officer fully trained as a geophysicist.[161]

And training an officer in geophysics would be expensive. As these recommendations suggest, whether to apply geophysical methods, according to the report committee, was a question of balancing costs and benefits, and it

---

[161] 'Report of the Geological Survey Committee,' DSIR 9/109, 14.

might not be a wise idea to proceed if they could not see a direct connection between the new methods and the Survey's use for the country. Their suggested solution was to outsource geophysics. Throughout the report, staffing has been a repeating concern, and the report committee's recommendations to a lack of geophysical talents is no different. They showed a reluctance to recruit new staff who had been specifically trained to be geophysicists, and concluded to a recommendation that

> research into the development of improved geophysical methods should not be undertaken by the Survey but would be better left to universities and other institutions, e.g. the School of Geophysics at the Imperial College of Science and Technology which was set up largely at the instance of the Department and is at present receiving financial assistance for its research work from the Department.[162]

This recommendation resonated in an era when geophysics was suspended at the Geological Survey, but geological work would still be a good platform to test and develop geophysical methods in the decades to come. By that time, it had become obvious that the Geological Survey had been recognised as a state institution that enjoyed both importance in domestic development and an international professional network, and their efforts to utilise various new techniques in their work was noted, although not highly spoken of. Mapping

[162] 'Report of the Geological Survey Committee,' DSIR 9/109, 15.

was the main task of the Survey's work (and it would remain so), and the Survey's agenda largely followed by the demands of government and external enquirers. On the other hand, mapping was also the only platform where the Survey could test geophysical techniques, as they had done in the 1920s. In these projects, the DSIR and the Geological Survey Board indeed played their role to enhance the communication between the Geological Survey (as a scientific institution) and the government. On the other hand, they also put the Survey within a scarce distance from any shortage in finance that could easily impact the geophysical agenda.

2.5 Conclusion

This chapter provides the basic context of the time period (1920s-1950s) when the Geological Survey developed its geophysical techniques. Firstly, this chapter explores the relationship between the Survey and its governmental administrative body. Secondly, this chapter is focused on the centennial celebrations and reflections, in the form of a report, that indicated the Survey's role and aspirations at that time. On the one hand, the Survey enjoyed an international network, an interest in new techniques, and a desire to understand geology in its broad sense. On the other hand, it was essentially a surveying and mapping organisation. In the next chapters, we will see how the situation changed both in action and in ideals.

Chapter 3: The Gravity Torsion Balance: a Step towards Geophysical Surveying

We have briefly mentioned in Chapter 2 that there had been a geophysical programme in the British Geological Survey in the 1920s and 1930s, and in this chapter, we will explore the beginning of the programme – the attempt to use a Eötvös torsion balance in surveying. We will begin with introducing the instrument and examine the background of the decision to use it. Then we will review the process prior to and of the tests and find out how the test results were appreciated by the Geological Survey. Finally, this chapter reveals the reasons why such a geophysical programme was unable to continue, and how the whole episode sheds light on the nature of the Geological Survey's work.

3.1 The Eötvös Torsion Balance and its Applications in the 1920s

In 1920s, the Eötvös torsion balance enjoyed a surge in publication mentions in British scientific journals. Most of these publications were introductory and intended to teach colleagues the basics of such a scientific instrument. Despite the plain content, such introductions to the Eötvös torsion balance would attract the interest of geologists because they tended to focus on the geological potential of this instrument. For example, one of these early articles was published in 1922 and was written by Captain H. (Herman) Shaw and E. Lancaster-Jones. Shaw had worked at the Science Museum since 1920 with a background in geophysics, so he was the right person to introduce such an instrument and must have easily identified this object in the museum's collection.[163] Shaw and Lancaster-Jones' paper provides for us a detailed description of the internal structure of the Eötvös torsion balance, that it:

> consists of a fine torsion wire, carrying a lever which supports at its extremities two weights, at different vertical heights, the whole being enclosed in a double walled metal case which can be rotated about a vertical axis. An azimuth circle enables the positions of the case to be determined and the orientation of the balance arm relative to it is observed by the aid of a telescope. The system has a period of swing exceeding 1,200 seconds, and after having been disturbed returns to rest in its equilibrium position in approximately two hours. The position of equilibrium and the motion of the beam are found to be remarkably stable and relatively constant, so that the instrument can be used not only in a well-protected laboratory, but also at night in the open air, with the

---

[163] 'Herman Shaw', *Physics Today* 3, no. 7 (1950): 39–40, https://doi.org/10.1063/1.3066962.

protection only of a canvas tent.[164]

In a later section, Shaw and Lancaster-Jones continued the description and noted that the torsion wire was a particularly subtle component in the instrument. The torsion wire was 60cm in length and 0.04mm in diameter and was made of platinum-iridium. Before a Eötvös torsion balance gets in use, a wire must undertake a “baking treatment,” where it is heated in an oven gradually until 100°C and then slowly cools down, so that the wire loses most of its own torsion and become sensitive to the gravity. At the top of the wire is the torsion head that allows adjusting and reading, and at the bottom is the horizontal balance arm, a rectangular platform of 40cm in length. At one end of the balance arm is a beam connected with a platinum wire in a cylinder, and at the other end a counterweight. To protect this system which already seems extremely sensitive, a double-walled metal box covers it all inside. The box is made of brass, with its two walls respectively 3mm and 4mm in thickness and 1cm of air gap in between.[165]

---

[164] H. Shaw and E. Lancaster-Jones, ‘The Eötvös Torsion Balance’, *Proceedings of the Physical Society of London* 35, no. 1 (1922), https://doi.org/10.1088/1478-7814/35/1/319, 151-152.

[165] Shaw and Lancaster-Jones, ‘The Eötvös Torsion Balance’, 158-160.

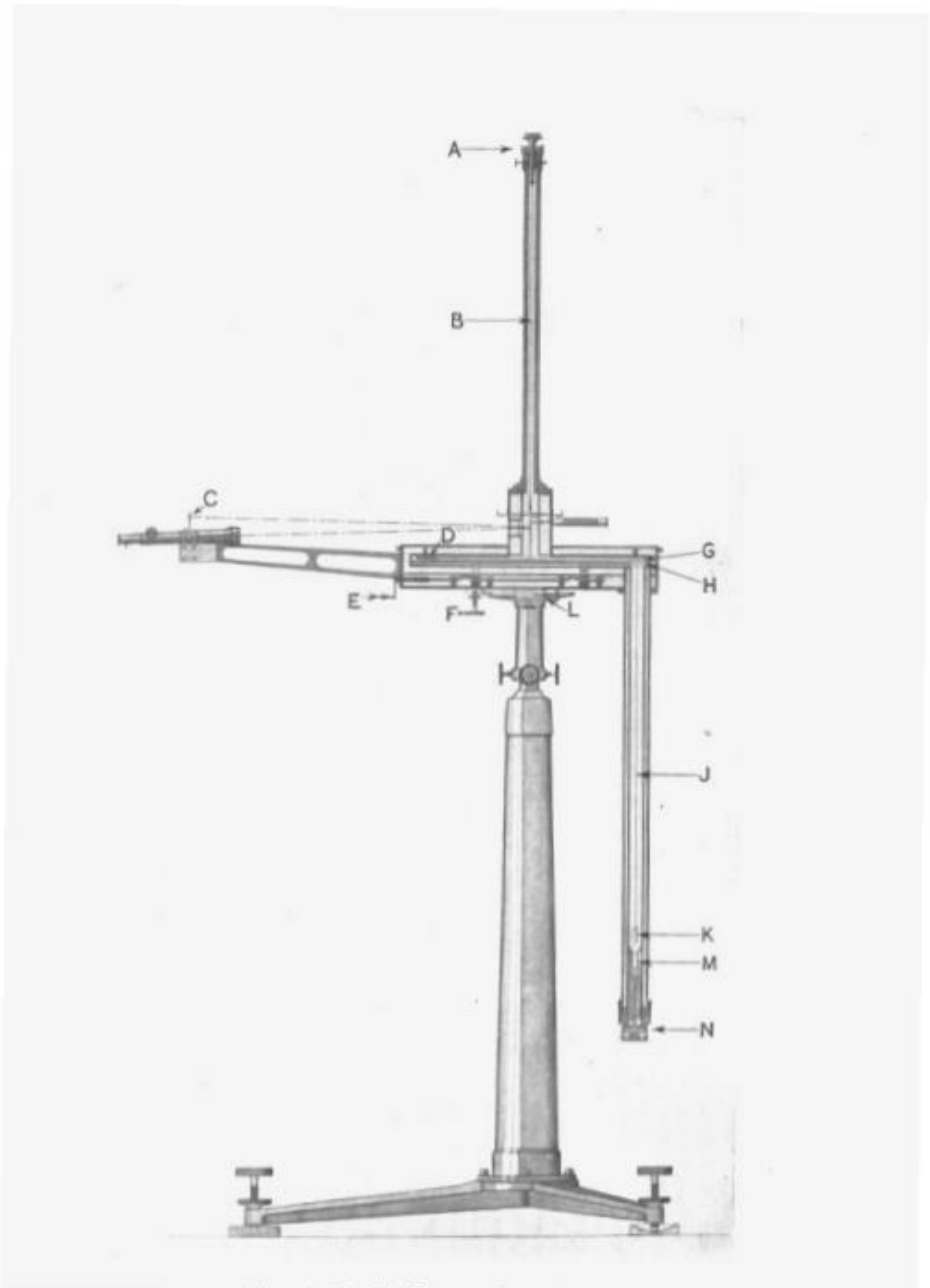


FIG. 2.—EÖTVÖS TORSION BALANCE.

To face page 158.

Figure 3.1. Eötvös Torsion Balance. From: H. Shaw and E. Lancaster-Jones, ‘The Eötvös Torsion Balance’, *Proceedings of the Physical Society of London* 35, no. 1 (1922), 158.

According to Shaw and Lancaster-Jones, the practical advantage of the Eötvös torsion balance lay in its structure that was different from other designs of gravity torsion balances. While previous gravity instruments measured the gravity itself with a pendulum and a bubble level, a Eötvös torsion balance measured the variations of gravity so that it indicated the geological differences directly. As the variations were normally rather small compared to the gravity, the Eötvös torsion balance's measurement had a higher precision. Plus, Shaw and Lancaster-Jones believed that the Eötvös torsion balance also had a high portability due to its design that allowed it to work reliably even in the field.[166] Their tests proved that "the reading of the instrument remained very stable,"[167] although details of their tests did reveal some weaknesses of the Eötvös torsion balance, which were inherent and unavoidable in the subtlety of its design: the torsion wire required regular treatments which might not be identical on different days, and "the increased age of the wire" could cause instability after only one month.[168] Having said so, Shaw and Lancaster-Jones were not field scientists, and they could not

[166] Shaw and Lancaster-Jones, 'The Eötvös Torsion Balance', 151.
[167] Shaw and Lancaster-Jones, 'The Eötvös Torsion Balance', 162.
[168] Shaw and Lancaster-Jones, 'The Eötvös Torsion Balance', 160-162. A more detailed version of Shaw and Lancaster-Jones' experiment data can be found in another paper, H. Shaw and E. Lancaster-Jones, 'Application of the Eötvös Torsion Balance to the Investigation of Local Gravitational Fields', *Proceedings of the Physical Society of London* 35, no. 1 (1922): 204–12, https://doi.org/10.1088/1478-7814/35/1/327.

decide whether these defects would completely limit its use in field conditions. Their tests of the instrument were conducted in the basement of the Science Museum.[169]

In another paper published in the next year, Shaw and Lancaster-Jones supplemented their experimental report with figures and calculations that would make sense in the actual field. The simplified calculations suggested that a function of the gravity field could be determined by a set of four magnitudes which could be read through the Eötvös torsion balance.[170] Although, in principle, the function was applicable only to geodesy, it had already been enough for the Eötvös torsion balance to be applied in locating mineral deposits. With this method, geologists could determine the density, shape, extent, and depth of a mineral deposit without the cost of drilling boreholes. Unless it came to complicated geological conditions such as mountain ranges, according to Shaw and Lancaster-Jones, this method had proved useful "in regions presenting a regular and comparatively unbroken surface, but having important irregularities below," which they noted were more common conditions of the land than mountain ranges.[171]

---

[169] Shaw and Lancaster-Jones, 'The Eötvös Torsion Balance', 162.
[170] H. Shaw and E. Lancaster-Jones, 'The Eötvös Torsion Balance and Its Use in the Field', *Nature* 111, no. 2799 (1923), https://doi.org/10.1038/111849a0, 850.
[171] Shaw and Lancaster-Jones, 'The Eötvös Torsion Balance and Its Use in

In the years after Shaw and Lancaster-Jones' papers, *Economic Geology* followed up with articles that were focused on the application of the Eötvös torsion balance.[172] The title of the journal already hinted that the application of the Eötvös torsion balance continued to be mostly an industrial and economic endeavour. In 1925, a book titled *Outlines of the Occurrence and Geology* gave "an elementary explanation of the geological conditions which have led to the formation of petroleum and its accumulation in sealed underground reservoirs,"[173] and it was around such a topic that the Eötvös torsion balance was particularly important because "this instrument, in a form easily carried and read by a single observer, ha[d] an error of less than 10^{-9}."[174] Geologists nowadays believe that the application of the Eötvös torsion

---

the Field'.

[172] Unfortunately, these papers are not available to read in full text. They can be found such as Stephen Rybar, 'The Eötvös Torsion Balance and Its Application to the Finding of Mineral Deposits', *Economic Geology* 18, no. 7 (1 October 1923): 639–62, https://doi.org/10.2113/gsecongeo.18.7.639 and Alan Mara Bateman, 'The Eötvös Torsion Balance', *Economic Geology* 19, no. 1 (1 January 1924): 84–86, https://doi.org/10.2113/gsecongeo.19.1.84.

[173] A M. D., review of *Outlines of the Occurrence and Geology* by I. A. Stigend, *The Geographical Journal* 66, no. 1 (1925): 72.

[174] A M. D., review of *Outlines of the Occurrence and Geology* by I. A. Stigend, 72. The reviewer also critically noted that magnetic surveying could be used as a supplement for the gravity torsion balance method for less time and less cost. In fact, this reviewer whose full name is unavailable suggested that the magnetic method be used for preliminary surveys of rather large areas, while the gravitational method assists in some selected areas. The main idea of the reviewer was not degrading the importance of the gravity

balance in locating mineral deposits started in 1918 when W. Schweydar used it for oil prospecting on a salt dome in northern Germany.[175] By the time when Shaw and Lancaster-Jones published their earlier article on this instrument in 1922, they had already been able to mention that the Eötvös torsion balance had been "in use by a number of oil companies in various parts of the world for the location of salt domes."[176] These results were not widely available as academic journal articles, which is a fact that would prove important later for the Geological Survey.

On the other side of the Atlantic Ocean, there were some early cases in which, no later than 1920, American scientists had deployed a gravity torsion balance in the scientific exploration of the interior of the earth. When Walter D. Lambert introduced current knowledge on the inside structure of the earth in a short paper, he explained how people found out about the constitution of the earth starting with the gravity constant, and then noted that laboratory researchers would be able to observe a deflection of a torsion balance

---

torsion balance but allocating each method to contexts where their respective advantages were put into use. Such considerations and choices have resonated throughout any debates over the application of the Eötvös torsion balance, including those around the British Geological Survey.

[175] M. N. Nabighian et al., 'Historical Development of the Gravity Method in Exploration', *Geophysics* 70, no. 6 (2005): 63ND-89ND, https://doi.org/10.1190/1.2133785.

[176] Shaw and Lancaster-Jones, 'The Eötvös Torsion Balance', 160.

"caused by the near approach of a large mass."[177] If there was a large mass hidden underground and caused the deflection, then researchers would calculate and know the density of the affected area based on the deflection. Referring to his own paper, Lambert reported later in the same year that his research showed some "peculiarities" in the distribution of the earth's gravity field, and that the "peculiarities of the earth's field may be examined experimentally by the Eötvös torsion balance."[178] Thus, he argued that an examination of the earth's gravity field by using the Eötvös torsion balance was promising.

Not long after Lambert, laboratory researchers realised the idea in real life that investigating underground geological structure was feasible using gravity torsion balance. In 1923, Henry S. Washington introduced to an academic audience his efforts in measuring the density of the earth using gravitational methods. In a short review to begin his paper, Washington pointed out that there had been an old method to determine the density of the earth by "measuring the attraction exerted by an isolated mountain", which was neither easy nor reliable, and by the time he wrote the paper had "been superseded by those based on laboratory experiment, such as with the torsion

---

177 Lambert, Walter D. "The Internal Constitution of the Earth." *Journal of the Washington Academy of Sciences* 10, no. 5 (1920), 125.

178 Adams, O. S. "The December Meeting of the Maryland-Virginia-District of Columbia Section." *The American Mathematical Monthly* 28, no. 4 (1921), 156.

balance."[179] As a comparison, Washington chose to measure the density of the earth crust on the volcanic mountain Mauna Kea in Hawaii, because another "mountain observers" including E. D. Preston had measured exactly the same mountain in 1892 with the old method, so that there was a comparison. Washington analysed the density in "a recent petrological study of the lavas", and "was struck with the discrepancies between [his] specific gravities and their average and those given by [E. D.] Preston."[180] Washington's conclusion was that Preston's previous calculations over-generalised five different volcanoes in Hawaii, and the actual density should have been much higher.[181]

Through the 1920s, Americans continued to be main explorers of the future of the Eötvös torsion balance. Scientists praised its sensitivity to variations in gravity.[182] A summarising article in 1927 claimed that "by means of the Eötvös torsion balance remarkable work has been accomplished, since by its use not

---

[179] Washington, Henry S. "The Density of the Earth as Calculated from the Densities of Mauna Kea and Haleakala." *Journal of the Washington Academy of Sciences* 13, no. 21 (1923), 453. http://www.jstor.org/stable/24532810.

[180] Washington, "The Density of the Earth as Calculated from the Densities of Mauna Kea and Haleakala," 453.

[181] Washington, "The Density of the Earth as Calculated from the Densities of Mauna Kea and Haleakala," 455-456.

[182] Sosman, Robert B. "Scientific Papers and Discussions at the 1925 Meeting of the Section of Volcanology, American Geophysical Union." *Journal of the Washington Academy of Sciences* 15, no. 18 (1925): 413–25.

only a very accurate determination of a level surface in a given locality is made possible, but also because it indicates positions of mineral deposits."[183] William H. Roever of Washington University, St. Louis called the Eötvös torsion balance "a very simple, though delicate, apparatus" to detect "the proximity of mountains, or of heavy mineral deposits".[184] Or, as another pioneer bravely predicted, it had become a "divining rod for oil" that had been wielded by progressive Californian oil companies.[185] Indeed, even the divining rod had limitations, as the sensitivity of the Eötvös torsion balance required users to take precautions against even the smallest disturbances including air currents.[186] But the gravitational method still looked promising and was expected to be applied to a larger variety of underground structures, even including an Egyptian pyramid.[187]

However, except for the only occasional field tests conducted by Americans which have been mentioned above, there were few published cases describing in detail how the torsion balance was used, and what exactly the results were. The British manufacturer Oertling in London reflected in a short

---

183 "75-Mile Gun Mile Out." *The Science News-Letter* 11, no. 302 (1927): 59.

184 "75-Mile Gun Mile Out.", 59.

185 "Gravity Balance May Be Divining Rod for Oil." *The Science News-Letter* 5, no. 191 (1924): 1.

186 "Gravity Balance May Be Divining Rod for Oil.", 2.

187 "New Instrument May Locate Old Tombs." *The Science News-Letter* 5, no. 178 (1924): 8.

review:

> When a scientific instrument assumes a commercial value beyond its intended scientific use, trustworthy and detailed descriptions of its construction and of the method of its operation become scant if not altogether inaccessible. This class of instrument includes the Eötvös torsion balance[188]

where

> extensive literature is available both as regards construction of the balance and the results of measurements. But since the torsion balance proved to be one of the most useful instruments available for the location of mineral ore deposits, and a considerable refinement has been achieved in its design, trustworthy sources of information and details, from which an independent judgment could be drawn, have been deplorably lacking. The commercial necessity of secrecy by users of the torsion balance renders valuable observational data inaccessible for an indefinite period.[189]

---

[188] E. R. F., 'Book Review of *The "Eötvös" Torsion Balance*. Pp. 90. (London: L. Oertling, Ltd., n.d.) 21s', *Nature* 118, no. 2968 (1926), https://doi.org/10.1038/118406a0, 406.

[189] F., 'Book Review of *The "Eötvös" Torsion Balance*. Pp. 90. (London: L. Oertling, Ltd., n.d.) 21s', 406.

As a business, Oertling was trying to persuade their readers that such an instrument as they described had become an essential purpose. Not only did Oertling contain descriptions and illustrations of their own model of the instrument “with commendable candour”, but the company also provided plenty of practical data and notes of their employment of the torsion balance.[190] Oertling’s book came right at a time when John S. Flett, then Director of Geological Survey in the 1920s shared the same concern over the lack of available torsion balance experiment data. He was also one of the readers of the scarce scientific reports who would believe that the torsion balance was useful since it provided a new method to explore underground. But to what extent would the instrument be useful in surveying as well? Presented by all the sources, Flett was consequently worried that the Geological Survey did not have any access to the torsion balances or reliable sources on its own, and his passion for geophysical methods led him to support the proposal and conduct of a campaign for the torsion balance in the coming years.

3.2 Geology and Petroleum Industry in the 1920s

As it happened in America, scientists’ interest in the gravity torsion balance

---

[190] F., ‘Book Review of *The “Eötvös” Torsion Balance*. Pp. 90. (London: L. Oertling, Ltd., n.d.) 21s’, 406.

reflected an era when the development of geology was closely linked with the expansion of petroleum industry. As Daniel Yergin argues, the decade of the 1920s was a period when geology in oil industry turned from "surface geology" to "seeing" underground, since the former had "gone as far as it could."[191] Oil companies, as well as their geologist allies, needed a way to find out whether a subsurface geological structure had trapped oil without digging everything out. With such an intention, not only the gravity torsion balance, but also other innovations were widely tested and applied, such as the magnetometer which measures vertical changes in the earth's magnetic field at a point and the seismograph which locates salted domes that might contain oil by detecting and measuring the underground transmission of energy waves of artificial explosions:

> Dynamite charges were set off, and the resulting energy waves, refracted through underground structures, were picked up by listening ears - "geophones" - on the surface, which helped to identify underground salt domes, where oil might be found. The reflection seismograph, introduced about the same time and soon to supplant the refraction technique, recorded the waves that bounced off rock interfaces underground, which allowed the shapes and depths of all kinds of underground structures to

[191] Daniel Yergin, *The Prize: The Epic Quest for Oil, Money & Power* (London: Simon & Schuster, 1993), 201.

be plotted.[192]

This was exactly why geophysics became more important at that time: it helped oil people “see” underground.[193] Similarly, it emphasises how geology, including geological surveying, has been closely connected with petroleum industry.

Sometimes the connection between geology and oil prospecting and consuming was maintained by the state, on which Peter Shulman has provided a case from history of the United States Geological Survey. By the 1910s, it had been clear to both geologists and the navy that the stock of oil in the United States was significantly greater than that of coal and the cost to use oil as fuel for the fleet significantly lower than that of coal. The staff of the United States Geological Survey had reported that the production of petroleum had become a necessity to sustain and conserve the function of the fleet, apart from other uses of the oil. As a result, the Director of the United States Geological Survey started to lobby for the government to prospect and conserve oil as a national resource. As it unsurprisingly turned out, the decisions at the Department of Navy and Interior level was based on the assessment of geological evidence for the United States Geological

---

[192] Yergin, *The Prize: The Epic Quest for Oil, Money & Power*, 201-202.

[193] Yergin, *The Prize: The Epic Quest for Oil, Money & Power*, 202.

Survey.[194] At the same time, the US Navy planned a total change of their ships from coal burning to exclusively oil burning.[195]

As a result of the above new dependency on oil as fuel in the Navy, and because the First World War had shown a trend towards rising oil consumption, petroleum geologists began to warn of the coming of a time of insufficient oil supplies and suggested an interdepartmental oil administration, since the navy had been equipped with not only new oil-burning fleet but also a system around the gaining and using of oil. As Shulman notes, the first issue of the American Association of Petroleum Geologists Bulletin in 1922 was in effect "the most comprehensive approximation of the US oil supply then assembled."[196] Sixteen geologists in total joined the project to estimate the stock of oil in the US, among them 10 on behalf of the association and 6 from the United States Geological Survey.[197] In this way, petroleum geologists shaped not only the act of oil production but also navy policies.

---

194 Peter A. Shulman, '"Science Can Never Demobilize": The United States Navy and Petroleum Geology, 1898-1924', *History and Technology* 19, no. 4 (2003), https://doi.org/10.1080/0734151032000181095, 370-371.

195 Shulman, '"Science Can Never Demobilize": The United States Navy and Petroleum Geology, 1898-1924', 372.

196 Shulman, '"Science Can Never Demobilize": The United States Navy and Petroleum Geology, 1898-1924', 374-375.

197 Shulman, '"Science Can Never Demobilize": The United States Navy and Petroleum Geology, 1898-1924', 377.

As is quoted by Shulman, the British War Cabinet had announced right before the end of World War I that the “Allied Cause had floated to victory upon a wave of oil.”[198] The quoted remark suggests that Britain was experiencing a similar zeal for oil explorations in the same era, for comparable reasons. Unlike Shulman’s American case, what Stephen Corfield coined as the “first oil exploration campaign in the UK” was largely conducted by industry, with the government acting as a sponsor. Corfield emphasises that oil exploration happened in Britain onshore, as World War I had reminded British government of the vulnerability of overseas oil production. As a result, the British government decided to select S. Pearson & Sons, as the drilling contractor.[199] To complete the task of finding oil for the British Isles, Weetman Pearson, who was the owner of S. Pearson & Sons and the Mexican Eagle Company and had discovered oil in Mexico, had a team of American geologists ready to “research into the possibility of drilling for oil in the UK.”[200] The company took both researching and drilling from the government, while receiving no more than £1,000,000 for its work.[201] Not all the boreholes were a success though: in the 11 boreholes where oil shows were expected, 5 of

---

[198] Shulman, ‘“Science Can Never Demobilize”: The United States Navy and Petroleum Geology, 1898-1924’, 365.

[199] Stephen M. Corfield, ‘The First Oil Exploration Campaign in the UK, 1918-1922’, *Geological Society Special Publication* 465 (2018), https://doi.org/10.1144/SP465.11, 39.

[200] Corfield, ‘The First Oil Exploration Campaign in the UK, 1918-1922’, 39.

[201] Corfield, ‘The First Oil Exploration Campaign in the UK, 1918-1922’, 39.

them had no oil flows or seams at all; even in the 6 boreholes where oil flowed, 3 had to be abandoned very soon after because the oil flows were simply too insignificant.[202] As a result, the campaign had to be claimed a failure.

Through the story of oil wells, Corfield shows one way to analyse a geological project: by investigating the personnel allocated to it, the selection of its location, and the results. The analysis is applicable to the torsion balance well. The onshore oil exploration case, in a way, can be likened to the story told below about the Eötvös torsion balance too: there was considerable support from the industry, sponsorship by the government, failure, and even individuals: John Cadman had played an important role in the whole process.

Cadman was born in 1877 in the mining village of Silverdale in Staffordshire. There he became familiar with coals and collieries and entered the Durham College of Science (now University of Durham) to study his BSc degree in mining and later MSc and DSc. He started his career as assistant manager at the Silverdale Collieries and then manager of the Collieries of Trindon Grange. He began to learn about oil when he was one of the H.M. Inspectors of Mines, while he became esteemed mainly for his cautious investigations of

[202] Corfield, 'The First Oil Exploration Campaign in the UK, 1918-1922', 42-51.

mine explosions.[203]

In 1904, Cadman transferred his attention from coal to oil when he organised the Mines and Petroleum Department in Trinidad, allowing its petroleum industry to grow from one that could “scarcely be said to exist” to a much-stimulated development.[204] In 1910, Cadman was appointed Professor of Mining at Birmingham University, where he founded the Department of Petroleum Technology, arguing that science should be practiced in all operations in oil industry. During World War I when Britain was seeking a stability in its oil supply, Cadman became a member of an Admiralty Fuel Oil Commission, and that was when he was responsible for recruiting Pearson and his team to find oil in mainland Britain, as Corfield discusses.[205]

In 1921, Cadman joined the Anglo-Persian Oil Company as a technical adviser and shortly afterwards became a director. As a “’professor’ scientist to become chairman of an industrial company with a capital of tens of millions of pounds” in petroleum,[206] Cadman was an expert with both “encyclopaedic knowledge” and determination to improve prospecting methods, including with

---

[203] See Frank Edward Smith, ‘John Cadman, Baron Cadman, 1877 - 1941’, *Obituary Notices of Fellows of the Royal Society* 3, no. 10 (1 January 1997): 915–27, https://doi.org/10.1098/rsbm.1941.0042.

[204] Smith, ‘John Cadman, Baron Cadman, 1877 - 1941’, 917.

[205] Corfield, ‘The First Oil Exploration Campaign in the UK, 1918-1922’, 39.

[206] Smith, ‘John Cadman, Baron Cadman, 1877 - 1941’, 918.

geophysical techniques.[207] Hence came the decade of tests of the gravity method and the cooperation with his own country's government and its Geological Survey.

3.3 Getting a Torsion Balance

Although the definition of "the first" usually requires extra caution and scrutiny of a historian, it is possibly plausible, as H. E. Wilson insists, that the Eötvös torsion balance was "the first geophysical equipment acquired by the Survey."[208] The purchase of the equipment was also a result of the Survey's long interest in gravity. In 1774, Nevil Maskelyne calculated the density of the earth's crust in northern Perthshire by measuring the deviation of gravity on mountains. Wilson suggests that Maskelyne's calculations might have been the earliest geophysical calculations on the topic, and the Geological Survey grew an interest in the calculations in the early twentieth century.[209] Such an interest led to the Survey's collaboration with the Anglo-Persian Oil Company

---

[207] Smith, 'John Cadman, Baron Cadman, 1877 - 1941', 919.

[208] H. E. Wilson, *Down to Earth: One Hundred and Fifty Years of the British Geological Survey* (Edinburgh & London: Scottish Academic Press, 1985), 153.

[209] Wilson, *Down to Earth: One Hundred and Fifty Years of the British Geological Survey*, 152-153.

in the 1920s, and to the opportunity to use the gravity torsion balance.

On 27 March 1925, Geological Survey Board discussed the possibility of utilising the Eötvös torsion balance in surveying, which was the first time that the idea appeared in its meeting minutes. At this stage, minutes show that the Survey was still unsure whether the utilisation was worth investigating. On the one hand, the utilisation of the balance was "confined to areas and problems of immediate importance where the conditions were considered especially favourable, i.e., where mineral or oil deposits had already been partially indicated by other observations, and where significant differences of specific gravity were likely to occur,"[210] and only in such conditions could the value of the balance establish in the field. On the other hand, even if the conditions had been met, "an investigation on this scale would be very expensive and would take a long time, since the field would presumably have to be covered by a systematic and close network of observations on the lines". Since the cost of the survey of an area of 50 miles square in some part of England would be £2,500 - £3,000 per year or even £5,000 per annum, likely taking 10 years. The first discussion of the proposal ended with a request for further research in order to identify a suitable area to study, and without any decision

[210] 'Minutes of the 21st meeting held at the offices of the Department on Friday, 27th March, 1935,' DSIR 9/112, National Archives, 2.

that could be submitted to the Department.[211]

Two months later, as the cooperation with the Anglo-Persian Oil Company deepened, there seemed to be some progress. Although details of the progress were not available at the meeting, the Board could confirm that the work in Persia "consisted of a series of tests with a torsion balance, the observations being taken from chosen sites over a specially selected area."[212] The meeting also confirmed that Mr. MacDonald[213], the geophysicist who was in charge of the cooperative tests, would return to England one month later to report further details.[214]

The Board did not meet again, or at least there are no available minutes of

---

[211] 'Minutes of the 21st meeting held at the offices of the Department on Friday, 27th March, 1935,' 3.

[212] 'Minutes of the 22nd Meeting held at the Offices of the Department on Thursday, 21st May 1925,' DSIR 9/112, National Archives, 2.

[213] This is supposed to be W. R. MacDonald, who was at time involved in a series of experiments on the gravity torsion balance conducted by the Anglo-Persian Oil Company, starting 1923. The experiments were focused on the Ahwaz anticline in nowadays southwestern Iran, and MacDonald, along with two other geologists Richard Davies and John Hugh Jones, "extended the survey to cover many of the other major structures" till 1927. Richard. J. Howarth, 'Gravity Surveying in Early Geophysics. II. From Mountains to Salt Domes', *Earth Sciences History* 26, no. 2 (2007): https://doi.org/10.17704/eshi.26.2.f04281625w2w7614, 250.

[214] 'Minutes of the 22nd Meeting held at the Offices of the Department on Thursday, 21st May 1925,' 2.

this, to discuss the torsion balance until November 1925, when the estimated cost of “an examination over an area of 2,500 sq. miles” in England was brought onto the agenda.[215] The problem arose because there was an agreement between one estimate submitted by Cadman as board member, to the Department and another submitted by Captain H. Shaw and Mr. E. Lancaster-Jones, while the final results from Persia were still unavailable and not expected until the following summer. A suggestion that was tabled at the meeting was that the final estimate be made by the Department “putting a contingent sum in the Estimates for 1926-27.”[216]

As planned, Dr. W. F. P. McLintock attended the board meeting on 9 July 1926 to present their results from Persia. The minutes show nothing about the content of the report, but the presentation by McLintock must have suggested a success, as it led to the board members asking whether a place in England to test the torsion balance had been in mind. Such a following question indicated an interest of the Board to continue exploring the potential of the torsion balance, and although the answer was no at that time, Ogilvie noted that representatives from the Geological Survey had discussed the issue in a special section at the recent International Geological Congress in Madrid, and

---

215 ‘Minutes of the 23rd meeting held at the Offices of the Department on Thursday, 12th November, 1925,’ DSIR 9/112, National Archives, 4.

216 ‘Minutes of the 23rd meeting held at the Offices of the Department on Thursday, 12th November, 1925,’ 4.

“literature on the subject would soon be appearing”, with the development of apparatus.[217]

There was no further progress on the estimate until November 1927, when the subject was raised again under the titled “geophysical surveys in Britain”, which would be a repeating topic for board meetings in the next decade.[218] By then, as we shall see below, the Geological Survey had purchased an Eötvös torsion balance from local manufacturer Oertling and had tested the equipment preliminarily across the Swynnerton Dyke in Staffordshire, work conducted by Dr. McLintock and Mr. J. Phemister.[219] Meanwhile, the Survey was preparing for a second test with the torsion balance in the Kelvin area in Scotland, which was approved on the board meeting.[220]

While details of the Eötvös torsion balance project had not been confirmed yet, passionate staff at the Geological Survey already started to promote it. As is mentioned earlier in this chapter, Flett was one of them. In February 1927, he sent a letter to the Secretary of the Department of Scientific and Industrial

---

[217] ‘Minutes of the 25th Meeting held at the Offices of the Department on Friday, 9th July, 1926,’ DSIR 9/112, 3.

[218] ‘Minutes of the 29th Meeting held at the Offices of the Department on Wednesday, 9th November, 1927,’ DSIR 9/112, National Archives, 5.

[219] ‘Minutes of the 29th Meeting held at the Offices of the Department on Wednesday, 9th November, 1927,’ 5.

[220] ‘Minutes of the 29th Meeting held at the Offices of the Department on Wednesday, 9th November, 1927,’ 5.

Research, reporting generally on the potential of gravity methods in mining. It was very likely that persuading the Department Secretary was not the only aim of the letter, for the letter was copied to the Treasury as well, as a suggestion of cost that would follow and an effort to secure funds.

In his letter, Flett argued that the Geological Survey had already fallen behind in applying the gravitational method, compared to the Spanish Geological Survey and the Russian Geological Survey who had employed it in field work, as well as when compared to "many oil companies" who had produced successes in mining and prospecting.[221] Flett noted that geologists in Britain were not involved in any of the applications; actually they might even have known very little about the progress, as the positive results of the application produced by nations and companies were not widely accessible to the public. As this chapter has noted, there was indeed a scarcity of well-described torsion balance projects even in academic journals.

In contrast, Flett expected that the British test of the instrument would publish its results rapidly, and the results be open for "inspections by all parties really interested and competent to judge or advise".[222] He also proposed a plan including selecting an area and staff for the test. The Geological Survey Board

---

[221] John Flett to Secretary of Department of Scientific and Industrial Research, 24th Feb. 1927, DSIR 9/34, 1.

[222] Flett to Secretary of Department of Scientific and Industrial Research, 3.

must have already discussed this plan at its meetings. For example, at the July 1926 meeting, while the scientific report was still confidential to participants, the minutes record that they had come to the question whether the report should be ready for publication, and the Board decided that the Director should consider with Sir John Cadman the most suitable method of publication and put forward Cadman's suggestions before the next meeting,[223] At the next meeting, it was reported that a Dr. Jones and a Mr. Macdonald of the Anglo-Persian Oil Company had completed another report which contained all the materials that had existed in McLintock and Phemister's study, and both reports were ready for publication. By then, the board meeting "decided to leave the matter to the Director to arrange with Sir John Cadman."[224] Although later minutes are unclear about what happened next, it seems safe to say that Flett's expectation on publication was reliable since it had been seriously and openly discussed, and there was not obvious disapproval among Geological Survey board members.

Despite his optimism, Flett did not neglect a realistic concern that could vitally impact the test: possibly, there was no problem that had to be solved by using the torsion balance.[225] That is to say, although applying the gravity method in

---

[223] 'Minutes of the 25th Meeting held at the Offices of the Department on Friday, 9th July, 1926,' DSIR 9/112, 3.

[224] 'Minutes of the 26th Meeting held at the Offices of the Department on Thursday, 4th November, 1926,' DSIR 9/112, National Archives, 2.

[225] Flett to Secretary of Department of Scientific and Industrial Research, 1.

mining and surveying would allow Britain to catch up with their colleagues in other countries, and although the application already sounded promising, it remained unnecessary for the Geological Survey to actually purchase one of such instruments to test itself.

In a memorandum in March which was passed to the Advisory Council, Flett repeated his opinions on the situation, adding that McLintock and Phemister had witnessed the Eötvös gravity balance employed in the field in the Middle East. In addition, Flett added that the aim of introducing a torsion balance into Geological Survey's work was not a case of simple catching-up, but a "dual object of training our staff and of proving how far these methods are useful."[226] For the latter, he elaborated that he:

> should select one or two officers of the rank of geologist (of higher) and two technical assistants (or general assistants). We have men competent for the work. In addition we should need to employ probably two labourers, and to buy or hire a motor lorry to transport the instruments and the shields.[227]

---

[226] John S. Flett, 'Memorandum by the Director of the Geological Survey on a Proposed Investigation of the Use of Geophysical Methods in Geological Surveying", 9th March 1927,' DSIR 9/34, National Archives.

[227] Flett, 'Memorandum by the Director of the Geological Survey on a Proposed Investigation of the Use of Geophysical Methods in Geological Surveying'.

And that:

> Special areas would be selected in England and in Scotland where the geological structure is known and where the circumstances are such as to afford a definite and easily executed test of the Eötvös method of geophysical survey.[228]

Although lacking in details, these words indicate that Flett was confident and determined to purchase a gravity torsion balance for the Geological Survey. In the meantime, the Geological Survey Board had been adequately informed of Flett's determination and had started to sort out the financial support for the programme. The process turned out long and ambiguous, but surprisingly, it suggested that a new understanding of the nature of the Survey's work had come into being.

3.4 Financing the Torsion Balance

I now want to retrace some of this story, following how the torsion balance project was seen within the Department of Scientific and Industrial Research, and how funds were sought for the instrument. Meanwhile, within government,

---

[228] John S. Flett, 'Memorandum by the Director of the Geological Survey on a Proposed Investigation of the Use of Geophysical Methods in Geological Surveying'.

Francis Ogilvie had submitted a letter to the Secretary of the Department of Scientific and Industrial Research as early as 5 December 1925, claiming that the Geological Survey was interested in the torsion balance and had been briefed of its basics by the colleagues at the Science Museum.[229] With the support of information and facilities from the Anglo-Persia Oil Company available for the Survey, Ogilvie suggested that the Department should provide an "opportunity in this country for a suitable test of the possibilities of the methods," and thus that they should expect a sum of £15,000 to be expended on further investigations on the torsion balance.[230] More than one month later Henry Tizard, then Assistant Secretary to the Department, sent his reply to Ogilvie's letter on 16 January 1926.[231] The response was a little

---

[229] F. G. Ogilvie to Secretary, 5 December 1925, National Archives UK, DSIR 9/34 Geophysics Investigation into Use of Geophysical Methods in Geol. Surveying, Financial Provision 1927 -, 1. S

[230] Ogilvie to Secretary, 5 December 1925, 3.

[231] As far as is accessible now, only 1 document was properly written and distributed over Ogilvie's letter. In this document, Henry Tizard tried to keep Richard Threlfall informed of Ogilvie's plan, thinking that Threlfall would be interested in it. Threlfall indeed might be interested, not only because he was then a member of the Advisory Council but also for he had spent considerable time on a quartz film torsion balance to measure the variation of gravity. Unfortunately, Threlfall's response is missing. For a biographical account of Threlfall, see H., W. B., 'Sir Richard Threlfall, 1861 - 1932', *Obituary Notices of Fellows of the Royal Society* 1, no. 1 (1 January 1997): 45–53, https://doi.org/10.1098/rsbm.1932.0010.

disappointing, and Tizard tried to warn that the Treasury might not be happy to add the £15,000 into next year's budget, his reason being that:

> No provision for such work was taken in the estimates or was allowed for in determining the margin.[232]

At that time, Tizard felt doubtful that Ogilvie would receive any money in the next financial year; nor did he believe that the proposal would even get recommended.[233] Meanwhile, though, Tizard tried to show his support by encouraging Ogilvie to turn to the consulting engineer and electro-chemist Richard Threlfall, who, due to personal research interest, had a gravity torsion balance of his own, although Threlfall's instrument might not be able to meet the full demand.[234] Nevertheless, the communication over the torsion balance plan between the Geological Survey and its board and the Department of Scientific and Industrial Research seemed to pause and only resumed one year later.

On 24 February 1927, Flett submitted his formal proposal for the gravity torsion balance test to the Advisory Council of the Department. The proposal made three points in general. First, Flett argued that the application of the

---

[232] H. T. Tizard to Ogilvie, 16 January 1926, National Archives UK, DSIR 9/34 Geophysics Investigation into Use of Geophysical Methods in Geol. Surveying, Financial Provision 1927 -, 1.

[233] Tizard to Ogilvie, 16 January 1926, 1.

[234] Tizard to Ogilvie, 16 January 1926, 2.

gravity method to investigate under the earth's surface had proved to be promising and had been widely used by geological surveys in other states and by commercial companies. He summarized the fact that existing positive test results had left the Geological Survey with little information, despite their interest in the instrument and that they had been closely watching the development. Second, although it was still undecided what pragmatic problems a nationwide geophysical surveying could solve, Flett insisted that

> it would be well for us to carry out a restricted programme of geophysical work with the dual object of training our staff and of proving how far these methods are useful.[235]

By "a restricted programme," Flett meant that the Survey would select special areas in England and in Scotland, as they had discussed. The programme would benefit the staff by employing both geologists and technical assistants, where, as Flett expected,

> For this purpose I should select one or two officers of the rank of geologists (or higher) and two technical assistants (or general assistants). We have men competent for the work.[236]

---

235 John S. Flett to Secretary, 24 February 1927, National Archives UK, DSIR 9/34 Geophysics Investigation into Use of Geophysical Methods in Geol. Surveying, Financial Provision 1927 -, 2.

236 Flett to Secretary, 24 February 1927, 2.

In a paragraph later, Flett added that geologists who would be allocated for the geophysical programme would temporarily pause their ordinary work, such as mapping. Apart from personnel arrangements, his wording also suggests that he himself would be in charge of the programme and select geologists. He indicated this by using “I should,” which was not common in his other documents in the file.

Last but not least, Flett stated the estimated cost of the programme:

> The cost of one Eötvös balance and of the other instruments necessary (with spares) is about £1,000 and a programme of several months work could be carried out for £1,500 to £1,700 (not counting the salaries of our established staff employed).[237]

He then explained that the Geological Survey expected to purchase a gravity torsion balance of their own from the manufacturer Oertling, as well as another that the manufacturer had offered to lend. By applying two torsion balances, Flett hoped that they would make quicker progress, as one single torsion balance might be interrupted and perform slow when showing the effect.

Having justified his geophysical programme, Flett added a new level to its significance. Following his possible discussion with Cadman, Flett decided

---

[237] Flett to Secretary, 24 February 1927, 2.

that the results of the survey should be published and made available to the public. On the one hand, he imagined that responses from a wide audience would allow the Geological Survey to find out what exactly the problem there was for the gravity method. On the other hand, the results "would interest a large number of geologists and mining engineers and would afford the basis of an impartial judgement of the uses and limitations of such surveys."[238] It can be inferred from Flett's word that his expected audiences were mainly practical geologists whose work was focused mainly on mining and other economic resources. The expectation reconfirms what people had believed at that time, that the Geological Survey was a helpful reference for economic development, but only an economic reference; or, at that time, Flett found it necessary to present the Geological Survey in this way.

The Advisory Council discussed Flett's proposal on their meeting on 9 March 1927. In contrast to Tizard's pessimistic attitude earlier, the Advisory Council's attitude was positive, reaching the agreement "to recommend that the limited investigations into the use of geophysical methods in geological surveying proposed by the Director of the Geological Survey be approved; and that, if necessary, an addition not exceeding £1,700 be made to the allocation of

---

[238] Flett to Secretary, 24 February 1927, 3.

funds for the work of the Survey by transfer from the 'margin'."[239] The approval and the allocation of funds met both of Flett's request.

When H. Frank Heath, then Secretary of the Department, added another minute to the Privy Council, he provides one more justification for Flett's plan: that launching the programme immediately would assure Britain retain a leading position in the empire in the area of gravity measurement. He noted:

> The Australian Government are very anxious to secure the co-operation of the British Government in a large scale exploration of the auriferous area to the North of Kalgoorlie in Western Australia by means of the Eötvös and other geophysical apparatus. This proposal is coming before the Committee of Civil Research, but if we can get ahead with the proposals of the Director, Sir John Flett, the information which will be published to the world cannot fail to be of great importance, though not, of course, conclusive, to any exploration of the kind contemplated by the Commonwealth Government,[240]

---

[239] 'Extract from Confirmed Minutes of Meeting Held on 9th March 1927', n.d., National Archives UK, DSIR 9/34 Geophysics Investigation into Use of Geophysical Methods in Geol. Surveying, Financial Provision 1927 -.
[240] H. F. H. to Lord President, 15 March 1927, National Archives UK, DSIR 9/34 Geophysics Investigation into Use of Geophysical Methods in Geol. Surveying, Financial Provision 1927 -, 1-2.

And, as a result,

> so that it appears to me that both from a purely scientific, as well as from an imperial point of view, the recommendation of the Advisory Council is sound.[241]

Heath therefore knew Flett's plan and even understood his ambition. He explained again Flett's proposal to the Lord President of the Council, the responsible government minister, saying that Flett's team would consist of three men respectively qualified in mathematics, physics, and geology, a combination showing how the nature of Flett's programme might bring a change to the Geological Survey. Heath's words were strong enough, claiming that the outcome of Flett's programme would "reveal the facts," and that Flett would "guard against any psychological bias in the officers using these instruments."[242]

While Heath's minute was being received and considered, he sent another note to the Treasury. The note was drafted on 14 and dispatched on 21 March. It provides an insider's view justifying the funds, and thus sheds light on the nature of the Geological Survey's new geophysical programme, or at

[241] H. to Lord President, 15 March 1927, 2.

[242] H. to Lord President, 15 March 1927, 2.

least on how the government perceived it. The memorandum refers to “the development grant-in-aid.” As it explains,

> The scope of the development grants-in-aid as explained to Parliament is defined on page 67 of the Civil Service Estimates 1924-24, Class IV. vote 9, under sub-head D. 2., and includes Geological Survey. As, however, the Geological Survey is staffed by established civil servants and is engaged in a steady programme of work it has, in recent years, been semi-officially agreed between H. M. Treasury and the Department that the development grant-in-aid is not applicable to the work of the Survey without specific Treasury authority. By a parity of reasoning the normal provision for the Survey may properly be augmented from the development grant-in-aid with Their Lordships’ authority when there is an expansion in the normal service through a Government requirement (as in 1920-21 – see appropriation account, page 377) or when an unforeseen research requirement emerges and is approved by the Advisory Council.[243]

First of all, the memorandum gives an impression that the Geological Survey’s proposed programme was beyond its conventional activities. On the one

---

[243] ‘Memorandum to the Secretary, H. M. Treasury’, 14 March 1927, National Archives UK, DSIR 9/34 Geophysics Investigation into Use of Geophysical Methods in Geol. Surveying, Financial Provision 1927 -, 1-2.

hand, it went beyond the "normal provision for the Survey," adding new methods and techniques to the survey. On the other hand, it challenged the allocation of funds that used to be under tacit consent between the Department of Scientific and Industrial Research and the Treasury. As the memorandum suggests, the Survey had been expected to create funds for themselves from their savings, but the geophysical programme was in this sense exceptional. But it was not surprising: the Treasury's development grant was exactly "intended to be used if necessary for such purposes."[244] Drafting another memorandum to the Treasury, Lloyd confirmed his reasoning that it should not be the default settings that the Geological Survey paying for its novel programmes by itself.[245] As he elaborated his argument:

> It is not desirable, in principle, to make it a condition of a piece of research of this kind that savings must be made on the routine service of the Geological Survey in order to pay for it. It will be a useful precedent moreover to submit to the Treasury a case of research in methods of geological survey and obtain Treasury authority to use the margin of it.[246]

---

244 'Memorandum to the Secretary, H. M. Treasury', 14 March 1927, 3.

245 Ll. S. Lloyd to the Secretary, 14 March 1927, National Archives UK, DSIR 9/34 Geophysics Investigation into Use of Geophysical Methods in Geol. Surveying, Financial Provision 1927 -.

246 Lloyd to the Secretary, 14 March 1927.

By early April, however, it had become clear that the Treasury did not sanction the funds. Letters within the Department now suggests that staff in the Department had tried to argue against the Treasury's primary rejection. For example, Ll. S. Lloyd said in a minute to Tizard that he had written an official letter to the Treasury in March, claiming that the purpose of Flett's geophysical programme met and did not go beyond the scope of the Treasury's development grant-in-aid.[247] In the end, Lloyd suggested that a new and longer letter be sent to the Treasury arguing again for funding, with Heath's imperial argument included. Tizard approved.

Based on the content of Lloyd's newly drafted to the Treasury, we can infer that the Treasury did not sanction the fund because it did not think it necessary to do so. As Lloyd understood, their

> sanction to carry out this investigation as a charge on the provision actually shown in the estimates for the Geological Survey was not sought, since no further financial authority is, in their view, necessary.[248]

---

[247] Ll. S. Lloyd to Tizard, 8 April 1927, National Archives UK, DSIR 9/34 Geophysics Investigation into Use of Geophysical Methods in Geol. Surveying, Financial Provision 1927 -.

[248] Ll. S. Lloyd to The Secretary, H. M. Treasury, 9 April 1927, National Archives UK, DSIR 9/34 Geophysics Investigation into Use of Geophysical Methods in Geol. Surveying, Financial Provision 1927 -, 1-2.

With this in mind, Lloyd explained again that the programme was of "scientific urgency."[249] To convince the Treasury, Lloyd not only repeated Flett's and Heath's arguments, but also referred to the authority of the Advisory Council, that the government had "always relied on the Advisory Council for the determination of scientific priority and order of expenditure on the approved services,"[250] concluding that the fact that the Advisory Council had recommended Flett's programme should have been taken seriously by the Treasury. Lloyd referred to Lord Balfour,[251] whose words were quoted here that "we should get on without delay."[252]

Next, Lloyd reassured the Treasury that the programme had been reasonably planned to reassure against any worries of the Treasury. Particularly, he claimed that the geophysical programme was not necessarily an open

---

[249] Lloyd to The Secretary, H. M. Treasury, 9 April 1927, 3.

[250] Lloyd to The Secretary, H. M. Treasury, 9 April 1927, 3.

[251] Although this might be surprising, it is very likely that the "Lord Balfour" here was exactly the same person as the one in "Balfour Declaration." Where Arthur James Balfour said the quoted words is unknown, but Balfour was indeed interested in science and its administration, so he might actually have said the words. Apart from numerous biographies of Balfour, a particularly interesting source is Lord Rayleigh's short memoir Lord Balfour in his Relation to Science, which was published soon after Balfour's death and was focused on his scientific thoughts and activities. See 'Lord Balfour in His Relation to Science', *Nature* 127, no. 3194 (1 January 1931): 87–87, https://doi.org/10.1038/127087a0.

[252] Lloyd to The Secretary of H. M. Treasury, 9 April 1927, 4.

commitment; rather, it would be “a limited one” that would “be completed in a few months.”[253]

When supporting Flett’s geophysical programme, Lloyd raised up a point that looks critical in understanding the nature of the Geological Survey’s work and its relation to geophysics. After setting the limited scope of the programme, Lloyd continued to argue that:

> It can probably, and must if necessary, be carried out as a charge on the provision specifically voted for the service of the Geological Survey. The Committee of Council do not hold that the provision for this service is not applicable to research in the improvement of the methods of geological survey. On the contrary, they consider that the Minister is responsible for maintaining the professional efficiency of the service at the highest pitch; and it is the constant effort of the Director to secure this result. The proposed investigation of geophysical methods is part of this process, differing only in degree from the continuous action taken to maintain the efficiency of the Survey.[254]

Despite baffling wording, Lloyd was trying to say that exploring the geophysical methods was part of, and would benefit in general, the Geological Survey’s work. Comparing with the statements quoted in Chapter 2 which

---

[253] Lloyd to The Secretary of H. M. Treasury, 9 April 1927, 2.

[254] Lloyd to The Secretary of H. M. Treasury, 9 April 1927, 2-3.

confirmed the Survey's contribution in providing geological data for economic developments, Lloyd's words are not as clear nor as decisive, but, for him, the Survey's work must have already gone beyond drawing maps in the most conventional way. As a result, it was not only possible but also necessary that the Geological Survey continued to improve its methods and increase its efficiency; and to realise the improvement, the Survey should be allowed to try the torsion balance.

Apart from explaining again that the Geological Survey's programme required additional funding instead of paying themselves, Lloyd's letter provided a new perspective to understand the Survey's work. Possibly, his words reflected an attitude held by at least part of the Department of Scientific and Industrial Research, that the Survey's exploration to a new method should be encouraged. It also reflected that the understanding of the Survey's work was not limited to what they had practiced and produced, i.e. drafting and compiling maps, and the Survey was expected to be an institution that was able to innovate on its own.

Having said so, the letter itself was not enough, again, to persuade the Treasury. Later that month Tizard and Lloyd were asked to meet privately with the Treasury and talk it through. Still, A. P. Waterfield, who initiated the invitation for a meeting, was concerned about the "interpretation of" the "financial powers" between two departments.[255] That is to say, the Treasury did not agree with the Department of Scientific and Industrial Research on the allocation of funding for such programmes – a problem that had a larger scope than a single geophysical test. There were no following documents that allow us to describe the content of the meeting, although the later development of the geophysical programme showed that the Survey got some money eventually.

[255] A. P. Waterfield to H. T. Tizard, 26 April 1926, National Archives UK, DSIR 9/34 Geophysics Investigation into Use of Geophysical Methods in Geol. Surveying, Financial Provision 1927 -, 1.

The first geophysical equipment acquired by the Survey – the Eötvös Torsion Balance.

Figure 3.2. Eötvös Torsion Balance purchased by the Geological Survey. From: H. E. Wilson, *Down to Earth: One Hundred and Fifty Years of the British Geological Survey* (Edinburgh & London: Scottish Academic Press, 1985), 153.

3.5 Failure or Success?

The story of the gravity torsion balance did not end with the silence from the

Treasury and the last page of relevant files, because it is not even determined what the end really was, or what the outcome of the tests was. Katherine Anderson has a focused investigation of the use of the Eötvös torsion balance in the Geological Survey and identifies the Survey's interest in the context of "the economic and technocratic vision of the British Commonwealth."[256] As has been learnt from Heath's letter, the United Kingdom, with Australia and Canada similarly interested in the method, was not the only country that explored the potential of the Eötvös torsion balance in the 1920s. Using different sources from this chapter,[257] Anderson argues the protectionist requirements in the Commonwealth largely affected the choice of the instrument and the performance of the experiments using it. Compared to other leading models of the Eötvös torsion balance in the world at that time such as the Suss in Hungary, the Britons chose the Messrs. L. Oertling, Ltd,

---

[256] Katherine Anderson, 'An "Experimental" Instrument: Testing the Torsion Balance in Britain, Canada and Australia', *Annals of Science* 76, no. 1 (2019): 72.

[257] Anderson refers to a large number of sources from British Geological Survey Archives, and the work and value that she has added to the literature are very much appreciated. Unfortunately, due to the pandemic lockdown, the British Geological Survey Archives remained inaccessible in all my research and writing-up years, and I regret being unable to use it in my own research project. Still, sources used in this chapter and in this dissertation, which Anderson paid less attention in her paper, shall act as an important perspective into the case of torsion balance, as has been explained in chapter 1.

which had performed disappointingly in several tests. Thus, Anderson remarks that the experiment with the Oertling torsion balance was not only a scientific one to produce reliable survey results, being “experimental in terms of whether such geophysical investigations could be added readily to the other survey work of officers of the Geological Survey,” but was also “part of larger national experimentation with post-war economic and technical development policies,” because the decision to purchase the Oertling torsion balance instead of other models was largely influenced by the Safety-Guarding of Industries Act of 1921.[258] The act renewed in 1926, and the protectionism behind it was also the reason for Australia buying the same type of unreliable torsion balance soon afterwards.[259]

In Anderson’s account, the Geological Survey’s test of the Eötvös torsion balance was destined to be a failure, and actually failed, because the Survey couldn’t purchase a reliable instrument due to commonwealth policies. However, for geologists and officers at the Geological Survey who witnessed and recorded the geophysical programme, the purchase was far from a failure. As John S. Flett remembered, the Eötvös torsion balance was tested in Persia at first, and the test “seemed so promising that it was decided to

---

[258] Anderson, ‘An “Experimental” Instrument: Testing the Torsion Balance in Britain, Canada and Australia’, 75-76.

[259] Anderson, ‘An “Experimental” Instrument: Testing the Torsion Balance in Britain, Canada and Australia’, 75-76.

acquire a torsion balance and test out the methods in this country."[260] After tests in various areas within Britain, he added that the "investigations showed that the torsion balance was an extremely useful instrument for mapping suitable concealed structures such as faults, dykes, unconformities, buried channels and sub-drift topography."[261] For the record, it should be noted that the results turned out good for senior Geological Survey staff. The potential of the torsion balance appeared equally, if not more, promising in Edward Bailey's account, as he listed every test with its time, location, and result, such as:

> 1927-28. Drifted-filled channel aligned with the Kelvin river, N.W. of Glasgow. Result: […] This result is probably trustworthy and, if so, is of great scientific interest.
>
> 1928-29. Pentland Fault, S.W. of Edinburgh. Result: An exact sub-drift position of the fault was suggested, and also certain structural accompaniments.

---

[260] Flett, *The First Hundred Years of the Geological Survey of Great Britain, 1835-1935* (London: H. M. Stationery Office, 1937), 189.

[261] Flett, *The First Hundred Years of the Geological Survey of Great Britain*, 1835-1935, 189.

1930. Thrussington, Melton Mowbray district […]. Result: Gravity anomalies suggested an uneven sub-Trias floor of Precambrian rocks. […] A known fault gave a clear signal.[262]

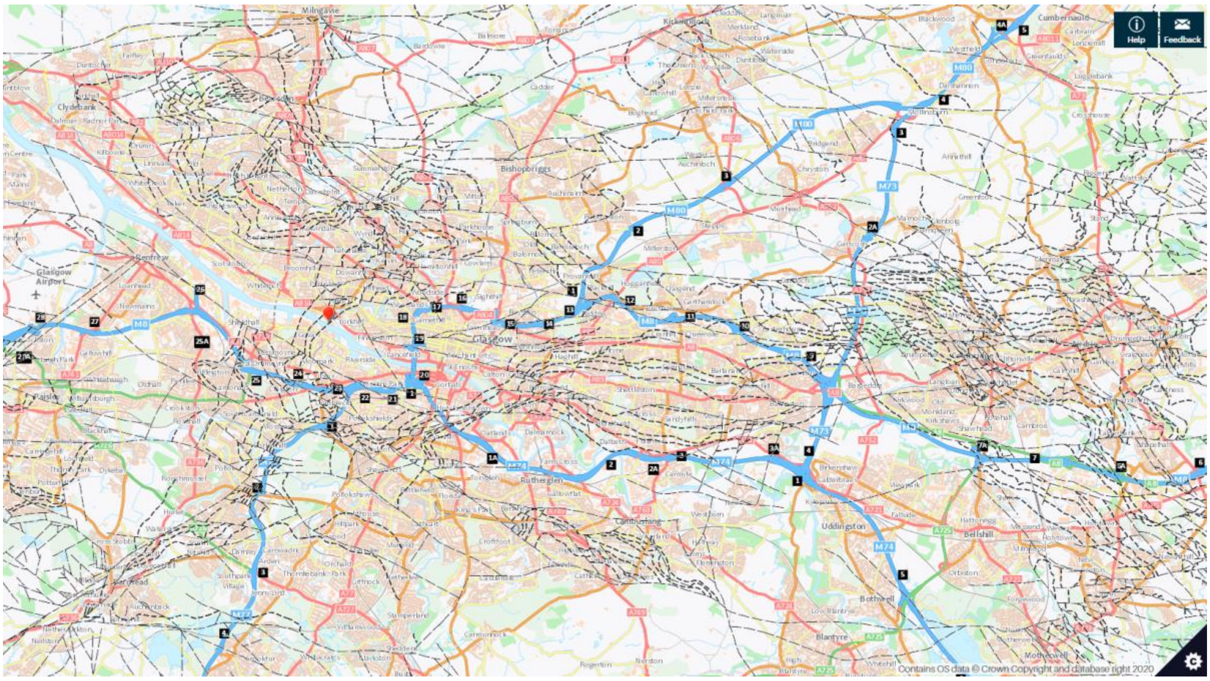


Figure 3.3. Faults near the River Kelvin, Scotland. British Geological Survey materials © UKRI [2024].

None of these reports create suspicion that the test of the equipment failed, and the outcomes of the torsion balance seemed as satisfying as expected.

McLintock and Phemister's report on the performance of torsion balance, however, offered a third account for the Thrussington test, in which they noted

[262] Edward Bailey, *Geological Survey of Great Britain* (Thomas Murby & Co., 1952), 207.

that the Oertling torsion balance's "daylight reading at any season of the year was quite unreliable."[263] According to their report, the reading on the torsion balance showed an odd inconsistency:

> This unreliability does not depend entirely on variation of temperature; it is greatest on a bright sunny day and is least on a dull, cloudy one; but under any conditions of daylight the balance readings are, in our experience, quite untrustworthy.[264]

Having said so, the result was not surprising; on the contrary, McLintock and Phemister had been aware of the possible "unreliability" that the Oertling torsion balance might produce. As they said in the report:

> It has been known for a long time that observations made during daylight under field conditions tend to be less satisfactory than those made at night and, as work at night, especially with the visually-read type of balance, has obvious disadvantages, satisfactory behavior during daytime is a claim constantly made by modern balance-makers for their

---

[263] W. F. P. McLintock and James Phemister, 'Report on Tests Conducted with Suss Balance and Oertling Balance at Thrussington, Leicestershire, December 13th-20th, 1929.', n.d., National Archives UK, DSIR 36/1396 Geological Survey: Mainly GSRC Papers (some relating to the Australian Geophysical Expedition) on the usage of different geophysical instruments, 1.

[264] McLintock and Phemister, 'Report on Tests Conducted with Suss Balance and Oertling Balance at Thrussington, Leicestershire, December 13th-20th, 1929,' 1.

instruments.[265]

Plus, it seemed that “untrustworthy” did not mean worthless in McLintock and Phemister’s context, and the negative description of the balance’s performance does not entirely contradict what Bailey remembered as showing “a clear signal” of a known fault. It might have been the case that the torsion balance could roughly portray the geological structure underground, but could not tell accurately what lay beneath it. The latter, indeed, was the main purpose that it was used in mining and surveying industry. On the other hand, McLintock and Phemister decided that, considering its mere ability to find underground structure, it would still be used as a double check with “the magnetic anomaly outlined by Mr. A. F. Hallimond in the neighbourhood.”[266] The implicit decision that the geophysical work at the Geological Survey, whether conducted mainly on a personal basis or a governmental basis, was regarded as one project, and there was not yet a transcending assumption of which technique would win.

---

265 McLintock and Phemister, ‘Report on Tests Conducted with Suss Balance and Oertling Balance at Thrussington, Leicestershire, December 13th-20th, 1929,’ 1.

266 McLintock and Phemister, ‘Report on Tests Conducted with Suss Balance and Oertling Balance at Thrussington, Leicestershire, December 13th-20th, 1929,’ 1.

3.6 Conclusion

This chapter has examined what has been regarded by one historian of the Geological Survey as its first attempt to apply geophysical techniques in their work – buying and testing a Eötvös gravity torsion balance. Another historian (Anderson) regards the episode as a failure. Through almost every step in this geophysical project, it is very clear that the project was immature, showing an absence of important targets and reliable plans. Although the project was not intended to be an original research, an academic today would certainly evaluate it as one in lack of plausible research questions, logical methods, and realistic schedules. Nevertheless, the Survey was able to gain experience of the torsion balance and therefore also one important means of geophysical investigation. Even if the success of the tests might not be completely straightforward, it might be positive enough for the Survey staff that they *had* the instrument.

On the other hand, although just having the torsion balance was not enough to be regarded as a leap in the development of the Survey's work, the geophysical project reflected a potential leap in understanding the Survey's work. Senior staff at the Survey, including Flett, showed an ambition that the Survey was willing to seek and invest in new techniques, an ambition consisting of both a desire to catch up with advancing techniques and a wish to learn. This ambition was also sensed by the government staff who would support the potential of technical progress in the Survey. The support was based on a national economic concern, but also indicated a belief that the Survey could and should innovate itself to improve its work. Both the Survey and its governmental links had realised that geophysical techniques were new to the Survey's work. Such techniques were welcomed, but would not yet change the nature of the Survey's work.

Chapter 4: Surveying, Mining, and Geophysical Work in the World War II

The link between war and science has been a popular topic in the literature of History of Science. When it comes to geology, historians' case studies tend to be very specific, especially when it comes to the twentieth century, concentrating on the two World Wars as well as the Cold War. Edward P. F. Rose and Michael S. Rosenbaum have indicated in several places that the cooperation between geologists and the military in Britain can be dated back to the nineteenth century, cooperation rooted in their common interest in the "best use of ground."[267] On the one hand, military use of the ground requires an understanding of the geology behind (or in this case, beneath): the selection of locations of defensive facilities, the plan of routes on battlefields, the utilisation of soil, and so on. On the other hand, well into the twentieth century, geologists provided expert advice on a larger variety of military actions: providing groundwater supply, building tunnels to protect or damage facilities, finding sites for military constructions, and so on.[268] Rose and

---

[267] E.P.F. Rose and M.S. Rosenbaum, 'British Military Geologists: The Formative Years to the End of the First World War', *Proceedings of the Geologists' Association* 104, no. 1 (1 January 1993), https://doi.org/10.1016/S0016-7878(08)80153-8, 41.

[268] Rose and Rosenbaum, 'British Military Geologists: The Formative Years to the End of the First World War', 41. We would see some cases in more detail later in this chapter.

Rosenbaum's evidence for the existence of military geology in the nineteenth century lies in the background of a generation of geologists, who received military training as "the basis for a distinguished geological career."[269] For example, James Smith of Jordanhill who was a military officer in the Renfrewshire Militia, Scotland, was also an early advocate of Pleistocene geological changes. George Bellas Greenough was a Light Horse Volunteer and also a founder and the first president of the Geological Society of London. Henry Thomas de la Beche, arguably the first Director of the Geological Survey, spent two teenage years at the Junior Department of the Military College at Great Marlow; and Roderick Impey Murchison, who was successor of de la Beche and who was famous for establishing the Silurian and Permian systems and was once Director of the Geological Survey, served in the Regular Army before becoming a geologist.[270] The list here is not exhaustive.

In another paper, Rose provides more evidence to illustrate a close connection between British geologists and the military dating back to the nineteenth century. An early case was J. MacCulloch's geological map of Scotland which, Rose argues, was "the by-product of two specific military geological tasks."[271] MacCulloch joined the Royal Artillery in 1795 after a five-

---

[269] Rose and Rosenbaum, 'British Military Geologists: The Formative Years to the End of the First World War', 42.

[270] Rose and Rosenbaum, 'British Military Geologists: The Formative Years to the End of the First World War', 42.

[271] Edward P.F. Rose, 'Geologists and the Army in Nineteenth Century Britain:

year training in medicine. In 1804, he became chemist and assayist at the Board of Ordnance, the predecessor of what became the Ordnance Survey, and started lecturing at the Royal Military Academy, Woolwich, and training officers for the Artillery and Royal Engineers. From 1819 to his death in 1835, MacCulloch was lecturer in geology at the East India Company's military seminary in Addiscombe. His change in career might be the result of his election into the Geological Society in 1809 and his first geological assignment to "find in Britain a limestone suitable for millstones used in gunpowder manufacture."[272] He spent several years working in the field across England, Wales, and Scotland until deciding to dig suitable quarries on the Isle of Skye in 1812. The other geological task of MacCulloch's came from the Board of Ordnance in 1814, and his task was to support the trigonometrical department's work. As it turned out, geologists found that there are "unacceptable" inconsistencies between trigonometrical and astronomical measurements, and MacCulloch helped with fieldwork to mitigate the inconsistency starting from Scotland.[273] Since he received few instructions on the specific outcome that the trigonometrical department was expecting from

---

A Scientific and Educational Symbiosis?', *Proceedings of the Geologists' Association* 107, no. 2 (1 January 1996), https://doi.org/10.1016/S0016-7878(96)80006-X, 130.

[272] Rose, 'Geologists and the Army in Nineteenth Century Britain: A Scientific and Educational Symbiosis?', 130.

[273] Rose, 'Geologists and the Army in Nineteenth Century Britain: A Scientific and Educational Symbiosis?', 130.

him, the task was completed with “a geological map of Scotland as a whole,” although such a map did not show much military value.[274] Although he was made militarily redundant in 1820s, MacCulloch remained influential to military geology education by publishing two geological textbooks (*A Geological Classification of Rocks* and *A System of Geology*) afterwards. Both books were intended to be used for his teaching at the military seminary in Addiscombe, and the publication of them benefitted profoundly from the financial support of the East India Company.[275]

On the other hand, Rose starts to question whether the military received reciprocally from geologists in such a relationship, and his answer is yes. By referring to the career experience of two military officers, Rose argues that geology was a practical subject for the military. For Richard Baird Smith, who was trained with the East India Company in Addiscombe, military geology was “fascinating” and “meriting the attention of the Corps of Engineers.”[276] It was an applied science especially useful for the potential of “siting boreholes,”

---

[274] Rose, ‘Geologists and the Army in Nineteenth Century Britain: A Scientific and Educational Symbiosis?’, 130.

[275] Rose, ‘Geologists and the Army in Nineteenth Century Britain: A Scientific and Educational Symbiosis?’, 130-131.

[276] Rose, ‘Geologists and the Army in Nineteenth Century Britain: A Scientific and Educational Symbiosis?’, 139. Quoted from SMITH, R. B. 1849. *Essay on geology, as a branch of study especially meriting the attention of the Corps of Engineers. Corps Papers, and Memoirs on Military Subjects; of the Royal Engineers and the East India Company's Engineers*, 1, 27-34.

"road alignment and construction," and "bridge building."[277] As for Frederick Wollaston Hutton, the value of military geology lied in

> Predicting sources of fuel (coal); potable water (borehole site selection); site selection for military encampments; development of building stone and aggregates; foundations for major engineering works, road and tunnel alignment; diggability of ground for tactical earthworks; factors influencing cross-country movement; fordability of rivers and stability of bridge abutments – and terrain assessment for military purpose.[278]

As Rose summarises, what Hutton remembered "were precisely the British military applications of geology in World War Two."[279] Although we will see in this chapter that the specific techniques and organisations of geology actually presented differently in the Second World War, there was indeed a similarity in the main purposes of wartime geological actions, with water and resources remaining the key targets.

This chapter will explore how the wartime arrangements during the Second World War influenced the geophysical agenda of the British Geological

---

[277] Rose, 'Geologists and the Army in Nineteenth Century Britain: A Scientific and Educational Symbiosis?', 139.
[278] Rose, 'Geologists and the Army in Nineteenth Century Britain: A Scientific and Educational Symbiosis?', 139.
[279] Rose, 'Geologists and the Army in Nineteenth Century Britain: A Scientific and Educational Symbiosis?', 139.

Survey. As we have seen in the past chapters, by the breakout of the war, the British Geological Survey had made its first steps in applying geophysical techniques and instruments in its surveying, although the step did not yet amount to a substantial and reliable leap in geophysical applications. It is very natural to assume that wartime demands would have left little chance for the British Geological Survey to practice untested surveying methods, and indeed, this chapter will show that the Survey also needed to continue its surveying and mapping work in a conventional way. However, we will then see that the possibility of geophysical developments did not disappear, and that the Survey could have its use in wartime geophysical efforts.

4.1 Geological Survey's Wartime Work

As for the Second World War, we continue to start with the memoirs of Geological Survey directors, which provide a detailed account of much of what had happened during the years. This time the main source is Bailey's memoir, which provides a general view of the Survey's wartime contributions, and confirmed the transformation of role from "routine map and memoir production" to "a consultant fashion to the forces and supply agencies at home and abroad", such as in the following aspects:

(1) home mineral resources, with a wartime importance enormously

enhanced by need to economise in shipping and foreign exchange;

(2) underground water for new airfields, camps and factories; and

(3) subterranean facilities for storage and personnel.[280]

Bailey explained how the Geological Survey's work went on with each resource, including water, coal, oil-shale, and gemstones. As the themes of 93 wartime pamphlets suggest, their key projects included:

> Water, 48; Scottish Limestones, 8; Coal and Oil Shale, 7; Refractories, 7; Iron Ores and Magnetic Survey, 5; Phosphates, 3; Felspar, 3; Mica, 2; Sand and Gravel, 2; and Barytes, Diatomite, General (for the Lothians), Glauconite, Ochre, Peat, Slate, Tin, one apiece.[281]

These wartime pamphlets not only met military demands, but also recorded "a great mass of carefully co-ordinated facts" which were used in the transition back to peacetime work after the war.[282] We will now investigate what exactly promoted the transition of the role of the Survey, and how it was relevant to both the Survey's geophysical and non-geophysical work.

---

280 Edward Bailey, *Geological Survey of Great Britain* (Thomas Murby & Co., 1952), 240.

281 Bailey, *Geological Survey of Great Britain*, 245.

282 Bailey, *Geological Survey of Great Britain*, 245.

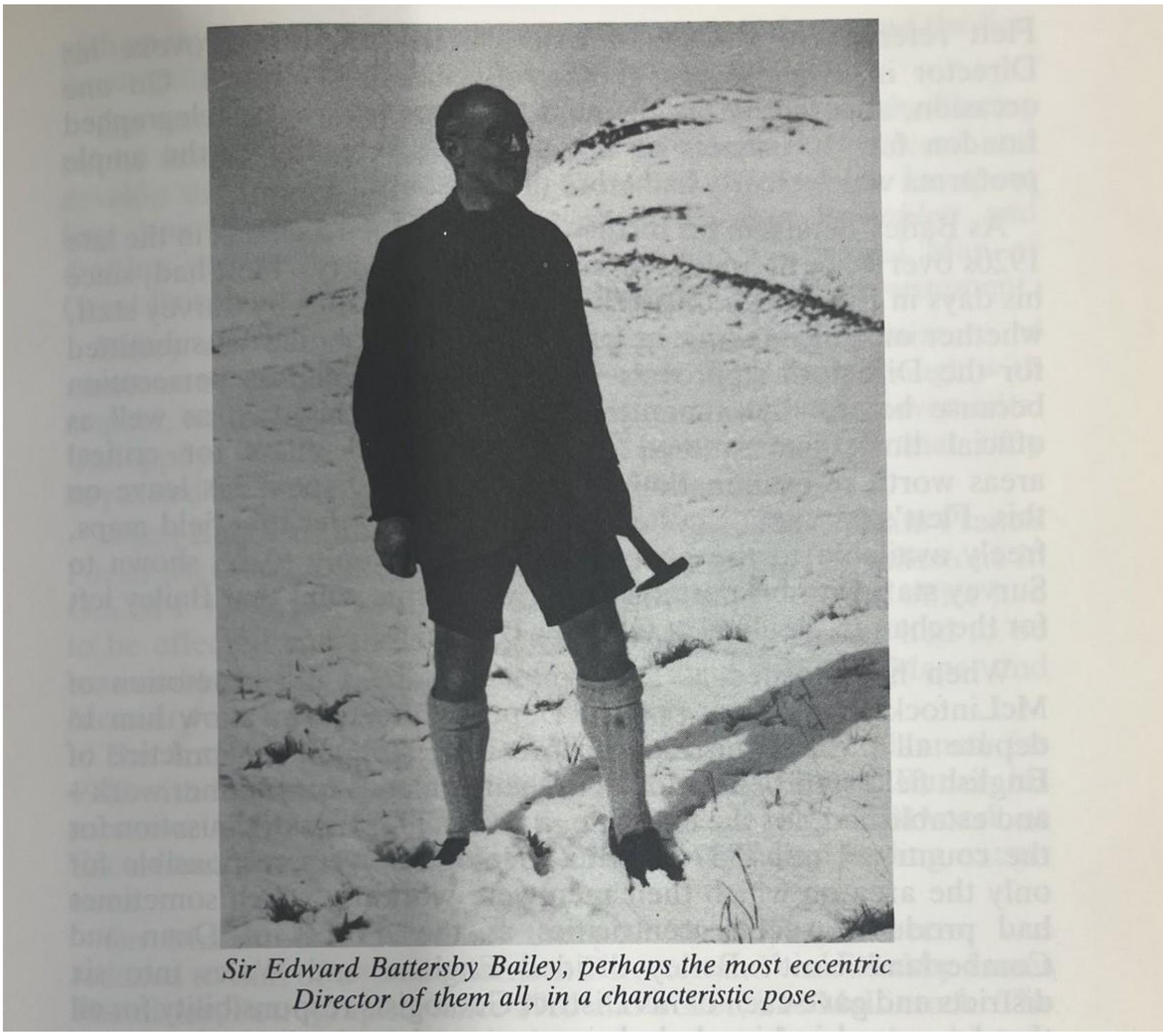

Sir Edward Battersby Bailey, perhaps the most eccentric Director of them all, in a characteristic pose.

Figure 4.1. Edward Bailey. From: H. E. Wilson, *Down to Earth: One Hundred and Fifty Years of the British Geological Survey* (Edinburgh & London: Scottish Academic Press, 1985), 23.

4.2 Arrangements for the Department of Scientific and Industrial Research and the British Geological Survey

With the same scarcity of literature on the history of the Department of Scientific and Industrial Research, apart from that on its beginning years, it is difficult to say for sure how the DSIR was organised as part of war efforts. If Henry Melville's account is reliable, then the impact of the war on the department might not have been huge, as the government had made two "vital decisions" that scientific workers were "to be largely, in some cases almost entirely, reserved from entry to the armed forces," and that, "in the first instance at least, the staff of research institutions should not be substantially broken up as a means of strengthening other such institutions whose work must necessarily expand."[283] Melville claimed that such a policy "was generally applied to DSIR, though not rigidly of course, because some staff were made available to other departments," and in fact, "DSIR establishments were turned over, as quickly as possible, to work of immediate war-time importance."[284]

Examples of "DSIR establishments were turned over" in Melville's account included the Road Research Laboratory, which "dropped almost all its work on roads" for "the study of the civil engineering problems of civil defence," and assisting the Royal Air Force in operations "against the Möhne dam and in other offensive applications of its acquired experience of the effects of explosives on structures and how those effects could best be measured and forecast," as well as contributing its expertise to "the construction of concrete

---

[283] Harry Melville, *The Department of Scientific and Industrial Research* (London: Allen and Unwin, 1962), 40.

[284] Melville, *The Department of Scientific and Industrial Research*, 40.

runways on airfields." The Building Research Station was involved in some of these projects as well as the study of "building materials and of rapid repair of bomb-damaged structures." The Food Investigation Organisation assisted the Ministry of Food and the Forces in dehydrating foods.[285]

The number of DSIR sub-branches that Melville mentioned is limited. As for the British Geological Survey, reports on its wartime arrangements must be discovered somewhere else, although Melville's is still helpful for reference. In his memoir, Edward Bailey confirms that no Geological Survey staff was admitted "into the fighting ranks."[286] Specifically, he states that the military "took very few … geological consultants on to its staff, preferring in large measure to come to the Survey with specific problems."[287] As he remembered, W. B. R. (William Bernard Robinson) King became Head Geologist to the Army after the war began, although King no longer worked at the Survey by that time. J. V. Stephens might have been the only Geological Survey staff who held the only military position offered to the Survey.[288] Bailey

---

[285] Melville, *The Department of Scientific and Industrial Research*, 40-41.

[286] Bailey, *Geological Survey of Great Britain*, 240.

[287] Bailey, *Geological Survey of Great Britain*, 242.

[288] Bailey, *Geological Survey of Great Britain*, 242-243. Unfortunately, there is no more detailed account on the position; nor is there much information about J. V. Stephens. Bailey noted that Stephens had qualifications in both engineering and geology (Bailey, *Geological Survey of Great Britain*, 243). Stephens must have gained his qualifications, at least that in geology, at Liverpool University in 1920s, when he was a fellow student of George Hoole

himself also travelled once to Malta with the military in early 1943 to investigate the underground water and irrigation of the area, although, as the investigation suggested, the trip had little military benefit.[289]

Of course, it was impossible that the Geological Survey could stay free from the effects of the war. Apart from their main building in South Kensington being occupied by the headquarters of the London Civil Defence Region,[290] the war demanded the Survey to alter their focus, although not abruptly. One of the notable alterations was the arrangements for coal surveying. After a new Ministry of Fuel and Power was created out of the Department of Mines in 1942, retaining responsibilities for general mining operations, the Survey was responsive to inquiries on prospect mining areas for their years of steady work on the subject.[291] As Bailey proudly described the Survey's advising:

Mitchell, with whom he built up a warm friendship working together at the Geological Survey's York office (Cyril James Stubblefield, 'George Hoole Mitchell, 31 December 1902 - 11 March 1976', *Biographical Memoirs of Fellows of the Royal Society* 23 (1 January 1997), https://doi.org/10.1098/rsbm.1977.0014, 370). Stephens had worked on the mapping of Derbyshire in 1930s (Bailey, *Geological Survey of Great Britain*, 231), and authored the *Geological Survey's memoir Wells and Springs of Derbyshire* in 1929 (J. V. Stephens, Wells and Springs of Derbyshire, *Memoirs of the Geological Survey* (Water Supply) (London: His Majesty's Stationery Office, 1929).

289 Bailey, *Geological Survey of Great Britain*, 243.

290 Bailey, *Geological Survey of Great Britain*, 238.

291 Bailey, *Geological Survey of Great Britain*, 251.

> The amount of assistance given by the Geological Survey steadily increased. In most areas officers started by adding surface advice to their more normal coalfield duties; but from the latter half of 1942 [W.] Edwards and [S.] Buchan had to devote themselves extensively to crop investigation, working from Wakefield and Chesterfield respectively. Mitchell, at the same time, was heavily engaged in the Midlands. They all thoroughly enjoyed the mining camp atmosphere of the adventure. Naturally they not only gave advice, but also recorded information afforded by the consequent temporary exposures. In Yorkshire the Survey was able at once to suggest suitable prospecting areas, two of which yielded over 1,000,000 tons apiece. In the Notts-Derby area, not recently revised, a special set of wartime prospecting maps was prepared for the Directorate of opencast mining.[292]

---

[292] Bailey, *Geological Survey of Great Britain*, 251. Another remarkable point that Bailey made following the quoted paragraph is that the mining staff were surprisingly aware of their ecological influence. As he then described: "opencast working was strictly regulated to prevent, so far as possible, the production of permanent unsightly deserts. It was laid down that consent must be obtained from the Ministries of Agriculture and of Town and Country Planning before any specified site might be opened up; and to avoid vexatious disturbance no coal under 3 feet in thickness was to be considered (Bailey, *Geological Survey of Great Britain*, 252)." The point here may be interesting for someone who has an interest in both the Geological Survey and history of environment, planning, and geo-conservation, or someone who is interested in the departmental interaction around the Geological Survey.

4.3 Hydrogeological Survey during the War

The groundwater survey is a good example to illustrate the British Geological Survey's work during the war, thanks to the relatively abundant literature. The link between groundwater survey and the British military was established as early as the World War I. King, who Bailey referred to as "invited back to the Army,"[293] had been one of the two British officers deployed to General Headquarters of the British Expeditionary Force in northern France in May and June 1915, where he was "tasked with compiling data and providing advice on water supply."[294]

Edward P. F. Rose argues that recruiting hydrogeologists "was an innovation for the British Army, was significant in contributing to the water supply infrastructure that underpinned final victory in at least three major theatres of war, and was an influence on the post-war development of hydrogeology in the UK."[295] King at the Western Front was his case study on one of the "three major theatres of war," the others being the Gallipoli Peninsula and Egypt. By then, the British Army was used to obtaining small portions of potable water

---

293 Bailey, *Geological Survey of Great Britain*, 242.

294 Rose Edward P. F., 'Groundwater as a Military Resource: Pioneering British Military Well Boring and Hydrogeology in World War I', *Geological Society, London, Special Publications* 362, no. 1 (1 January 2012), https://doi.org/10.1144/SP362.4, 53.

295 Rose Edward P. F., 'Groundwater as a Military Resource: Pioneering British Military Well Boring and Hydrogeology in World War I', 70.

"from streams, rivers and other surface waters, from civilian wells and distribution systems, and from near-surface groundwater."[296] It was also a time when a generation of military officers "had no routine training to acquaint them with developments in either geology or well drilling."[297] While Rose notes that there had been a long tradition throughout the nineteenth century in the British military education of teaching elementary geology "related to water supply and the siting of boreholes,"[298] such training had vanished by the breakout of World War I, possibly as a result of the fact that small portions of water supply had been adequate for most military operations. The Western Front, however, turned out to be astonishingly prolonged, and trench warfare meant that the demands for water would easily overwhelm the supply. Thus, Rose suggests, the normal means of securing the supply of fresh waterwas blocked, as "the concentration of an increasingly large number of troops in this area led to a considerable demand for water in a region where civilian supplies were partly disrupted by military operations and surface waters were locally insufficient or sometimes polluted by ordure, munitions or bodies."[299]

---

[296] Rose Edward P. F., 'Groundwater as a Military Resource: Pioneering British Military Well Boring and Hydrogeology in World War I', 49.

[297] Rose Edward P. F., 'Groundwater as a Military Resource: Pioneering British Military Well Boring and Hydrogeology in World War I', 50.

[298] Rose Edward P. F., 'Groundwater as a Military Resource: Pioneering British Military Well Boring and Hydrogeology in World War I', 50.

[299] Rose Edward P. F., 'Groundwater as a Military Resource: Pioneering British Military Well Boring and Hydrogeology in World War I', 50.

As a result, the British Army had to turn to experts who had learnt drilling for water, in other words, geologists.

By the time he left for the Western front, King had built up a good experience at the Geological Survey since 1912, surveyed in the Flint and Oswestry district, and thus had been nominated as capable to "provide expert advice relating to water supply" as the military requested.[300] It should be noted that King was neither the only nor the first Geological Survey geologist who contributed to World War hydrogeology: the Director to the Geological Survey, Aubrey Strahan, had been reporting on the water supply in the areas in Belgium and northern France and compiling a geological map of Belgium.[301]

---

[300] Rose Edward P. F., 'Groundwater as a Military Resource: Pioneering British Military Well Boring and Hydrogeology in World War I', 54.

[301] Recent research by British Geological Survey Archives staff shows that Strahan's involvement in the action was valuable for both the survey and the army as well. At the beginning of the war, Strahan was responding to information request from the War Office "for the loan of geological maps of France and Belgium" and was asked for advice on "obtaining temporary supplies of drinking water at short notice from superficial deposits and from the Upper Cretaceous chalks and Palaeogene sands and clays which crop out in the region" (pp. 3-4). Apart from responses to these enquiries, Strahan contributed the valuable suggestion to the army that "It might be worth your while to consider the advisability of having one of our geologists with the troops to advise in the selection of the best spots for trials for water," and the War Office accepted the offer (pp. 4-5). David G. Bate and Andrew L. Morrison note that there was no previous record showing that the British Army had employed professional geologists in such situations, and the War Office had to do so as the groundwater demand in the western theatre arose. See

King learnt mostly from Strahan's work "with particular regard to borings" prior to his departure, and supervised "the drilling of boreholes to supply potable water to British troops," as well as developing further "specialist water supply maps to be used by planning staffs, or by water supply engineers in the many cases where it was impracticable for him to be present in person."[302]

In the Gallipoli Peninsula and the Balkans, geologists mainly worked on mapping instead of supervising boring for water. As Rose describes, there were three army officers who used to work at the Geological Survey (C. H. Cunnington, R. W. Pocock, and T. H. Whitehead), and who produced a geological report of the area.[303] Although details of the three geologists are not fully available, the British Geological Survey records suggests that Cunnington could have had a similar background to Strahan and King, and that they had worked collaboratively on an extensive report on the strata in British counties.[304] Pocock (Roy Woodhouse Pocock) joined the Geological

---

David G. Bate and Andrew L. Morrison, 'Some Aspects of the British Geological Survey's Contribution to the War Effort at the Western Front, 1914-1918', *Proceedings of the Geologists' Association* 129, no. 1 (2018): 3–11.

302 Rose Edward P. F., 'Groundwater as a Military Resource: Pioneering British Military Well Boring and Hydrogeology in World War I', 54.

303 Rose Edward P. F., 'Groundwater as a Military Resource: Pioneering British Military Well Boring and Hydrogeology in World War I', 57.

304 A. Strahan et al., *On the Thickness of Strata in the Counties of England and Wales Exclusive of Rocks Older than the Permian* (London: His Majesty's Stationery Office, 1916).

Survey in 1912 and worked in Hertfordshire before the war.[305] Whitehead (Talbot Haes Whitehead) started his career at the Survey in 1914, and he served in the Suffolk Regiment during the war before being deployed to the eastern Mediterranean.[306] Whitehead would succeed MacGregor to be Assistant Director at the Scottish Office to the Geological Survey in 1945,[307] and Pocock and Whitehead would later co-author the book *British Regional Geology: the Welsh Borderland* in 1948.

The years between World Wars did not see any significant changes in the way the Geological Survey conducted their groundwater surveys, but there was indeed a surge in the production and use of relevant information. Firstly, as John D. Mather notes, “the number of enquiries received by the Survey relating to water supply began to increase significantly,” so much so that Henry Dewey, then District Geologist to the Southern England District, reported that “much of his time was spent answering such enquiries” in 1931, and that he received more than 400 enquiries on this single topic in 1932.[308]

---

[305] T. H. Whitehead, ‘Dr. R. W. Pocock’, *Nature* 174, no. 4424 (1 August 1954), https://doi.org/10.1038/174294c0, 295.

[306] ‘Geological Survey (Scottish Office) Mr. T. H. Whitehead’, *Nature* 156, no. 3973 (1 December 1945), https://doi.org/10.1038/156743b0, 743.

[307] ‘Geological Survey (Scottish Office) Mr. T. H. Whitehead’, 743.

[308] John D. Mather, ‘War as a Catalyst for Change: Groundwater Studies in the Geological Survey of Great Britain Before 1950 and the Impact of Two World Wars’, *Geological Society, London, Special Publications* 362, no. 1 (1 January 2012), https://doi.org/10.1144/SP362.8, 145.

Furthermore, the Geological Survey published a number of reports, papers, and memoirs related to water supply.[309] Last but not least, the establishment of an Inland Water Survey Committee in 1935 brought a new mode of compiling water supply information, as is indicated in the career of Francis Hereward Edmunds. Edmunds joined the Survey in 1922 and started working in southern England. When the committee selected the Nene Catchment and the Thames above Teddington Lock as its first area for further examination, Edmunds was assigned to assist the committee and to put together available information. While the Geological Survey had previously filed survey results by counties, the committee was expecting now to break boundaries and reorganise by catchment areas, which made sense because county boundaries seldom matched catchment area boundaries. The final outcome, though, was a compromise between the Survey and the committee, who Mather assumed represented the benefit of water engineers that were more "used to the concept of catchments," were tables and geological maps equipped with water supply information.[310] Another remark from an engineer at the Barnet Gas and Water Company also reflects the disagreement

[309] Mather, 'War as a Catalyst for Change: Groundwater Studies in the Geological Survey of Great Britain Before 1950 and the Impact of Two World Wars', 148. Mather gives no specific numbers of such publications. However, footnotes in this chapter has contained several titles that may be helpful.
[310] Mather, 'War as a Catalyst for Change: Groundwater Studies in the Geological Survey of Great Britain Before 1950 and the Impact of Two World Wars', 146-148.

between engineers and geologists that Mather suggests, as this quoted person commented on one of Edmunds' papers on geological structure and groundwater flow. The comment goes:

> I have not been able to make a thorough study of Mr Edmunds' paper, but I think that I ought to say a few words on behalf of my brother engineers who are members of this Association. I do not want Mr Edmunds to think that we technical members of the Association do not appreciate the very great trouble he has taken in preparing this most interesting document. It will be placed in our archives and will, from time to time, be referred to by those of us who have to consider the matter with which it deals, and I do thank Mr Edmunds most sincerely for the trouble he has taken.[311]

Nevertheless, Edmunds continued to work for the committee as a Geological Survey staff, until the Survey established an independent Water Unit in 1937, as a gesture that the Survey, or at least its new Director, Edward Bailey, had recognised the importance of studying groundwater on a national basis.[312]

---

[311] Mather, 'War as a Catalyst for Change: Groundwater Studies in the Geological Survey of Great Britain Before 1950 and the Impact of Two World Wars', 148.

[312] Mather, 'War as a Catalyst for Change: Groundwater Studies in the Geological Survey of Great Britain Before 1950 and the Impact of Two World Wars', 149.

Meanwhile, the Geological Survey had adapted the style of their accounts of water supply by including a catchment area in the geological map of the nearby district.[313]

For Mather, the fact that geologists were not formally recruited into fighting in the war was the characteristic that made the Second World War different from the First. As a result, the Geological Survey could still deploy adequate staff to work on important topics, such as groundwater.[314] Mather categorises their work into two main parts: collecting, compiling, and publishing data, which was mostly done by junior staff, and consulting and advising, which was for the more experienced staff.[315]

Groundwater information was collected and edited in the form of wartime pamphlets. A pamphlet usually consisted of several parts and was published on a certain area. Among all 47 wartime pamphlets that had been published by the end of 1946, there were 16 on water supply, a significant proportion.[316]

---

313 Mather, 'War as a Catalyst for Change: Groundwater Studies in the Geological Survey of Great Britain Before 1950 and the Impact of Two World Wars', 149.

314 Mather, 'War as a Catalyst for Change: Groundwater Studies in the Geological Survey of Great Britain Before 1950 and the Impact of Two World Wars', 149.

315 Mather, 'War as a Catalyst for Change: Groundwater Studies in the Geological Survey of Great Britain Before 1950 and the Impact of Two World Wars', 149.

316 Mather, 'War as a Catalyst for Change: Groundwater Studies in the

Mather argues that publishing these pamphlets proved the success of an independent Water Unit because it allowed the relevant staff to be more focused on the title that they were working on. It also allowed the chief editing geologist to recruit co-authors who had the expertise on the topic, in this case, on hydrogeology, so that they could "summarise and interpret" instead of merely being asked to "observe and record."[317] For example, Mather refers to the innovative way of compiling water supply information by A. W. Woodland, whose wartime pamphlet had a geological nature, but managed to include rainfall data that largely influenced groundwater level.[318]

On the other hand, the Geological Survey continued to deal with increasing inquiries since the interwar years. One major problem they tackled was the geographical redistribution of the population due to the establishment of air stations, military camps, hospitals, munitions factories, and oil refineries in areas without water supply or sewage disposal systems. The Survey produced over 600 reports on proposed sites for new boreholes, many of which required a daily water supply of 200,000 gallons or more. They also

Geological Survey of Great Britain Before 1950 and the Impact of Two World Wars', 151.

317 Mather, 'War as a Catalyst for Change: Groundwater Studies in the Geological Survey of Great Britain Before 1950 and the Impact of Two World Wars', 150-152.

318 Mather, 'War as a Catalyst for Change: Groundwater Studies in the Geological Survey of Great Britain Before 1950 and the Impact of Two World Wars', 152.

provided information during drilling operations, and approximately 90% of the drilled wells were successful. They also assisted with locating new sewage and listing boreholes in London for emergency water supplies.[319]

With hydrogeological work as a case study, we can see, following Mather, that the Geological Survey was a success in its military contributions from the First to the Second World War. With the enhanced expertise and relatively abundant staff, they managed to assist in a larger variety of wartime projects in the Second World War and thus strengthened their lead in surveying for practical tasks. Meanwhile, while the explorations of geophysical techniques might seem to have stopped as the Geological Survey was occupied with practical tasks, the Survey never really lost interests and connections to this new field, and indeed, it was considering the possibility of making use of geophysics in the war.

4.4 Beside the Geological Survey, a Geophysics Committee

The British government during wartime did take geophysical techniques seriously, which might have been a distant result of the Geological Survey's

---

[319] Mather, 'War as a Catalyst for Change: Groundwater Studies in the Geological Survey of Great Britain Before 1950 and the Impact of Two World Wars', 152-154.

geophysical programmes being known and discussed within the Department of Scientific and Industrial Research and even up to the Treasury. A sub-committee on geophysics was established under the Advisory Council on Scientific Research and Technical Development, Ministry of Supply, in 1940. Its activities suggest that the sub-committee acted as a continuation of the Geological Survey's previous effort on reviewing the geophysical survey methods.

It is safe to say that the Geological Survey was involved in the sub-committee's programmes, since Edward Bailey, then Director of Geological Survey was one of the official members at the sub-committee.[320] The composition of the sub-committee's membership indicated a mixture of industrial (mainly petroleum industry) geologists and academic geologists, which unsurprisingly showed the typical kind of network that a survey geologist could have enjoyed. Chairman of the sub-committee was C. A. P. (Charles Archibald Philip) Southwell,[321] who had been under the great influence of John Cadman, for he graduated from a new petroleum technology programme set up by Cadman at Birmingham University, and joined Cadman at the Anglo-Iranian Oil Company in 1930.[322] Southwell himself had been

---

320 "First Report of the Geophysics Sub-Committee", 12th July 1940, National Archives, WO 195/259, 1.

321 "First Report of the Geophysics Sub-Committee", 12th July 1940, 1.

322 H. S. Torrens, 'Southwell, Sir (Charles Archibald) Philip (1894–1981), Petroleum Geologist and Industrialist', 23 September 2004,

recalled from the Middle East to be “in charge of exploring for oil reserves in England, using imported American technologies and organizing British experiments on horizontal drilling.”[323] Among the additional members was J. H. Jones, also from Anglo-Iranian Company. On the other hand, there were E. Lancaster-Jones and H. Shaw from Science Museum among the official members, with E. C. (Edward Crisp) Bullard and A. O. (Alexander Oliver) Rankine as additional members.[324] Bullard graduated with a PhD in physics and taught in the Department of Geodesy and Geophysics at Cambridge in geophysics. The reason for his appearance at a wartime geology was very likely to have been his research in geomagnetism, which could have been helpful in removing magnetic mines for war demands.[325] Rankine possibly was between the two types: he had been a profession of physics, and, by the beginning of World War II, had joined Anglo-Iranian Oil Company, first as a geophysics advisor and then as chief physicist.[326]

---

https://doi.org/10.1093/ref:odnb/47970. Anglo-Persian Oil Company had been renamed the Anglo-Iranian Oil Company in 1935 on the insistence of the Shah.

[323] Torrens, ‘Southwell, Sir (Charles Archibald) Philip (1894–1981), Petroleum Geologist and Industrialist’.

[324] “First Report of the Geophysics Sub-Committee”, 12th July 1940, 1.

[325] Dan Peter McKenzie, ‘Edward Crisp Bullard, 21 September 1907 - 3 April 1980’, *Biographical Memoirs of Fellows of the Royal Society* 33 (1 January 1997), https://doi.org/10.1098/rsbm.1987.0004, 76.

[326] ‘Prof. A. O. Rankine, O.B.E., F.R.S.’, *Nature* 139, no. 3524 (1 May 1937), https://doi.org/10.1038/139830b0, 830.

At the first meeting of the Geophysics Sub-Committee on 14th June, 1940, the constitution of the sub-committee was discussed and the sub-committee agreed on a constitution that "would limit the scope of the Sub-Committee's activities to the field of mining operations for military purposes."[327] The meeting also emphasised that the principle requirements for such techniques came up from "military use, both offensive and defensive."[328]

Considering the long-term experiments on gravity balances conducted by the Survey in the previous decades, it is surprising that the new sub-committee report seemed to have abandoned this technique. Instead, the sub-committee discussed the magnetic and electric methods, seismographic methods, both of which had been invented earlier in the century, and audio methods, which were new. The audio methods aimed to detect geo-structures by sound-making and -recording devices and to make an image out of the data. Moreover, the sub-committee were certain of a particular use, that it "would probably be the primary means of detecting enemy drilling operations," although it was "of little use for the survey of our own drilling activities under military conditions."[329] Based on such analysis of use, the sub-committee recommended that "all available types of listening equipment should be made available to the Anglo-Iranian Oil Company for comparative field trials to

---

327 "First Report of the Geophysics Sub-Committee", 12th July 1940, 1.

328 "First Report of the Geophysics Sub-Committee", 12th July 1940, 1.

329 "First Report of the Geophysics Sub-Committee", 12th July 1940, 2.

determine the limits of their performance with respect to drilling operations," and that trained staff should "be present at the trials to operate the equipment to the best advantage."[330] The recommendations also noted a Newark drilling[331], a report of which would be drawn up and would provide relevant information for military users.[332] Yet, there had been no sign that the instrument had been put into use, and details about how to put the instruments into use were vague in the report. Perhaps, as we can still infer from the tone, equipment for such methods must have been ready for use in Britain at that time, and that experiments had already taken place, before their military significance was discovered by the government.

The Geophysics Sub-Committee had their second meeting one month later. With the month in between, the second meeting was able to review several results of the techniques that were discussed before, namely "on the use of a magnetic compass and inclinometer, with photographic recording, for the Survey of horizontal drill-holes, and on tests of geophone equipment for the

---

330 "First Report of the Geophysics Sub-Committee", 12th July 1940, 2.

331 This is likely to be in Newark-on-Trent, Nottinghamshire, although the only source for this is unreferenced https://levinehistory.wordpress.com/2015/12/15/how-robin-hood-won-the-second-world-war-or-how-american-roughnecks-saved-the-british-oil-industry/. Having said so, it is very likely that Nottinghamshire (being a mining area) did enjoy a particular geological structure that had attracted gravity torsion balance tests and thus other similar instruments and experiments.

332 "First Report of the Geophysics Sub-Committee", 2.

detection of drilling operations."[333] Compared with the development of geophysical techniques a decade ago, the results were produced rather quickly, and the sub-committee thus was able to make an even quicker decision on next steps.

The second meeting narrowed the options. According to the minute, the sub-committee agreed that the seismographic survey methods had a "complexity and lack of accuracy" which entailed a discontinuation of further investigations.[334] Meanwhile, the sub-committee favoured the magnetic compass and inclinometer, as an improvement on the alternative which was the gelatine compass and inclinometer, and suggested that assessment of the audio methods be left until after further tests. As for the former, the sub-committee was convinced that a magnetic compass and inclinometer with photographic recording "offered the most promising method for the internal survey of horizontal, long-distance bore holes," as the manufacturer promised that the equipment would be available within days, while the previously discussed gelatine compass and inclinometer would take a length of time to make an observation.[335] As for the audio methods, the sub-committee was willing to see further data on its performances in different soils, and the data

---

[333] "Second Report of the Geophysics Sub-Committee", 16th July 1940, National Archives, WO 195/265, 1.

[334] "Second Report of the Geophysics Sub-Committee", 16th July 1940, 1.

[335] "Second Report of the Geophysics Sub-Committee", 16th July 1940, 1.

could be collected from other drilling operations, since the equipment had proved working in Newark.[336]

What is strange here concerns the magnetic and electric methods. On the one hand, the sub-committee recorded that there was "the potential military need for methods of surveying horizontal bore-holes from the surface of the earth along the line of drilling," especially in holes for "the laying of supply and signal lines at a depth sufficient to protect them from bombardment."[337] On the other hand, the sub-committee "felt that electro-magnet methods would be the most suitable for this purpose, and agreed that adequate instruments were now available."[338] They agreed that the technique "would be completely investigated," and that Jones was appointed to prepare the report.[339] However, the following recommendation turned out to be "no further development of magnetic or electric survey equipment be now pursued,"[340] with no more explanations given. A reasonable way to understand it is to take it as a temporary recommendation that would have worked until the Jones' report was fully prepared; otherwise, the sharp contrast looks simply unexplainable.

---

336 "Second Report of the Geophysics Sub-Committee", 16th July 1940, 2.
337 "Second Report of the Geophysics Sub-Committee", 16th July 1940, 1-2.
338 "Second Report of the Geophysics Sub-Committee", 16th July 1940, 2.
339 "Second Report of the Geophysics Sub-Committee", 16th July 1940, 2.
340 "Second Report of the Geophysics Sub-Committee", 16th July 1940, 2.

The third report in the series, however, seems at first glance not very connected to the previous two, but it was actually based on what had been discussed in previous meetings to answer an arising practical problem. As the beginning of the third report declares:

> The Sub-Committee met on February 27th to consider a matter referred to it by the Advisory Council. It had been suggested that the Germans might be tunnelling the Channel for a possible bridge head on the nearest point on the Kentish coast, and that consequently some thought should be given to the development of suitable means of detection.[341]

By then, the report stated that the recommendations above had been passed on from the Executive Officer of the Advisory Council to the Senior Military Advisor, Ministry of Supply, and the sub-committee was assisted by two members of the Mining Committee to discuss the problem.

As it turned out now, the problem that the sub-committee was concerned of has moved from drilling for oil to defending the Channel. The new problem led to a report which is logically very clear but lacks technical details, compared to the other two reports. In conclusion, the sub-committee argued that the tunnelling scheme was not possible given that a required rate of tunnelling

---

[341] "Third Report of the Geophysics Sub-Committee", 3rd March, 1941, National Archives UK, WO 195/646, 1.

would have to reach between an impossible “80 and 120 yards a day,”[342] and where the scheme could not be conducted in a secrecy.[343] As is noted in the report, “no member present at the meeting had knowledge of any existing tunnelling machine capable of anything approaching this rate of progress,” and disposing the spoil “in a manner that would escape observation from the air” alone would be no easy matter, let alone “serious problems associated with ventilation at the face and with the continual advance and operation of the machinery as the work progressed.”[344]

It is obvious that the conclusion has little to do with what was discussed in the previous two meetings, although we can also see why geological expert advice might be sought. As a recommendation, the sub-committee noted that they already had “methods of detection which should enable us to locate the workings,”[345] which seems to refer the boring hole surveying techniques that were reviewed previously. However, the methods mentioned here were actually “our continual aerial reconnaissance of the French coast,”[346] which was technically not geophysical.

Unfortunately, there are no further reports of the Geophysical Sub-Committee

---

342 “Third Report of the Geophysics Sub-Committee”, 3rd March, 1941, 1.

343 “Third Report of the Geophysics Sub-Committee”, 3rd March, 1941, 1.

344 “Third Report of the Geophysics Sub-Committee”, 3rd March, 1941, 1.

345 “Third Report of the Geophysics Sub-Committee”, 3rd March, 1941, 2.

346 “Third Report of the Geophysics Sub-Committee”, 3rd March, 1941, 2.

in the series. Considering that the sub-committee had already been designated to an irrelevant purpose on as its third report suggests, one may assume that the original purpose of the sub-committee was not pursued anymore, and that the disappearance of the sub-committee was a sign that those geophysical techniques were not actually applied during the war, although they were given importance. Other sources also say nothing about applications of these techniques during the war. Bailey's own account of wartime oil explorations suggested the lack of success of the geophysics sub-committee's work by speaking nothing about it. In his memoir, he gave only a rather short paragraph (comparing to, say, three pages about water) on "oil-shale," and only claimed the anticipatory contributions by Geological Survey Geologists Macgregor and Richey, who revised the oil-shale information of the West Lothian area to meet wartime demands.[347] Of course, Bailey's account should not be taken as the only authoritative narrative of wartime Geological Survey; nor is it superior to other sources, but it is indeed obvious that Bailey sounded more proud of their geological maps than of any of the sub-committee recommendations.

[347] Bailey, *Geological Survey of Great Britain*, 254.

4.5 New Connection to Geophysics: Searching for the Radioactive

Last but not least, during the Second World War the Geological Survey sent its staff on a survey for something new with a taste of geophysics: uranium on another continent. As is mentioned in Margaret Gowing's account of atomic energy in Britain, the Geological Survey "produced the first of a long line of uranium surveys" when Edward Appleton started to take responsibility within the Tube Alloys project.[348] C. F. (Charles Findlay) Davidson of the Geological Survey was the key person in a small team to complete a joint uranium survey in America in 1944,[349] and the outcome of this survey was limited on the British side because the Geological Survey had been focused on British Isles and the European Continent instead of America.[350] Davidson seemed to have worked on the uranium survey quite independently from the Geological Survey, for Gowing's account made little connection between him and his institutions behind. Neither does any other existing literature attempt to find out how the Survey staff was summoned to Tube Alloys to become the geophysical component of such an international atomic project.

During World War II, Davidson built up good contacts with the military, which was rare for the Geological Survey, since the Survey actually made few

---

[348] Margaret Gowing, *Britain and Atomic Energy, 1939-1945* (London: Macmillan & Co Ltd, 1964), 180.

[349] Gowing, *Britain and Atomic Energy, 1939-1945*, 303.

[350] Gowing, *Britain and Atomic Energy, 1939-1945*, 306.

arrangements to adapt itself to wartime demands. Davidson joined the Survey in 1934 after graduating with a degree in geology and mineralogy. As Assistant to the Curator of the Geological Survey Museum, he mainly assisted with exhibiting physiographical geology, economic geology, and the geology of Scotland. He earned his doctoral degree in 1942 for his research on the Archean Rocks in the Rodil District, Isle of Harris, Scotland.[351] At that time, he was also in charge of a Military Geology Unit of the Geological Survey, and then became Chief Geologist of the Special Investigations Division (later Atomic Energy Division since 1951) to carry out "field and laboratory studies of atomic energy raw materials."[352] As his colleague remembered decades later, his debut in radiogeology was preparing for a bibliographical report on the global uranium resources for the Lord President of the Council in 1941.[353]

With the war coming to an end, Davidson naturally became part of the post-war arrangements for the Special Investigations Division, especially when the

---

351 His paper is still the prime search result today if one searches for "Rodil District." Charles F. Davidson, 'II.—The Archæan Rocks of the Rodil District, South Harris, Outer Hebrides', *Earth and Environmental Science Transactions of The Royal Society of Edinburgh* 61, no. 1 (1944): 71–112, https://doi.org/10.1017/S0080456800018056.

352 S. H. U. Bowie, 'Obituary Notices - Charles Finlay Davidson, O.B.E., D.Sc., F.R.S.E., M.I.M.M.', *Proceedings of the Geological Society of Glasgow*, 1969, 2.

353 Bowie, 'Obituary Notices - Charles Finlay Davidson, O.B.E., D.Sc., F.R.S.E., M.I.M.M,' 2.

division was interested in maintaining a good flow of geologists from the Geological Survey. At the beginning of a memorandum about such arrangements, the division confirmed that in “1944, one geologist was earmarked by the Director of the Geological Survey and Museum (D.S.I.R.) for this work, and he has since given almost the whole of his time to it,” [354] who could have been nobody else but Davidson. And, apart from him, the memorandum suggested a further possibility of allocating personnel from the Geological Survey to work on uranium and thorium deposits. It claimed that the need “for an expansion of this staff has long been recognised by all who are in close touch with the Raw Materials side of the project.” [355] By saying “all”, it had alluded to at least “the Americans”’ and James Chadwick’s opinions, as the Americans required a larger organisation to deploy on the project, and Chadwick (who was one the key British physicists of wartime atomic projects) wanted people for “the obviously urgent expeditions of investigation and for mineralogical and bibliographic research work.” [356]

Thus, the requirements of personnel started to show an emphasis on geophysical background, including not only staff for “the technical literature”,

---

[354] ‘Establishment of Geologists in Geological Survey and Museum for T. A. Purposes’, n.d., National Archives UK, CAB 126/20, 1.

[355] ‘Establishment of Geologists in Geological Survey and Museum for T. A. Purposes’, 1.

[356] ‘Establishment of Geologists in Geological Survey and Museum for T. A. Purposes’, 1.

but also those “for the execution of essential mineralogical research on uranium and thorium ores.” [357] To be specific, the arrangements were expected to be:

> For all this work it is estimated that a staff of four trained geologists and one technical assistant is necessary, inclusive of the two geologists already engaged in these duties. One officer should be of District Geologist rank to take charge of the group.[358]

The requirement of “District Geologist rank” suggested a comprehensive standard for the candidates, as the title itself had already indicated an established background and a recognised achievement for a geologist. Apart from repeatedly mentioning that the project was “essential”, the geologist team members were expected to focus on Tube Alloys as well as being integrated into the Geological Survey. The memorandum suggested that this be done in the following ways:

> (1) The geologists require the common services provided by G.S.M. These include the library facilities, map collections, mineralogical and chemical laboratories, and comparative mineral collections, all of which

---

[357] ‘Establishment of Geologists in Geological Survey and Museum for T. A. Purposes’, 1.

[358] ‘Establishment of Geologists in Geological Survey and Museum for T. A. Purposes’, 1.

are essential for the conduct of the work and are not available elsewhere.

(2) The help of the senior officer of G.S.M., much as the petrographer, palaeontologist, and others, is under this arrangement readily available whenever the T.A. work demands such specialist assistance.

(3) Occasional interchange of personnel between the T.A. geologists and other geologists of the G.S.M. establishment, at the discretion of the Director, is likely to increase the efficiency and experience of both staffs.

(4) As has already been evidenced, the general interest of the Director of G.S.M. in the work of the T.A. specialists is conductive to smooth and effective working of the arrangements.

(5) The status of the T.A. geologists as G.S.M. officers is helpful when they are establishing relations with official geologists elsewhere in the British Commonwealth, and also facilitates contact with overseas geologists visiting the U.K.[359]

In fact, it would still take some time before the radiation work became an organically integrated part of the Geological Survey. In addition, the Atomic Energy Division acted overseas most of the time in exploration for radioactive ores, with little involvement in the Survey’s daily work. Still, participating in the

---

[359] ‘Establishment of Geologists in Geological Survey and Museum for T. A. Purposes’, 2.

wartime radioactive was an opportunity for the Survey to expand its connection with physicists and geophysicists, and the Atomic Energy Division would become irreplaceable when the Survey started to catch up on geochemistry (see Chapter 7).

4.6 Conclusion

This chapter has discussed the wartime assignments of the Geological Survey and has tried to find out how it influenced, if at all, the geophysical trends at the Survey. On the one hand, to meet the wartime demands from the government, the Survey did not have much initiative to develop their own geophysical agenda. On the other time, staff at the Geological Survey participated in projects in some of the fields that were not their main focus in the interwar years, such as in hydrology. There was also a considerable leap in the horizon of the Survey, when one of its scientists, namely Davidson, was responsible for the search of uranium, which built up a connection between the Survey and the nation’s advanced practice in physics. The connection would continue in the coming decades, when the Survey returned to develop a suitable geophysical agenda.

Chapter 5: New Opportunities for Geophysics in the Survey's Boring Programme

With World War II coming to an end, the Geological Survey began making updated plans for its post-war work. For the Survey, the war had left some of its important agenda interrupted, although it managed to played an active part during wartime, as chapter 4 suggests. Now it was time to resume. Mapping the country was still the Survey's principal job, and the immediate post-war plans addressed this task. On the condition that the end of war was expected to bring a new, stable flow of staff in, the Survey was ready for mapping. Meanwhile, the inter-war years had left the Survey a number of boreholes to examine, and the wartime demands had reminded the Survey of a gap in their knowledge about the country's geology in general. As a result, the Survey wanted to launch a general programme of boring in the country, with the aim of collecting as much information as possible. It was in these projects that new opportunities to develop geophysical techniques and reshape the Survey existed.

5.1 New Tasks after the War

According to its later Secretary, Harry Melville, the closing of the Second

World War marked an optimistic time for the Department of Scientific and Industrial Research because it found many uses of its war-time achievements for everyday applications. For example, Melville listed:

> Radio communication, broadcasting, talking pictures, and television had come about as the result of physical research and invention, and their use, so widespread as to become a commonplace to most British citizens, had meant the development of many specialised manufacturing firms which could keep in the forefront only by constant scientific investigation. In the chemical industry, too, there were great advances. A striking example of this is the plastics industry, which was being rapidly built up. Its possibilities spurred many both to basic research into polymerisation and to applied research into potentialities of new plastics. There was great activity in research into the production of new chemicals for therapeutic uses.[360]

All these examples show that the war seemed to show ways for scientific research to make industrial applications, which was exactly what the DSIR was founded for. For scientific research in these subjects, the DSIR found itself unable to do anything more to enhance the connection between such scientific research and industry; rather, the Department turned to the scientific

---

[360] Harry Melville, *The Department of Scientific and Industrial Research* (Allen and Unwin, 1962), 42.

organisations where there might still be gaps to fill.

Meanwhile, the Geological Survey's work would inevitably gain more importance as the country needed to recover from a fuel crisis. Coal production had dropped about one fifth since the Second World War, and the inadequacy of supplies of fuel was soon joined with an extreme winter.[361] As a national surveying organisation, and thus the organisation to consult during a shortage, the Geological Survey continued its wartime effort to map the country's fuel and mineral deposits by designing a new agenda for more drilling (boring) projects, so that it could build a better knowledge of the distribution of coalfields of the country. Its role had become critical to the national interest – the Geological Survey also mentioned this factor in a report that would be discussed later in this chapter – as the shortage of fuel had impacted various sectors such as chemicals, textiles, and building industry.[362] It was also a support to the nationalisation of coal industry that would happen during the post-war Labour administration, by assisting the sorting out of he existing pattern of the ownership of relevant resources.

As a result, an expansion of scientific teams was inevitable, and the Geological Survey was no exception. Not only did the number of geologists on the Survey increase, but they also came from an increased variety of

---

[361] Alex J. Robertson, *The Bleak Midwinter 1947* (Manchester: Manchester University Press, 1987), 181.

[362] Robertson, *The Bleak Midwinter 1947*, 147-148.

backgrounds. Furthermore, the role of the Survey more broadly was discussed. In this chapter, we will firstly find out how the Director's plan for post-war recruitment turned into a reflection on the role of the Survey. We will see that the scientific staff of the Survey had been seeking a cooperative way to conduct research as well as mapping by the end of the war. Last but not least, by investigating the Survey's boring programme, we will also notice that the scientists' inclination to innovative techniques was not yet fulfilled immediately.

5.2 Planning for Post-War Survey Personnel

Towards the end of the Second World War, staff at the Geological Survey and at the Department of Scientific and Industrial Research started to plan for the Survey's future organisation. Edward Bailey, who remained Director at the Geological Survey, did not think that the war had severely interrupted the Survey's work, as has been mentioned in chapter 4. Nevertheless, he had to admit that the war had made a negative impact on the Survey's personnel, for it had interrupted a stable flow of geological students and thus geological professionals into new posts. His judgement was based on a plan to continue mapping coal resources in the future, which had to reconcile the facts of the Survey's demand for geologists to compete mapping and the fact that the number of working staff had been decreasing. In a letter to Edward V.

Appleton, then Secretary at the DSIR, Bailey outlined his preliminary ideas of the Survey's post-war agenda. He suggested that the ideas were developed after a meeting with Franklin Sibly, at the Advisory Council.[363]

On the one hand, Bailey expected to continue working on the coal distribution of the country, which was:

> partly for the convenience of Fuel Research but it is also an obvious bit of fundamental clean up urgently required owing to the nationalisation of coal. In the days of individual ownership the correlation of seams from leasehold to leasehold was relatively much less important than today. We have in the past done much, but we hope to speed up greatly in those areas that we haven't remapped recently.[364]

What Bailey called "have in the past done much" here refers to the tremendous work that the Geological Survey had done in the past century locating the country's coal resources. It had been the Survey's main task, partly because its close connection to the geology of the country, and partly because the Survey's mission to provide useful economic information for the country.

---

[363] E. B. Bailey, 'G. S. M., Coal & Man', 29 July 1943, National Archives UK, DSIR 9/110 Geological Survey Future Organisation of G. S. M, 1.
[364] Bailey, 'G. S. M., Coal & Man', 29 July 1943, 1.

On the other hand, speaking of the war drawing to an end and the Survey returning to its normal pace remapping the coal, Bailey suggested:

> I feel myself from what Hogg wrote to me after the last meeting of Advisory Council that we are not likely to find difficulties raised by Head Quarters if we ask for additions of suitable staff for coal research in the near future. It is practically arranged that we are to get as a Temporary Geologist a Lecturer from Sheffield, well known to us for the quality of his research work. It is also agreed that we may recruit two or three female draughtsmen, with whom we have got in touch. I believe that our present finding troubles in getting help are determined by the difficulty of finding people whose recruitment would not interfere with military (in the broad sense) needs; and that we are not suffering from H. Q. restrictions. There is, however, an aspect of the problem which Sibly put forward. Universities are not allowed to finish training geologists because there is not a sufficient present demand for them. Sibly thinks that if you investigated the matter and were able to tell the authorities that such and such a number of vacancies is expected in the Geological Survey in post-European war days, it might lead to an education of geologists who, whether they went to the army or no on completing their degrees, would be available for our very busy reconstruction period.[365]

[365] Bailey, 'G. S. M., Coal & Man', 29 July 1943, 2.

In this paragraph, Bailey noted two main points regarding future recruitment for the Geological Survey. First, he proposed to hire a member of the research staff from a university to improve the personnel of the Survey, although the exact identity of the person is not disclosed. Second, he said he would like to focus on university students who had been interrupted from their previous training in geology and seek solution from authorities to make these students eligible for the Survey. These ideas were not fully developed yet, and recruiting would still be an extended task ahead in planning the future organisation of the Survey. As Appleton indicated in his response to Bailey's letter, these suggestions were "sound," but to put them into execution was another thing that would require both the DSIR and, say, the Ministry of Labour's collaboration, and he was willing to implement this.[366]

Bailey's response to Appleton was a full account of the prospective staff increase and tasks of post-war Geological Survey, starting by a claim that they were "cutting our coat to our cloth, sparing what time we can to coal, and reluctantly giving much less help than we should like to the Ministry of Town and Country Planning."[367] According to Bailey, they had already compromised to cut down staff on maps and water and non-ferrous minerals. Moreover, the

---

[366] E. V. Appleton to E. B. Bailey, 5 August 1943, National Archives UK, DSIR 9/110 Geological Survey Future Organisation of G. S. M, 1.

[367] E. B. Bailey, 'Post-War Increase of G. S. M. Staff', 28 August 1943, National Archives UK, DSIR 9/110 Geological Survey Future Organisation of G. S. M, 1.

situation of existing staff was not helpful either. Among their 58 scientific staff at the beginning of the war, the Geological Survey now had 2 already died or retired, 1 resigning, 5 in the Army or with other major commitments, 7 to retire by the end of the decade, and 2 who should have superannuated already, including Bailey himself.[368] With these calculations, it had become obvious that the Geological Survey would lose nearly one third of its geological staff soon.

Meanwhile, Bailey referred to several previous memoranda and memoirs, noting that mapping was still regarded as the main obligation of the Geological Survey.[369] If there was no increase in staff, he estimated, the Survey would need another 45 years to complete their colour-printed one-inch map project, while only 20 years would be required with 23 additional staff, 30 years with 9. Considering that the loss of employees would not happen all of a sudden, but gradually in several years, Bailey decided that 25 additional staff should be recruited within the next 5 years.[370]

---

[368] Bailey, 'Post-War Increase of G. S. M. Staff', 28 August 1943, 1-2.
[369] Bailey, 'Post-War Increase of G. S. M. Staff', 28 August 1943, 2. Among these references, Flett's *First Hundred Years of the Geological Survey of Great Britain* has appeared frequently in earlier chapters of this dissertation. Bailey also referred to a "Director's Report" in 1937 and a "Post War Reconstruction" minute in 1941. Unfortunately, neither of them is currently available in the Geological survey Board papers.
[370] Bailey, 'Post-War Increase of G. S. M. Staff', 28 August 1943, 3-4.

Bailey sought a meeting with Sibly, G. R. D. Hogg, who was then Assistant Secretary at the DSIR, and Eric Barnard, then Principal Assistant Secretary to Appleton who was away. While waiting for the meeting, Bailey updated Sibly that the Survey's Scotland office required a further increase of 1 District Geologist, as well as 5 Geologists (referred as "Fieldmen" and "Indoormen"), 1 Palaeontologist and 1 Petrologist.[371]

On 24th September 1943, Barnard sent Appleton a minute along with Bailey's Minute earlier in August and his follow-up letter to Sibly and summarised some key points of the meeting, which they had completed some time ago in the past month.[372] This minute was presented in a logical way by identifying demands for different categories of maps: geological maps and memoirs were "out of date," with some of them "100 years old and geological knowledge and methods have radically changed since the beginning of this century," and many of them "were made from a 1'' to the mile survey" and was far from satisfactory; drift maps were "only available for part of the country," and they were now urgently required for "town and country planning," for "the soil

---

[371] E. B. Bailey, 'Additional Staff', 9 September 1943, National Archives UK, DSIR 9/110 Geological Survey Future Organisation of G. S. M.

[372] The original text here goes "Please see D., G. S. M.'s minute of 28.8.43 (Flag A). Mr. Hogg and I have discussed it with Sir F. Sibly and him, and make the following comments," indicating that the meeting had already taken place. E. Barnard to Secretary, 24 September 1943, National Archives UK, DSIR 9/110 Geological Survey Future Organisation of G. S. M, 1.

survey maps for which the Ministry of Agriculture is responsible," and for "other purposes such as the use of gravels and clays for the making of concrete and bricks;" and finally, maps for teaching of geology, no matter whether they fell into the two categories above or not, were mostly "pre-1900 hand-coloured" and "too expensive for this purpose."[373] Perhaps as an elaboration of the truth, perhaps to make the Geological Survey's claim for staff sound more persuasive, the analysis of the demand in map production in this minute was clear, detailed, and vivid. The minute also noted that a recruitment for extra staff would satisfy the Survey for its other tasks such as "coal and water surveys," while they surely helped with the production of maps as well.[374] Considering the requirements in map production above, it was also understood that new staff should join the Survey with updated geological knowledge and methods, setting them apart from to those before the beginning of the century; they might be expected to have expertise or experience in coal, water, or soil surveying.

To conclude, the minute drew attention to a "special action to provide more geologists" and included what must have been a version of recruitment plan already discussed and drafted by Bailey et at.[375] The plan inherited Bailey's

[373] Barnard to Secretary, 1.

[374] Barnard to Secretary, 1.

[375] Barnard to Secretary, 1.

idea of recruiting from drafted men, saying that Bailey was

> enquiring from the Central Register and certain professors of geology what geologists, trained or part trained, there are in the forces and diverted, for war purposes, to other work, who are likely to become available on the conclusion of hostilities; and what numbers of geologists are likely to become available in the two or three years immediately after the war.[376]

Bailey must have been reminded of the procedure of initiating such an action too, and the minute also listed his further steps of, first of all, liaising with the "Central Register," reporting to the DSIR via the Geological Survey Board, and finally forwarded all the relevant documents to the Secretary again.[377]

Indeed, signed on the same day as the minute, Bailey consulted W. Wardlaw, the Scientific Advisor at the Ministry of Labour and National Service, for further advice on his recruitment plan soon after the meeting, by indicating that his department officers had suggested him ask Wardlaw on a "hypothetical case."[378] If policies after the war allowed a prompt recruitment of college students whose courses were interrupted by their service, Bailey

---

[376] Barnard to Secretary, 1.

[377] Barnard to Secretary, 1.

[378] E. B. Bailey to W. Wardlaw, 23 September 1943, National Archives UK, DSIR 9/110 Geological Survey Future Organisation of G. S. M.

asked Wardlaw,

> Have you any figures as to partially educated geological students in the Forces? Is there reason to believe that men drafted to scientific posts, such as radio location, would be glad and able to take a geological course at the Universities to fit them for our needs? How many men are likely to be available within a year of demobilisation? Within two years? Within three years?[379]

Wardlaw responded quite late and he was not enthusiastic. In his reply to Bailey, Wardlaw indicated that Bailey's post-war recruitment plan was "almost exactly those which come within the scope of the new Inter-Departmental Committee in Further Education and Training under the Chairmanship of Lord Hankey," which had "the function of determining the number of persons who should be encouraged to enter upon courses of education and training above the secondary school standard after the war."[380] He also alluded to a conversation that he had with the Secretary of the Committee in question, and that the Secretary was "about to approach D.S.I.R. for an estimate of the numbers of scientists in the various categories who are likely to be required for civilian research after the war," including geologists.[381] This response

---

379 Bailey to W. Wardlaw, 23 September 1943.

380 W. Wardlaw, to E. B. Bailey, 12 October 1943, National Archives UK, DSIR 9/110 Geological Survey Future Organisation of G. S. M., 1.

381 Wardlaw to E. B. Bailey, 12 October 1943, 1.

meant that a confirmation of the number of geologists in demand would have to wait until the Secretary's approach, and Wardlaw concluded that he would not "be much use" attempting to respond to Bailey's questions, and he had "no figures for the men who entered the Forces without completing their geological courses."[382] As Wardlaw circulated Bailey's letter with Hogg several days later, he referred to a telephone conversation with Hogg about "post war requirements for scientists," repeating the idea that he would like to dealt with the requirements for geologists only "when the general question is under review."[383]

Bailey talked more with Appleton in November. The outcome of the talk was a general picture of the future organisations of the Geological Survey, especially about its people. Naturally, first of all in Bailey's picture was the increase of staff in the Survey's new division in Scotland and its uncompleted maps around the area. However, different from his earlier proposals circulated around his departmental colleagues, Bailey's general picture also tells us much about the interpersonal relationship through the professional hierarchy. As mapping work was distributed downwards from Assistant Directors, it manifested levels of geologists' ambition to get a promotion and brought opportunities for geologists to learn on the job. Such working experience in

---

382 Wardlaw to E. B. Bailey, 12 October 1943, 1-2.

383 W. Wardlaw to G. R. D. Hogg, 16 October 1943, National Archives UK, DSIR 9/110 Geological Survey Future Organisation of G. S. M.

turn enriched all levels of geologists as a whole. To summarise, Bailey defined that

> It is the job of the Geologist, if possible, to educate his District Geologist, and of the D.G. his Assistant Director, and of the Assistant Director his Director.[384]

He called it “general terms” and “a tried and valued machinery” of the Survey. With perhaps a hint of humour, Bailey ended these “notes” with a famous anecdotal saying of Napoleon that every geologist “carries in his knapsack the hammer of a Director.” In this case, it

> Is most important for the sake of the Survey that every Geologist should be asking himself “What can I do to fit myself to become Director?” Or “What should I do if I became Director tomorrow?” Adding perhaps, “What a damned shame that I am not Director today!”[385]

Indeed, these words have a connection to the necessity of increasing staff, but it is still curious why Bailey portrayed such an emotional illustration of the atmosphere at the Survey. Since he claims that these points were “arising out of” his talks with Appleton, it is likely that Bailey confidently took his points as

---

384 E. B. Bailey, ‘The Future’, 21 November 1943, National Archives UK, DSIR 9/110 Geological Survey Future Organisation of G. S. M.

385 Bailey, ‘The Future’.

persuasive and as a reinforcing his earlier versions of recruitment proposals.

Perhaps as another sign of Bailey's confidence in his plan, or at least in the possibility that his plan had become mature and would be implemented, Bailey contacted W. J. Pugh, who had recently been promoted to Deputy Vice-Chancellor at University of Manchester and remained Professor of Geology and Director of the Geological Laboratories there, several days after the plan was written into the memorandum above. Also very likely is that Pugh had already received some "papers" related to those post-war recruitment ideas, as Bailey's letter suggests at the beginning.[386] He continued to outline the conclusions of his meeting with Sibly and the other administrators, that he had received satisfactory responses from the Department, that they had been considering a post-war staff plan, and that the plan would become "an attainable programme" in due course.[387] As a reasonable step following the Department's work on the programme, Bailey mentioned to Pugh more details which would appear in the future recruitment, that he had

> in view three offices of almost equal rank, with various allotments of indoor staff. For the moment I shall only talk of field units. The offices would be at Edinburgh, Leeds and London.

---

[386] E. B. Bailey to W. J. Pugh, 25 November 1943, National Archives UK, DSIR 9/110 Geological Survey Future Organisation of G. S. M, 1.

[387] Bailey to W. J. Pugh, 25 November 1943, 1.

> At each (except perhaps Edinburgh, if it is decided to postpone the Outer Hebrides for the next 20 years) there would be four District Geologists each with four Senior or ordinary Geologists, and in each office there would be a reserve of four Geologists, to maintain the operating units at full field strength in times of leave, sickness or memoir writing.[388]

Based on the numbers above, Bailey asked Pugh that he was thinking

> to close Manchester and Newcastle and develop instead a first-rate North of England Office at Leeds.[389]

And he asked for Pugh's comments on this. With Pugh's titles at that time, Bailey's letter can be regarded as his early move to reach out to university geologists at senior positions, who would be important stakeholders if his plan was to implement.[390]

There were indeed some modifications to Bailey's grand plan, after the Geological Survey Board discussed it, but generally there was good news. On 15 December, A. E. Trueman, the Chairman of the Geological Survey Board, wrote to Bailey with the result from the Board, that

---

[388] Bailey to W. J. Pugh', 25 November 1943, 2.

[389] Bailey to W. J. Pugh', 25 November 1943, 2.

[390] Unfortunately, due to current shortage of accessible papers, Pugh's response to this is unknown.

> it was recognized that any prospect of completing the work indicated depends on such increases. The Board was also aware that its recommendations for a programme of activities extending over a long period of years could not be binding on your successors as Director or on future boards: it was realized that conditions may necessitate considerable modifications in such a programme.[391]

As Trueman confirmed, the Board had agreed on the necessity of an increase on the number of staff to assure the completion of mapping work, and later correspondence suggests that the Survey's staff plan would join "the general post-war programme of the Department."[392] As a result, the Geological Survey started to develop the plan in more detail, by managing the future accommodation for staff and museum objects. Apart from estimating staff numbers, as previous correspondence had done, the new document also put Bailey's preference for a new Leeds office into governmental paperwork for the first time. In response to Barnard's concern that "the expansion proposed was a very substantial one and would need strong justification on the economic basis,"[393] this memorandum, signed by and on behalf of Geological

---

[391] A. E. Trueman to Director, 15 December 1942, National Archives UK, DSIR 9/110 Geological Survey Future Organisation of G. S. M.

[392] G.S.M. to Department of Scientific and Industrial Research, 5 January 1944, National Archives UK, DSIR 9/110 Geological Survey Future Organisation of G. S. M., 1.

[393] G.S.M. to Department of Scientific and Industrial Research, 1.

Survey and Museum, explained in a way that resonated what they had been familiar with and what we have been familiar with as the Survey's mission:

> (i) The Director might well ascertain informally the extent of the support for such an expansion which might be forthcoming from Departments of State which needed, or were concerned with industries which needed the information and service the Survey could provide, e.g.
>
> Ministry of Fuel and Power
>
> Ministry of Health
>
> Ministry of Town and Country Planning
>
> Agricultural Research Council and the Agricultural Departments
>
> although D.S.I.R. might later find it desirable to ascertain more formally the extent of the probable demands of such Departments and the support they would be able to give to the projected programme.
>
> (ii) The "case" to be presented should anticipate the question, frequently raised in the past "When will the task of the Geological Survey of Great Britain be completed?"
>
> (iii) Questions might arise as to the degree of permanency which the expanded staff should have. The answer might well affect the conditions

of service of new staff (e.g. “established”, “unestablished”, “F.S.S.U.”). Some forecast was therefore desirable (so far as possible) of the reduction which might be anticipated after completion of the 6-inch survey.

(iv) An estimate should be available of the cost of printing of maps, having regard to the enhanced rate of production to be anticipated.[394]

The interpretation of the Geological Survey’s mission here is a governmental version. Although authored as “G.S.M.,” the memorandum was very likely to have been drafted and agreed by Trueman, as the new Chairman to the Geological Survey Board, and Barnard, as Barnard later distributed the document to Bailey and noted that he and Trueman “had a most useful meeting” so to “enclose a note that we have made on its which you may like to have for record, particularly on the points where it falls to you to take action.”[395] It turned out that Bailey was not totally convinced of the claims, for he replied with a note that “iii” in the memorandum would “entail careful discussion with G.S.M. Scientific Staff association.”[396] Bailey’s concern was that his staff might have had different demands for the conditions defined by

---

[394] G.S.M. to Department of Scientific and Industrial Research, 1-2.

[395] E. Barnard to E. B. Bailey, 6 January 1944, National Archives UK, DSIR 9/110 Geological Survey Future Organisation of G. S. M.

[396] E. B. Bailey to E. Barnard, 11 January 1944, National Archives UK, DSIR 9/110 Geological Survey Future Organisation of G. S. M.

“established”, “unestablished”, “F.S.S.U.,”[397] and the memorandum then was delivered to G.S.M. Scientific Staff Association for discussion.

Although beginning with staff conditions, the discussion revealed even deeper gaps in the understanding of the Survey’s mission between the Survey staff and their governmental administrators. As quoted above, the government was trying to justify the expansion of the Geological Survey by arguing that such expansion would better produce information to serve departments with industrial concerns, with the narrow focus on maps. It was an argument that dated back to the 1930s, as is analysed in Chapter 3 of this dissertation. Meanwhile, scientific staff of the Survey had their own vision of their future organisation, as is illustrated in their memorandum to the Director, signed by Talbot H. Whitehead, Chairman to the G.S.M. Scientific Staff Association.

Firstly, this memorandum confirms that mapping should have “sufficient priority” in the Geological Survey’s programme, adding that it was not only about providing information to external parties but also “fundamental to all G.S.M. activities”. The reason for the priority did not only lie in “considerations

---

[397] The Federated Superannuation System for Universities. Basically, when talking about the “establishment” or “continuity” status of the scientific staff at the Survey, the focus was whether the way they were employed would impact their pension. For interested researchers, this would make another good topic to talk about the conditions of geologists in post-war years. This chapter is mainly focused on the job inclination indicated in the pension demands.

relating to mineral resources, soils and water supply, etc.," or "the urgency of problems of regional planning," but also in "scientific, especially educational, interest."[398] Instead of placing the Geological Survey at a supporting position for economic and industrial development, the Scientific Staff Association's statement portrays the Survey as an organic whole that had its own internal functions and connections.

Secondly, the Scientific Staff Association's vision of the external relationship of the Geological Survey illustrated the Survey's role in another perspective, that they expected the scientific staff of the Survey

> should be in close touch with Scientific and Professional opinion outside Government Service and active participation of G.S.M. officers in the affairs of Scientific Societies and Professional Institutions should be officially encouraged by all possible means.[399]

By writing so, the scientific staff of the Geological Survey expressed a proactive attitude to reach out and become part of the geological academic and professional network. Although the Survey staff had never lacked in university education and conference exposure, and the Survey had never

---

[398] Talbot H. Whitehead and A. J. Butler, 'The Future Organisation of G.S.M.', 16 April 1944, National Archives UK, DSIR 9/110 Geological Survey Future Organisation of G. S. M., 1.

[399] Whitehead and Butler, 'The Future Organisation of G.S.M.,' 2.

stopped to gain inspirations from academic and vice versa, the scientific staff now called for an institution that would be allowed to communicate with peers as an institution, possibly with aims in research and knowledge, instead of merely a map publisher.

Thirdly, the Scientific Staff Association's memorandum indicates that the methods of the Survey would inevitably be drawn from beyond geology; hence, this variety in disciplinary background would need to be reflected along the new recruitments. For example, one notable consideration would be "the incorporation of the Chemical Laboratory staff within the G.S.M. Establishment, due opportunity for promotion being afforded, and that a chemist be recruited for Scotland."[400] The consideration was joined by the suggestion that surveying methods "should be supplemented by (a) facilities for putting down boreholes (b) the employment of geophysical methods and (c) use of aerial photographs in areas where the six-inch maps show little topographical detail."[401] If the Survey were to implement these considerations and suggestions, then recruiting scientists from an unconventional background and permanently absorbing unfamiliar methods would be natural. An interesting point that might be related to the absorption is that the memorandum clearly states the request for equipment spaces, that each

400 Whitehead and Butler, 'The Future Organisation of G.S.M.,' 2.

401 Whitehead and Butler, 'The Future Organisation of G.S.M.,' 3.

> officer on joining should be given a complete list of the equipment available for his personal use. Such equipment should be improved and periodically overhauled. Protective clothing should be provided where necessary.[402]

Although these sentences do not make it clear what equipment would be provided for new officers at the Survey, the expectations about such equipment is noteworthy enough. As the scientific staff's association claimed, better supply of personal and protective tools for field staff in any discipline, along with their prospect for diversified survey methods, the Survey activities must have already increased in scope, leading to an increased demand for equipment.

Calling themselves "scientific staff," the G.S.M. Scientific Staff Association described their organisation in a way that is similar to a multi-functional, self-driven institute, instead of a streamlined mapper and producer of data for governmental uses. As the Scientific Staff Association became deeply involved in the discussion on the post-war organisation of the Geological Survey, apart from staff conditions, they revealed more evidence and arguments that supported their picture of the Survey.

The Scientific Staff Association's memorandum reached Appleton in August

402 Whitehead and Butler, 'The Future Organisation of G.S.M.,' 3.

1944, following which they sent another note to Bailey to extend an invitation to Appleton to "carry out his original intention of visiting G.S.&M. again for personal contact and conversations with members of the staff."[403] Appleton's response, again through Bailey, confirmed that he would visit, and asked that he "should have liked to see more explicitly expressed in the memorandum the Association's awareness of the industrial and economic purposes that are the fundamental reason for the existence of the Survey and Museum."[404] To start a new round of their discussion that involved the function of the Survey, Bailey replied to Appleton in a tune that consistent with his scientific staff, that

> I do not agree with your "only general criticism" of the Association's memorandum, in which you say you would have liked "to see more explicitly expressed the Association's awareness of the industrial and economic purposes that are the fundamental reason for the existence of the Survey and Museum". I think that the Association has expressed the position perfectly in par. 3: -[405]

---

403 Talbot H. Whitehead to Director, 2 August 1944, National Archives UK, DSIR 9/110 Geological Survey Future Organisation of G. S. M. In the letter Whitehead also expressed that the association had "a general feeling of disappointment" for their earlier memorandum not reaching Appleton sooner.

404 E. V. Appleton to E. B. Bailey, 4 August 1944, National Archives UK, DSIR 9/110 Geological Survey Future Organisation of G. S. M.

405 E. B. Bailey, to Edward V. Appleton, 9 August 1944, National Archives UK, DSIR 9/110 Geological Survey Future Organisation of G. S. M.

He continued by reflecting on the Association's claim in the memorandum, that a balance of priority should be decided between not only mineral resources, soils, water supply, and regional planning, but also the scientific and educational interest of the Survey.[406]

Following an interval during which the Geological Survey produced more documents on the details of a renovation of their North of England office, the general discussion resumed in early 1945, with Appleton visiting the Survey's Scottish and Manchester offices and meeting with local members of the Scientific Staff Association. Appleton's trip in the north was mainly focused on the conditions of the staff, and the topic of the Survey's function was escalated later during his visit to the Survey's London office. As he met with the Association members there, Whitehead gave a few specific statements that not only concerned the employment conditions there but also referred to the general function of the Survey.

Whitehead provided an example of the cooperation between colleagues at the Survey, and he called it "'team-work' research in geology."[407] As his statement went:

> A unit mapping an area works as a team and the problems met with are

---

[406] Bailey to Edward V. Appleton, 9 August 1944.

[407] 'Statement by Whitehead', n.d., National Archives UK, DSIR 9/110 Geological Survey Future Organisation of G. S. M., 1.

> solved by discussions between them and with their colleagues at Head Quarters (especially the Palaeontologists, Petrographer and Chemists). It is in this respect that the Survey can make its best and most characteristic contribution to geology in general. It is the only body, with the exception of some large industrial economies, such as the oil companies, which maintains the permanent organisation necessary for such "team-work" research in geology. This kind of research is complementary to, and does not compete with, the independent research of individuals at the universities and elsewhere.[408]

In the statement, Whitehead naturally took the Geological Survey as a research counterpart to "individuals at the universities and elsewhere," and indicated that the most important contribution of the Survey was to "geology in general," instead of the government or the alike. A multi-disciplinary team, as in Whitehead's example, was necessary for the Survey to maintain its capability to contribute to geology by conducting research.

Appleton responded to the claim by raising the pure/applied science division, and noted that the "twofold" characteristics lay deeply in the Department of Scientific and Industrial Research's work. The misunderstanding was that he "had felt from the Association's memorandum on the future organisation of G.S.M. that the staff concentrated its attention too much on the production of

---

408 'Statement by Whitehead', 1.

geological maps and had insufficient interest in their utilisation."[409] As the meeting minute shows, Appleton clearly "had little knowledge of" the scope of the Survey's industrial contacts, and thus the Survey's scientific staff had to explain that, at present,

> both on selecting areas to be mapped and in executing the work particular attention is always paid to economic problems, that the completed map is the basis from which practically all enquiries are answered, and that apart from the great number of industrial enquiries and problems dealt with directly by G.S.M. the Survey maps and records are constantly used by consultants.[410]

As explained, Appleton's original misinterpretation was exactly the opposite to the claims from the scientific staff. He was also surprised to learn from the meeting that "the great majority of papers published by members of the staff in geological journals (i.e. the bulk of G.S.M.'s output of pure research) are the results of work done in private time (although they often arise from

---

[409] A. J. Butler, 'Meeting between Sir Edward Appleton, Mr. Hogg, and Dr. Wooldridge (Headquarter, D.S.I.R.) and the London Office Members of the G.S.M. Scientific Staff Association, held at G.S.M. on 23rd March 1945', 3 April 1945, National Archives UK, DSIR 9/110 Geological Survey Future Organisation of G. S. M., 2.

[410] Butler, 'Meeting between Sir Edward Appleton, Mr. Hogg, and Dr. Wooldridge (Headquarter, D.S.I.R.) and the London Office Members of the G.S.M. Scientific Staff Association, Held at G.S.M. on 23rd March 1945', 2.

problems met in official work) and that the staff has devoted a great part of its leave to such work."[411] While Appleton, upon learning this, agreed that such contributions should form "part of the official programme" of the Geological Survey, there is no evidence in the meeting minute that he would do further to change the Survey's role as an "official geological advisor to Government Departments."[412]

With no further discussions on the role of the Geological Survey, what we can see here is a gap between the government and the scientific staff, including the Director, at the Survey by the end of the Second World War. The nature of the Survey's work had gradually changed from merely surveying to a range of deeper investigations. By "deeper" (in both senses) an immediate project in the Survey's post-war agenda was to conduct more boring of holes, and the boring programme would become one more case that illustrates the introduction of unconventional techniques and methods, while at the same time a strange inability to realise it.

---

[411] Butler, 'Meeting between Sir Edward Appleton, Mr. Hogg, and Dr. Wooldridge (Headquarter, D.S.I.R.) and the London Office Members of the G.S.M. Scientific Staff Association, Held at G.S.M. on 23rd March 1945', 2.
[412] Butler, 'Meeting between Sir Edward Appleton, Mr. Hogg, and Dr. Wooldridge (Headquarter, D.S.I.R.) and the London Office Members of the G.S.M. Scientific Staff Association, Held at G.S.M. on 23rd March 1945', 2.

5.3 Desirability of a Boring Programme and the Geological Survey's Aims

As the year of 1944 came to an end, Appleton, taking the recommendations of the Advisory Council, requested that the Geological Survey submit a report on the desirability of a boring programme. Both Appleton and the Advisory Council agreed that the report should outline "a general programme of boring forming part of its normal work," although the scope and organisation of such a programme was unknown yet.[413] Both the Survey and its governmental administrative body started to work on the programme by meeting monthly from early 1945. As they informed Appleton, Bailey and Trueman met for a preliminary talk on the weekend after the initial request. They decided on the monthly meeting and that the report would be due in April or May 1945.[414]

Appleton insisted that Frank (Frank Edward) Smith be the first witness. Smith was former Chairman of the Advisory Council and also former Secretary of the Department of Scientific and Industrial Research. In his early years, he had been a student at Royal College of Science, now Imperial College London, studying chemistry, mathematics, and physics, as well as "some mechanical

---

[413] E. V. Appleton to Director, Geological Survey and Museum, 11 December 1944, National Archives UK, DSIR 9/111 Desirability of General Programme of Boring.

[414] A. E. Trueman to. E. V. Appleton, 18 December 1944, National Archives UK, DSIR 9/111 Desirability of General Programme of Boring.

drawing, geology and astrophysics."[415] For a long time, physics was Smith's major, and the career he started at National Physical Laboratory was as an Assistant, soon to be promoted to principal assistant and then superintendent of the electricity department. Indeed, he conducted some research on the standardisation of current and resistance, and his work led him involved with several governmental and international organisations on units and standards.[416] He joined the Admiralty during the First World War, and he was much rewarded for his invention of anti-submarine magnetic mines and his good political judgment.[417] After the war, Smith joined the newly established Department of Scientific and Industrial Research "with his highly developed expertise in organization and administration," becoming its third Secretary for nearly ten years.[418] After resigning from the position, Smith spent another five years at the Advisory Council, before, by the time the Geological Survey was investigating the desirability of a boring programme, becoming an adviser on scientific research and development at Anglo-Iranian Oil Company.[419]

Compared with the Board for, say, the gravity torsion balance programme as

---

[415] Charles Frederick Goodeve, 'Frank Edward Smith, 1876-1970', Biographical Memoirs of Fellows of the Royal Society 18 (1 January 1997), https://doi.org/10.1098/rsbm.1972.0019, 526.

[416] Goodeve, 'Frank Edward Smith, 1876-1970', 527.

[417] Goodeve, 'Frank Edward Smith, 1876-1970', 530-534.

[418] Goodeve, 'Frank Edward Smith, 1876-1970', 535.

[419] Goodeve, 'Frank Edward Smith, 1876-1970', 541.

is analysed in chapter 3, the membership of the committee for the desirability report on the boring programme shows a greater variety in expertise. Truman, chairman of the Board, was professor of geology at University of Glasgow at that time. He had a background in palaeontology, and earlier researched on the evolution of invertebrates from the Liassic fossils. His research could be loosely connected to the boring programme in the sense that "the non-marine Lamellibranchs have become of extreme economic importance in the correlation of seams in British and Continental coalfields."[420]

Also on the Board was T. G. Bocking. Among his publications there is a co-authored book *Field and Colliery Surveying: a Textbook for Students of Mining and Civil Engineering Surveying* (1929). According to a book review, Bocking might be a surveying engineer who was able to use a set of skills, both experimental and mathematical.[421] The other members were four university professors, many of them were regarded as leading geologists in Britain at that time. A. (Arthur) Holmes had just moved from Durham to Edinburgh the year before. Having studied physics and then geology in college, Holmes had

---

[420] 'Geology at Glasgow : Prof. A. E. Trueman, F.R.S.', *Nature* 158, no. 4009 (1 August 1946), https://doi.org/10.1038/158299a0, 299. Lamellibranchs, now often referred to as Bivalvia, such as clams and oysters.

[421] M. T. M. O., 'Review of Field and Colliery Surveying: A Textbook for Students of Mining and Civil Engineering Surveying by T. A. O'Donohue and T. G. Bocking', *Science Progress in the Twentieth Century* (1919-1933) 24, no. 94 (1929), 365.

been doing a variety of research relevant to the earth since then, from collecting radioactive petrological samples in Mozambique, to working for the oil industry in Burma, and to teaching in universities.[422] His research interest had covered key topics such as geochronology, radioactive rocks, the earth's thermal history, and an early version of the plate tectonics.[423] The book *Principles of Physical Geology* (1948) that he was writing at that time would become classic textbook in geology for generations of students.

L. J. (Leonard Johnston) Wills was also an eminent geologist on the Board. In the 1940s, Wills was based at University of Birmingham, and, like Holmes, he was "no narrow specialist" either.[424] Graduating in Natural Sciences and then Geology from Cambridge, Wills started his career researching plant and animal fossils, and then, at the Geological Survey, turned to mapping rocks in North Wales. Another research interest of his was the geo-history of the Dee and Severn Rivers, dating back to the glacial episodes. His books *The Physiographic Evolution of Britain* (1929) and *Palaeogeography of the Midlands* (1948) became popular textbooks in stratigraphy. Another leading geologist on the Board, H. L. (Herbert Leader) Hawkins, had spent most of his career at the University of Reading as the founder of its geology

---

[422] K. C. Dunham, 'Arthur Holmes 1890-1965', *Biographical Memoirs of Fellows of the Royal Society* 12 (1966), 291-293.

[423] Dunham, 'Arthur Holmes 1890-1965', 295-299.

[424] 'Geology at Birmingham: Prof. L. J. Wills', Nature 164, no. 4159 (1 July 1949), https://doi.org/10.1038/164096a0, 96.

department.[425] He started his early career research in zoology, a subject that later brought him international reputation for his research on the evolution and habitats of Echinoidea.[426]

The report was undated. It notes, though, that it was based on the recommendations of the Advisory Council on 25th October 1944, which was then transmitted to the Director of the Geological Survey on 11th December. The report also states that the Geological Survey Board had “held five meetings at which evidence, written and oral, has been given by witnesses representing official bodies, learned and professional societies and industrial organisations.”[427] Since Bailey and Trueman had agreed to meet monthly for the report, then it must have taken more than half a year to complete it.

By “general,” the Board indicated that such a boring programme should mitigate the gap of information that had been left in previous private and governmental boring projects. As is mentioned above, since the Mining Industry Act of 1926 came into effect, any private borehole with a depth of over 100 feet should be notified to the Geological Survey, and the Survey was

---

425 ‘Professor H. L. Hawkins’, *Nature* 221, no. 5177 (1 January 1969), https://doi.org/10.1038/221294a0, 294.

426 Zoological class that consists of sea urchins.

427 A. E. Trueman et al., ‘Report on the Desirability of a General Programme of Boring by the Geological Survey’, n.d., National Archives UK, DSIR 9/111 Desirability of General Programme of Boring, 2.

authorised to examine such boreholes. There were also boreholes in search for water, which were normally over 50 feet deep, and it was not compulsory to borers to report such boreholes to the Survey. By the time the Geological Survey Board collected evidence for their report, boring projects for water were fewer in number than those for minerals. Furthermore, mineral boreholes were mostly in or near known coalfields, while water boreholes "spread over a much wider area, especially in England."[428] The imbalance in the distribution of boreholes in the country had left a gap of information about the country's geology. As the report puts it, the Geological Survey had:

> Gained a great deal of information from borings put down for these various purposes and the data so acquired have been of fundamental importance in the interpretation of structures and in the completion of maps. It is obvious, however, that the boring which has been carried out hitherto has been directed to the solution of particular problems and that some areas and groups of strata have been explored much more comprehensively than others. Thus there are great gaps in our knowledge of the deeper structure of many areas.[429]

As a result, the Geological Survey Board found it necessary to launch a

---

[428] Trueman et al., 'Report on the Desirability of a General Programme of Boring by the Geological Survey', 4.

[429] Trueman et al., 'Report on the Desirability of a General Programme of Boring by the Geological Survey', 5.

programme that would entail a general understanding of the country's geology and would mitigate the information gap that had existed. It should be noted that, in such a programme, the Geological Survey would need to focus on the grand picture instead of particular assignments, although it did not mean that practical values were neglected – the Survey and its board now believed that a grand picture would benefit the economy as a whole and thus be necessary.

With such necessity in mind, the report starts to picture the general programme of boring as part of the Survey's normal work. Surely, as the report also clarifies, the Survey would continue to focus on making geological maps, which had been their main job for decades, and "that the completion of the series of one-inch maps, based on six-inch mapping, and the frequent revision of coalfields and other areas of special economic importance, will for some time continue to be its primary tasks."[430] Meanwhile, the Board promised that "no programme of boring will reduce the work involved in the making of maps, though it may add to their accuracy and completeness."[431] As is discussed in an earlier section in this chapter, such a separate programme surely required an increase in staff, and the Geological Survey was eager to make this come true.

---

[430] Trueman et al., 'Report on the Desirability of a General Programme of Boring by the Geological Survey', 3.

[431] Trueman et al., 'Report on the Desirability of a General Programme of Boring by the Geological Survey', 3.

The Geological Survey Board started to plan the general programme and divided it into two categories: “shallow borings designed to afford information for the interpretation of structures in areas being mapped,” and “deep borings designed to yield information regarding formations which may not appear at the surface in that area.”[432] Different from their literal meanings, “shallow” and “deep” here do not necessarily suggest differences in the depths of boreholes; rather, they indicate the depth of knowledge that the Geological Survey would gain from these actions. While shallow borings were dedicated to provide limited and ancillary information of a certain, known area, deep borings were expected to explore and discover more about the whole geological structure.

For shallow borings, the Board expected that they would “be ancillary to” the Survey’s mapping by increasing the accuracy of and information on these maps.[433] These borings were expected to have a depth less than one or two hundred feet, and only one borehole at a carefully selected spot should be enough for a certain, already mapped area. In most cases, these borings were expected to be used to check and add up to existing mapping information. Due to the close connection to the Survey’s main job, the Geological Survey Board suggested that the authority to conduct these

---

[432] Trueman et al., ‘Report on the Desirability of a General Programme of Boring by the Geological Survey’, 6.

[433] Trueman et al., ‘Report on the Desirability of a General Programme of Boring by the Geological Survey’, 6.

borings should be given to the Survey, and the Survey should be authorised to determine the depth of such boreholes according to their needs.[434]

The other category, the deep borings, was rather different, since they were not expected to help directly with geological mapping or in discovering new mineral deposits. Thus, it was "less closely related to the normal work" of the Survey. However, the Board argue for deep borings that it was "extremely desirable to acquire a much more precise knowledge of the underground structure of certain parts of Britain."[435] For example, they believed that it was

> Particularly true of a large area of South and East England where the Mesozoic rocks rest unconformably and at various depths upon a Palaeozoic floor. In Kent the Mesozoic rocks have been penetrated and the Kent Coalfield located as one feature of the Palaeozoic floor. But for much of the rest of the area in question it is impossible to produce any kind of reliable map showing even the broadest distribution of the rocks comprising the floor. This has been demonstrated most convincingly in the past year by the enquiries of the oil company which has been interesting itself in the exploration of this part of Britain.

---

[434] Trueman et al., 'Report on the Desirability of a General Programme of Boring by the Geological Survey', 6-7.
[435] Trueman et al., 'Report on the Desirability of a General Programme of Boring by the Geological Survey', 7.

In this example, the Board shows how a general understanding of an area gained through boring might be useful for economic developments. Although information on the rock types and strata in a certain area had no direct connection to resources, knowing the geological features of the area would be a help when it came to locating for economic reasons, and thus it would be best to have adequate knowledge prepared in advance. For such a depth in knowledge, the Geological Survey Board decided that it was possible to allow other bodies to take a role:

> The extent to which other bodies should be invited to co-operate in this exploration is discussed more fully below, but whether such bodies take part in the investigation or not, we believe that there is ample justification for the Geological Survey being provided with funds to enable it to make a preliminary investigation of the sub-Mesozoic floor especially of south and east England.[436]

Still with Kent as an example, the Board explained in the report in great detail how it expected such deep boring programme could be supported and conducted:

> The development of such a programme would necessarily have to be planned as the work proceed, the information obtained from the first

[436] Trueman et al., 'Report on the Desirability of a General Programme of Boring by the Geological Survey', 7-8.

> group if borings being used to indicate the most suitable location for further exploration. We believe that with twenty deep borings over this area it would be possible to add very considerably to our knowledge of its structure and we urge that such a deep boring programme be carried out with the least possible delay. A five-years' programme involving the sinking of a total of twenty deep borings would be a suitable scheme for opening up this problem. Subsequent boring would depend on the nature of the information obtained. The discovery of workable coal seams at comparatively shallow depths, or of other economic resources which might be suitable for development, would presumably be followed by further exploration, but this second stage, preparatory to economic development, would, we consider, more suitably fall under the control of other bodies, with the Survey working in close co-operation in this category would come borings near the borders of known coalfields required to ascertain the possibilities of their further development.[437]

By now, it had become clear that economic benefits were not the first priority of the Geological Survey. Compared with reports in earlier chapters, the extract quoted above seems rather careless about the possible economic reasons that would have been regarded necessary to justify the programme, only to be mentioned as one of the aspects of a much more important pursue

---

[437] Trueman et al., 'Report on the Desirability of a General Programme of Boring by the Geological Survey', 8-9.

for knowledge. Similar expression of interest (or of less interest) appears when the report deals with some general questions regarding the boring programme, as it goes:

> In the course of the evidence, attention has frequently been called to problems which may arise as a result of boring which yields information of reserves of mineral that are not the property of the nation. These problems raise wide political and economic issues which lie outside out terms of reference and the Board feel that it is sufficient if attention is called to them. The Board note that in many cases individuals or organisations may benefit from the results of a Geological Survey programme of boring, but that the development of such mineral resources is, in general, a benefit to the nation as a whole. The same factors, indeed, arise as a result of most of the Geological Survey's activities. On many occasions unsuspected resources have resulted from routine field mapping and it may be argued that the boring programme represents little more than an extension of this type of discovery.[438]

As the Geological Survey Board eagerly turned their eyes away from those known, existing focuses, knowledge became the key word of the report. The report mentioned several times elsewhere that the general boring programme

---

[438] Trueman et al., 'Report on the Desirability of a General Programme of Boring by the Geological Survey', 15-16.

was based on a need for information, whether because of designated economic interests or not. As a general understanding, the Geological Survey Board stated that they were:

> Impressed by the evidence of those who believe that it is in the national interest that fuller knowledge should be obtained of the underground composition and structure of the country, especially in relation to the distribution of potential mineral resources. We recognise that such exploration may be relatively costly and we are aware that at the present time the expenditure of considerable sums of money provided by H. M. Government can only be justified if the information to be obtained is directly or potentially of economic importance. We would point out, however, that almost every boring, sited so that the information it produces is new, must yield data of some potential economic significance. Even when some mineral deposit expected is shown to be absent, the information if of value, as a full study of the data obtained may throw light on the underground distribution of rocks and contribute to a basis for structural interpretation which will make it possible to delimit the areas of proved resources.[439]

As a result, the Board continued to say, they would:

---

439 Trueman et al., 'Report on the Desirability of a General Programme of Boring by the Geological Survey', 5.

> Emphasize that the success of a boring programme supported by Government funds must not be entirely judged on new discoveries of mineral or other resources. On the other hand, we are agreed that economic questions must largely determine any proposed programme of boring and, in particular, will determine the areas where structural information is most needed.[440]

In summary, the Board concluded:

> That it is desirable for a programme of boring to be undertaken in the national interest, and are impressed by the view that it is desirable to secure a much fuller knowledge of the mineral resources of this country. It is clear that the Geological Survey must be closely associated with any such boring programme. It will be able to advise as to the siting of proposed boreholes and must be responsible for the collection of data and the interpretation of the geological evidence yielded by the borings. Such a programme could be designed with particular reference either to the work of the Survey, or to the activities of particular Government Departments and bodies, working in close co-operation with the Survey, but seeking information for special purposed.[441]

---

[440] Trueman et al., 'Report on the Desirability of a General Programme of Boring by the Geological Survey', 5.

[441] Trueman et al., 'Report on the Desirability of a General Programme of

The statements above suggested a mild departure from a narrow focus on economic requirements, which the Geological Survey had observed for most of its history. To begin with, the report confirmed that the information that would be obtained from a general programme of boring would continue to serve economic development, and the specific actions in the programme would continue to be determined by economic needs. However, the Geological Survey Board who wrote the report and who governed the Survey's agenda decided that a general programme of boring should see beyond specific minerals or sites, but view the geological structures and the distribution of resources in the country as a whole. While mineral resources would be the most practically valuable part of such a general programme, the programme would ultimately bring about a better understanding of "the underground composition and structure of the country," which might not be directly connected to industrial demands, but would benefit the economic as a knowledge foundation.

Seeing the general programme of boring as something justified on broad intellectual grounds, the Geological Survey would not only be justified to conduct projects (and to ask for funds) that was not relevant to an immediate economic construction, but would also be free to explore new techniques and new geological sites in the programme, which might be regarded as less

---

Boring by the Geological Survey', 6.

useful for a time. Therefore, it was no wonder that the report noted geophysical techniques in a positive light, for example stating that:

> The Board strongly recommend that when any such geophysical unit is established the Geological Survey should have authority to bore in connection with the geophysical investigations. It would be undesirable to pursue a programme of geophysical work if the results of the investigations were not directly checked from time to time by borings suitably located.[442]

That is to say, the Geological Survey Board was very happy to explore and apply geophysical techniques when it came to the boring programme, and such techniques would be welcomed to be tested in the process of boring. Although without detailed plans, the Board had expressed here a trust for the future of geophysical techniques to be applied in the Survey's work.

5.4 Conclusion

This chapter reviews the Geological Survey's recruitment plan and investigation of the desirability of the boring programme. In both cases, the staff at the Survey expressed the desire to explore beyond the need of

---

[442] Trueman et al., 'Report on the Desirability of a General Programme of Boring by the Geological Survey', 13.

mapping or other economic demands. The Scientific Staff of the Survey, while arguing for their rights, took a variety of disciplines and the working conditions of colleagues in these disciplines into consideration. The boring programme report, acknowledges that the programme would not only produce practical information but also knowledge in general. The possibility of using geophysical techniques for this purpose was accepted. Both cases suggest that the Geological Survey was developing beyond merely an advising institution. However, neither campaigns made much progress quickly, and it would still take some time before the Geological Survey participated in a geophysical project.

Chapter 6: Airborne Magnetic Survey and the Application of Geophysics

In one of the few accounts of history of the Geological Survey, Wilson's *Down to Earth* (1985), the airborne magnetic survey that took place in 1950s is regarded as the Survey's very first success in geophysical projects.[443] As the name suggests, it was indeed a step into geophysics: magnetometry was a geophysical surveying technique that the Geological Survey had been interested in since the 1930s. The Survey succeeded by collecting enough data to produce a map of the magnetic field of an area of land. In this chapter, we will see how the project came into being from a post-war proposal. Moreover, we will also see how the project enhanced the Survey's connections, and how it showed that a change in the nature of the Survey's research was noticed and accepted by both the Survey staff and the government.

6.1 Early Proposal and Progress

The idea of a magnetic survey of England was not new. As has been

---

[443] H. E. Wilson, *Down to Earth: One Hundred and Fifty Years of the British Geological Survey* (Edinburgh & London: Scottish Academic Press, 1985), 154.

discussed in Chapter 3, magnetic methods had been one of the major surveying techniques since 1930s, and members of the Geological Survey had attempted it as a personal interest, although not yet as an institutional effort. After the Second World War, as the Geological Survey developed their post-war agenda in both mapping and other aspects of geology, as has been discussed in Chapter 5, the long-running interest in a magnetic survey coincided with interest from Ministry of Supply, with the support of Air Ministry and the Admiralty. The earliest idea of a new magnetic project dated back to late 1940s, just after the war's end. An extract found from an Advisory Committee on Airborne Research Facilities document suggests that, on a19 March 1946 meeting, the committee members "considered an application from the Geological Society for photographs to be taken of special areas of the United Kingdom."[444] Although it was not clear that "photographs" referred to magnetic photographs, the result of an airborne magnetic survey, the consideration indicated in the extract developed into a specific requirement in the next year that some type of research with airborne magnetometers should take place. On 15 August 1947, the Ministry of Supply held a meeting to consider the issue and invited staff from various sections of the government. Harry M. Garner chaired the meeting[445] and decided that the object of the

---

444 'Extract from Minutes of Meeting of the Advisory Committee on Airborne Research Facilities Held on 19 March 1946', n.d., British Geological Survey Archives, GSM/PY/A/18.

445 Principal Director, Scientific Research (Air), Ministry of Supply. "Garner,

meeting was “to determine whether the interest in the development of the equipment and technique for air magnetometry for scientific purposes, for Civil uses (e.g. for applied geophysical survey) and for military purposes, warranted the allocation of scientific and technical effort from the present limited resources of the country.”[446]

Garner explained that the equipment was expected to be applied “to the solution of two problems, one the determination of local anomalies in the earth’s magnetic field due to minerals or geological structures and the other, the more fundamental determination of the configuration of the earth’s magnetic field.”[447] In addition, Garner noted interest from the Council of Royal Society, emphasising the “scientific value of the new technique and its important practical value for sea and air navigation, as well as in applied geophysical survey for minerals.”[448] These are very candid statements indicating that the proposed airborne magnetometer research would have a

---

Sir Harry Mason, (3 Nov. 1891–7 Aug. 1977), Chief Scientist to Ministry of Supply, 1949–53." *Who's Who & Who Was Who*. 1 Dec. 2007; Accessed 18 Mar. 2024. https://www.ukwhoswho.com/view/10.1093/ww/9780199540891.001.0001/ww-9780199540884-e-154719.

[446] ‘Meeting to Discuss Research and Development of Airborne Magnetometers’, n.d., British Geological Survey Archives, GSM/PY/A/18.

[447] ‘Meeting to Discuss Research and Development of Airborne Magnetometers’, 1.

[448] ‘Meeting to Discuss Research and Development of Airborne Magnetometers’, 1.

twofold purpose – both in applied geology and in fundamental science. As a governmental scientist, Garner would not find it strange to make such statements, but the tone was not common in previous Geological Survey proposals.

The Geological Survey, with only one staff present, did not play any major role in the development of the proposal during the meeting. A. F. Hallimond, who was possibly the only Survey member familiar with magnetic surveying at that time, expressed his interest on behalf of the Department of Scientific and Industrial Research, hoping it would make surveying in the United Kingdom able to be conducted more economically.[449] He also joined the discussion by questioning technical details such as whether "a disadvantage of the airborne method were not that observations were necessarily conducted at a specific altitude, and not at surface level."[450] In other words, Hallimond was worried that survey results gained from high above the earth might not accurately represent conditions or features at ground level, since variations in altitude could affect the accuracy and interpretations of the survey results.[451] He was

---

[449] 'Meeting to Discuss Research and Development of Airborne Magnetometers', 3.

[450] 'Meeting to Discuss Research and Development of Airborne Magnetometers', 2.

[451] Although we lack in sound evidence for this, Hallimond's concern might suggest a failure in his early attempts in magnetic methods in the 1930s, that, at that time, inevitable variations in observation conditions could have resulted in unacceptable errors, just like the case of gravity torsion balance.

not over-anxious, but as C. A. Jarman took over – he would be the main contact on the Ministry of Supply side later, it was clarified that the instability could be mitigated if they determined the vertical gradient by surveying at different altitudes, or by conducting research at lower altitudes over the sea or flat terrains.[452]

The meeting reached unanimous approval of the airborne magnetic research, with J. C. W. Drable from Admiralty and S. F. Davis from Air Ministry also expressing interest in developing the technique.[453] On the other hand, Davis and R. Ll. Brown of the War Office insisted that their current effort on Military Survey should not be interrupted. In conclusion, Garner agreed that the Ministry of Supply would be proceeding the proposal.[454]

As the year was drawing to an end, another inter-departmental minute summarised progress that took place in the months after the meeting. Firstly, among two necessary modified sets of equipment

> one laboratory model instrument is now ready for flight test and No. 2 set will be ready in approximately one month. A new detector head has been

---

452 'Meeting to Discuss Research and Development of Airborne Magnetometers', 2.

453 'Meeting to Discuss Research and Development of Airborne Magnetometers', 2-3.

454 'Meeting to Discuss Research and Development of Airborne Magnetometers', 4.

> designed and its being manufactured for use in low magnetic latitudes.[455]

Secondly, to prepare for a survey of the elements of a certain field, “preliminary work has been carried out and a technique decided”[456], and that “manufacturing of the detecting element – fluxgate – has begun.”[457]

Thirdly, to modify an aircraft for the test where the equipment would be installed,

> Little progress has been made, and this will, unfortunately, delay the development of the equipment being modified under 1(a). The contract has just been placed and the aircraft delivered to the contractor, who, it is estimated, will have some two months’ work on the aircraft before flying can effectively begin.[458]

In spite of the unfortunate delay, the project was promising, and in March 1948, the involved government departments met again to discuss progress.

---

[455] E. T. Jones, ‘M.O.S. Progress Report on Research and Development of Airborne Magnetometers’, 31 December 1947, British Geological Survey Archives, GSM/PY/A/18.

[456] Jones, ‘M.O.S. Progress Report on Research and Development of Airborne Magnetometers’.

[457] Jones, ‘M.O.S. Progress Report on Research and Development of Airborne Magnetometers’.

[458] Jones, ‘M.O.S. Progress Report on Research and Development of Airborne Magnetometers’.

They updated that one set

> Of equipment had been tested at Abinger Magnetic Observatory and the records compared with those of the absolute instruments of that Observatory. The records indicated that the total force variometer reproduced faithfully the diurnal variation in the earth's magnetic field and that the instrumental drift over 48 hours does not exceed 5 gamma, a figure quite satisfactory for Applied Geophysical Survey. Sensitivity was more than adequate.[459]

And based on the results above,

> Quantitative air tests of the equipment will begin as soon as the aircraft is ready for the flight. Preliminary flight tests of a qualitative nature in a standard aircraft with the equipment merely placed in the fuselage and with the detector head slung on cords indicated satisfactory instrumental performance; but, as would be expected, large spurious anomalies were recorded during aircraft manoeuvres, e.g. raising lowering undercarriage, in turns, etc.[460]

---

[459] C. A. Jarman, 'Notes of Meeting to Discuss Research and Development of Airborne Magnetometers in Room 2028, Thames House South, Ministry of Supply on Friday the 5th March, 1948', 10 March 1948, British Geological Survey Archives, GSM/PY/A/18, 1.

[460] Jarman, 'Notes of Meeting to Discuss Research and Development of

With the test flights judged to have been satisfactory, the meeting decided that “no further business [was necessary and] the Chairman directed Mr. Jarman circulate a further progress report in six months’ time,” and also decided to invite the Department of Scientific and Research to complete details of the project, including the decision over the area to be surveyed. No staff from the Geological Survey was present at the meeting, but Jarman wrote to William F. P. McLintock, who was then Director of the Geological Survey, soon after the meeting, informing him of the project and asking him to suggest an area for a test survey.[461]

James Phemister replied to Jarman’s letter instead. He was now Assistant Director of the Geological Survey. In his letter, Phemister suggested three areas, including one “one west of Reading,”[462] which became the place for the Ministry of Supply’s two “check surveys” in May.[463] Jarman reported the success of the check surveys to Phemister saying that

> The results indicate that the equipment has been operating satisfactorily

---

Airborne Magnetometers in Room 2028, Thames House South, Ministry of Supply on Friday the 5th March, 1948’, 1.

[461] C. A. Jarman, ‘To Director of the Geological Survey’, 9 March 1948, British Geological Survey Archives, GSM/PY/A/18.

[462] James Phemister, ‘To C. A. Jarman’, 19 March 1948, British Geological Survey Archives, GSM/PY/A/18, 1.

[463] C. A. Jarman, ‘Airborne Magnetometers’, 13 May 1948, British Geological Survey Archives, GSM/PY/A/18.

> and that the anomalies, which, from a knowledge of the ground observations would be expected, duly appeared.[464]

To explore the results further, he continued and asked Phemister for “copies of the geological maps, preferably on a 1” to the mile scale, of the area bounded by Oxford, Princes Risboro[ugh], Reading and Newbury.” The sequence that Jarman arranged for every steps of the survey would be reused when an airborne magnetic survey covered a larger area, as we will see in a later part of this chapter.

It was very likely that Jarman also offered a demonstration of the survey for the Survey staff, for Phemister was found to have written a note within the D.S.I.R that such a demonstration “had been arranged by the Director of Instrument Research and Development at Langley Airport on 31st May,” and requested that it “would be useful for Mr. Bullerwell of G.S.M. staff to attend and take part in the demonstration flights to illustrate the operation of the above equipment.”[465] The Department gave its formal permission three days later, and the demonstration was a sign for the Geological Survey to get more deeply involved in the project. Phemister drafted his proposal that the Geological Survey should undertake the Survey and submitted it to

---

464 Jarman, ‘Airborne Magnetometers’, 13 May 1948.

465 James Phemister, ‘Demonstration of Total Force Magnetic Variometer’, 21 May 1948, British Geological Survey Archives, GSM/PY/A/18.

McLinktock two months after the demonstration.

Phemister argued that the Geological Survey should help the country to catch up with the rapidly developing geographical techniques, since

> Within the past generation geophysical instruments have developed rapidly and now form part of the working equipment of all great geological organisations whether official or commercial. Britain has lagged both in the development of instruments and in their application. An efficient instrument for serial measurement of changes in total force has now been constructed in Britain at public expenses. It is fitting that its earliest application should be undertaken by the Geological Survey.[466]

Then he argued for the practical reasons for such a survey, that

> The Geological Survey is closely concerned with the long term planning of coalfield development, and is called on by the N.C.B. for advice with regard the probable extension and structure of concealed coalfields. Normal surface geological surveying methods cannot supply sufficient data and it is necessary that all the help which modern advances in

[466] James Phemister, 'Memorandum on a Proposal for an Airborne Magnetometer Survey of Britain', 6 August 1948, British Geological Survey Archives, GSM/PY/A/18, 1.

> geophysical surveying may yield should sought.[467]

And on the other hand,

> Magnetic surveys are the least expensive and the most rapid of geophysical surveys.[468]

It should be noted that, to summarise all the points above, Phemister added that

> Apart from the geological application of a magnetic survey, charts of the variation of I [sic] over Britain are of both scientific and practical interest to physicists and all persons civil and military interested in the magnetic field. It is certain that if the Geological Survey does not undertake the work it will be done by or under the aegis of some other institution probably by a special grant from public funds. There would, however, be little likelihood that if carried out by another institution the survey would be done in the detail or on a plan suitable for geological application. On the other hand if carried out by G.S.M. the information would be completely adequate for all other requirements.[469]

---

467 Phemister, 'Memorandum on a Proposal for an Airborne Magnetometer Survey of Britain', 1.

468 Phemister, 'Memorandum on a Proposal for an Airborne Magnetometer Survey of Britain', 1.

469 Phemister, 'Memorandum on a Proposal for an Airborne Magnetometer

Phemister's argument shows two ambitions that were rather novel for the Geological Survey. Firstly, it demonstrates a scientific interest, even on behalf of physicists (not even "geophysicists" in Phemister's word). Although it has been illustrated in Chapter 4 that scientific staff at the Survey had developed a scientific interest, the interest was still unstable; nor did the Survey clearly know what to do to meet the interest. Secondly, Phemister's argument indicated that the survey would allow the Survey to be competitive with other institutions.

With Jarman willing to lend the aircrafts and equipment if the DSIR requested,[470] Phemister was optimistic that the cost of the survey could be covered. As he told McLintock, the "approximate cost of the Survey" would be £45,000 in total, including

> £20,000 for Stage I covering the greater part of central, eastern and southern England where conceled pre-Permian structure may have economic importance.
>
> £25,000 for Stage II, covering the whole of Scotland, England and Wales on a wider traverse-net than in Stage I.[471]

Survey of Britain', 1.

470 Phemister, 'Memorandum on a Proposal for an Airborne Magnetometer Survey of Britain', 3.

471 James Phemister to Dr. McLintock, 6th August, British Geological Survey

McLintock, adding his support, reported the proposal to the Secretary of the Department. Apart from Phemister's arguments and the fact that Phemister and Bullerwell had been with his consent in close cooperation with Jarman, McLintock added another advantage of the proposal was that it did not "call for a large increase in staff," as "the results obtained from the airborne instrument could be satisfactorily reduced and computed by two or three suitably trained officers of Experimental Officer grade."[472]

Archives, GSM/PY/A/18.

[472] W. F. P. McLintock, 'Airborne Magnetometer Survey of Great Britain', 6 September 1948, British Geological Survey Archives, GSM/PY/A/18.

An occasion in Southpark in 1956 with two ex-Directors, W F P McLintock and Sir Edward Bailey, greeting the then Director, William Pugh and the Assistant Director, Archie MacGregor.

Figure 6.1. Some postwar directors of the Geological Survey. From: H. E. Wilson, *Down to Earth: One Hundred and Fifty Years of the British Geological Survey* (Edinburgh & London: Scottish Academic Press, 1985), 26.

C. Jollife, the Deputy Director at the Department, entered the conversation. He received McLintock's letter and also talked with him to reach an agreement "in principle that you should proceed with this work," while also asking McLintock to discuss the matter first with the Geological Survey Board.[473] He also advised that McLintock should start arranging for the financial work earlier so that the funding could be ready within the current

[473] C. Jollife to Director of Geological Survey and Museum, 25 September 1948, British Geological Survey Archives, GSM/PY/A/18.

financial year.[474] A. E. Trueman, Chairman at the Geological Survey Board, was also in favour of the proposal, commenting that "the carrying out of such a survey would be of great benefit in giving a basis for the interpretation of structures over a large part of the country."[475]

In early 1949, everyone seemed on track to get ready for the project. Phemister was communicating with Decca, the navigation electronics company for the project, requiring their navigation data to get familiar with the system,[476] Jarman was updating Phemister with the latest configurations of the magnetometer,[477] and Bullerwell was in close discussion with Jarman about the solution to possible errors in the navigation system.[478] The Department of the Scientific and Industrial Research got involved to sort out further administrative procedures in summer. However, in October 1949, McLintock received a "soft" notice from the Department that the project might not become possible

---

474 Jollife to Director of Geological Survey and Museum, 25 September 1948.
475 A. E. Trueman to I. G. Evans, 14 October 1948, British Geological Survey Archives, GSM/PY/A/18.
476 James Phemister to the Decca Navigator Company, Limited, 15 February 1949, British Geological Survey Archives, GSM/PY/A/18.
477 C. A. Jarman, 'Applied Geophysical Survey: Total Force Magnetic Survey of the United Kingdom', 19 February 1949, British Geological Survey Archives, GSM/PY/A/18.
478 C. A. Jarman, 'Total Force Survey of the United Kingdom', 24 March 1949, British Geological Survey Archives, GSM/PY/A/18.

> If the Estimate position remains what it is at the moment, we should be alright for starting the survey the financial year and completing it the next – even though at the cost of postponing the next deep bore.
>
> We cannot however exclude the possibility that the Estimates position may worsen – to judge only from the papers – though I am hopeful this will not happen to D.S.I.R. But we have yet to hear.[479]

With the letter as a beginning, the financial prospect of the airborne magnetic survey quickly deteriorated, until Phemister learnt from a department meeting in March 1950 that they were "informed of a cut in our 1950/51 estimate which made simultaneous prosecution of our boring programme and the Airborne Survey impossible."[480]

6.2 Geological Survey into 1950s

An increase in the numbers of staff with a background in physics correlates with the Geological Survey preferring more geophysical projects. McLintock, who held a degree in science and who had been on the gravity torsion

---

[479] To Dr. W. F. P. McLintock, 24 October 1949, British Geological Survey Archives, GSM/PY/A/18, 1.

[480] James Phemister, 'Memo', 21 March 1950, British Geological Survey Archives, GSM/PY/A/18.

balance project which is discussed in earlier chapters, completed his five-year directorship in 1950. During his directorship, the Geological Survey had managed to recruit a number of physics degree holders, partly as an aftermath of the end of the Second World War. Among the recruitment was William Bullerwell, who had studied both physics and geology in college, and had worked on magnetic prospecting during the war.[481] At the Geological Survey, Bullerwell became head of the newly established Geophysical Unit since 1947, the division which supervised the airborne magnetometer survey in the coming decade.[482]

The Geological Survey had made little progress in geophysics since the McLintock and Phemister's gravity torsion balance trial, and the task that McLintock had assigned Bullerwell was to revive the geophysical work.[483] To prepare for this revival, Bullerwell's first project was a study of the Bristol-Bath district. His collaborator there, G. A. Kellaway, had identified a distinct geological complex in the Bristol Coalfield before, and Bullerwell then retrieved the gravity torsion balance to picture the variation of the gravitational

---

[481] Kingsley Charles Dunham, 'William Bullerwell, 27 September 1916 - 25 November 1977', in *Biographical Memoirs of Fellows of the Royal Society*, vol. 24 (London: Royal Society, 1978), 3, https://doi.org/10.1098/rsbm.1978.0001.

[482] Dunham, 'William Bullerwell, 27 September 1916 - 25 November 1977', 5-6.

[483] Wilson, *Down to Earth: One Hundred and Fifty Years of the British Geological Survey*, 154.

constant and evaluate the subsurface rocks.[484] The project led to the completion of his doctoral dissertation which combined the gravity survey with his long-term interest in magnetic surveys; plus, for Bullerwell, it also shed light on training new geophysicists for the Geological Survey.[485] In the 1950s, "gravity and magnetic surveys to complete the coverage of the United Kingdom were steadily pressed forward,"[486] and hence the conditions were right for the airborne magnetic surveys to be put onto the agenda again.

6.3 Nuffield Foundation Gets in Touch

The Nuffield Foundation, based on the wealth of the automobile manufacturer William Morris, the first Lord Nuffield, was established in 1943. Among its founding trustees was Sir Henry Tizard, who was first associate secretary and then permanent secretary of the Department of Scientific and Industrial Research. Again, it would be reckless to say that the trusteeship guaranteed a good collaboration between the Nuffield Foundation and the Department of Scientific and Industrial Research, but, as Tizard had continued to be "half in and half out of the Civil Service" since then, and as he kept "alive those

---

[484] Dunham, 'William Bullerwell, 27 September 1916 - 25 November 1977', 4.
[485] Dunham, 'William Bullerwell, 27 September 1916 - 25 November 1977', 4-5.
[486] Wilson, *Down to Earth: One Hundred and Fifty Years of the British Geological Survey*, 155.

friendships and contacts which he had formed through the years", then Ronald W. Clark must be right, that

> Tizard's influence on the ways in which the Foundation spent considerable sums in its early years was to be more obvious and more direct than that of most other trustees; and he was, as we shall see, to be very largely responsible both for its first major support of research in nuclear physics and for the decisions without which the Jodrell Bank radio telescope would, in all probability, never have been started, let alone finished.[487]

Another link to the Jodrell Bank radio telescope was firstly made via P. M. S. Blackett. In 1947, as he reported on some grants on physics that the Nuffield Foundation had provided earlier, Blackett noted that "A considerable amount of workshop work and a good deal of general construction work has been done in connection with radar developments situated at Jodrell Bank, twenty miles south of Manchester."[488] These grants from the Foundation, on the other hand, were largely dependent on the government plans. The Foundation

---

487 Ronald W. Clark, *A Biography of the Nuffield Foundation* (London: Longman, 1972), 13-14. Although Clark's account is largely referred to here, there are other account on the history of Jodrell bank. See Bernard Lovell, *The Story of Jodrell Bank* (Oxford: Oxford University Press, 1968) and Jon Agar, *Science and Spectacle: The Work of Jodrell Bank in Post-War British Culture* (Amsterdam: Harwood Academic, 1998).

488 Clark, *A Biography of the Nuffield Foundation*, 102.

was aimed “of supplementing rather than vying with Government efforts,” as it supported in both finance and expertise.[489]

The support for the aerial magnetometer survey was a by-product of the Nuffield Foundation’s original plan on the Jodrell Bank telescope. In this way, it also illustrates the relationship between the Nuffield Foundation and the government, which would help understand the funding process that happened later around the survey.

A. C. B. Lovell was Director of Jodrell Bank in the early 1950s. Tizard had known him during the war and met him in 1951 as part of a business trip. As Tizard learnt from the meeting, the preliminary design of Jodrell Bank radio telescope “had been supported by a grant from DSIR, and the project was strongly supported by the Royal Astronomical Society.”[490] Although Tizard was no longer a trustee at that time, he appreciated the ambition of the project and wrote a strong letter to the trustees advocating a grant to the project. The letter persuaded the trustees that the radio telescope was exploring “a field in which Great Britain leads the world, and should continue to keep her head.”[491] On the other hand, with plenty of experience in administrating scientific projects and policies, Tizard understood that it would be difficult to raise

---

[489] Clark, *A Biography of the Nuffield Foundation*, 48.

[490] Clark, *A Biography of the Nuffield Foundation*, 103.

[491] Clark, *A Biography of the Nuffield Foundation*, 103.

enough funds from the Department of Scientific and Industrial Research. He suspected that the Treasury simply couldn't offer enough funds to cover the £250,000 budget; moreover, the actual cost would be very likely to run much higher.[492] To avoid such lack of funds, the Nuffield Foundation granted £200,000 at the beginning.

In the year 1954-55, the Department of Scientific and Industrial Research realised that they had used up their budget for the financial year, and that they could not continue to support the radio telescope without exploiting either other institutions or the Department itself. The Nuffield Foundation was asked for help to form a joint fund for the telescope, while they preferred to offer a one-off aid. Thus, it was decided that the Nuffield Foundation would be helping by subsidising some aerial magnetometer surveys which were supposed to be financed by the Department of Scientific and Industrial

---

492 Clark, *A Biography of the Nuffield Foundation*, 103. Tizard kept his letter secret from the Secretary of the Department of Scientific and Industrial Research, and was straight forward enough to say that "I know that the Department of Scientific and Industrial Research is considering the proposal extremely sympathetically and I think it highly probable that they will recommend to the Lord President that a very substantial grant should be given, though perhaps so much as to cover the whole estimated cost. But I do think it extremely doubtful that the Chancellor of the Exchequer, however sympathetic he may be, will be able to provide the funds." Regarding the extra cost, he wrote that "it will almost certainly be found that costs will go up in course of erection and that something has been forgotten" and suggested a sum of £300,000 to be provided.

Research, so that the total sum of fund was limited, and the Department was relieved from financial crisis.[493]

6.4 Requesting Funds

Communications between the Department of Scientific and Industrial Research regarding the aerial magnetometer survey started in January 1955. In a letter to the Secretary, C. M. Cawley, who was in charge of the communications at the Department of Scientific and Industrial Research, reported on his meeting with W. A. Sanderson, who was there on behalf of the Nuffield Foundation, that the "question was raised very tentatively as to whether it might be possible for the Foundation to assist the Department by providing funds for some other activity which the Department would wish to support. This might, for example, be some project at a University or some project at one of our Stations, such as the pilot survey for the aerial magnetic survey of Great Britain."[494]

---

493 Clark, *A Biography of the Nuffield Foundation*, 105-106.

494 C. M. Cawley, 'Extract from Note of Conversation with Mr. Sanderson of the Nuffield Foundation', 12 January 1955, National Archives UK, DSIR 9/124 Aerial Magnetometer Survey of Great Britain, Grant from Nuffield Foundation for Pilot Survey.

Nevertheless, the aerial magnetometer survey was not the first option for the Department. For example, C. Jolliffe, who was in charge of grants, expressed his view that he still felt "that there would be some poetic justice in using money from the Nuffield Trust for road safety research."[495] However, it turned out that the "road safety research" didn't meet the Nuffield Foundation's wish to set a one-off grant. As Cawley put it, "It would be difficult enough in any case to ask the Nuffield Foundation to support a normal departmental activity and I think it would be impossible to ask them to finance only a part of any project. I think we have to select a project which they could feel (if they decided to support it) to be wholly their own affair."[496]

By February, though, it had been clear that the Nuffield Foundation was choosing the aerial magnetometer survey, as Cawley issued a letter to S. H. Smith[497] informing that the Foundation would like to discuss the proposal at

---

[495] C. Jollife to Dr. Cawley, 26 January 1955, National Archives UK, DSIR 9/124 Aerial Magnetometer Survey of Great Britain, Grant from Nuffield Foundation for Pilot Survey.

[496] C. Cawley to Jolliffe, 28 January 1955, National Archives UK, DSIR 9/124 Aerial Magnetometer Survey of Great Britain, Grant from Nuffield Foundation for Pilot Survey.

[497] Unfortunately, there is not yet evidence that S. H. Smith was a member of the Geological Survey Board or alike. We may infer from his tone, his knowledge of the whole thing, and the fact that he worked in the Department of Scientific and Industrial Research instead of the Geological Survey, to assume that he was the person in charge. The same unclearness is around C. M. Cawley; we can find out that he worked at the Department of Scientific

next trustee meeting on 24th March. Cawley drafted the proposal, and the document is very revealing about the situation of the project and the significance of the support to the aerial magnetometer survey.

To start with, Cawley referred to the 1940s attempt to conduct an airborne magnetic survey and its delay as a result of lack of funds. As the proposal put it,

> The Department was working in 1948 on a scheme for the aeromagnetic survey of the country, but the project had to be abandoned for reasons of economy."[498] With an analysis of the financial status of the Department, Cawley knew that the Department was very likely to put the completion of the radio telescope with top priority, and thus "it will be quite impossible for us to consider financing the pilot aeromagnetic survey in 1955, and we cannot at present say what the position will be in 1956.[499]

On the other hand, Cawley confirmed that the aerial magnetometer survey would support the Geological Survey's current mapping projects and reveal

---

and Industrial Research and that he was a geologist/geochemist who had worked on shale oil, but it is actually not yet clear what his position really was.

[498] 'Draft Letter to Mr. Sanderson of the Nuffield Foundation from Dr. Cawley', 16 February 1955, National Archives UK, DSIR 9/124 Aerial Magnetometer Survey of Great Britain, Grant from Nuffield Foundation for Pilot Survey, 1.

[499] 'Draft Letter to Mr. Sanderson of the Nuffield Foundation from Dr. Cawley', 16 February 1955, 1.

new information for the country. The rhetoric was not new: what Cawley referred to as the inadequacy of information from the surface of the earth had been the reason for geophysical explorations of the Geological Survey for decades, a

> great deal of geological information is obtainable from surface surveys, but the inferences about underlying strata are not always reliable, and studies by deep boring have sometimes given us some sharp surprises. For this reason, we seek to supplement the information obtained by "classical" surface surveys with that obtained by the use of geophysical methods and by sinking deep bore holes. We have hopes that aeromagnetic surveying will be a valuable supplementary method, but we can only assess its merits by trial. We would also hope that it would greatly assist us in choosing the most suitable sites for sinking bore holes.[500]

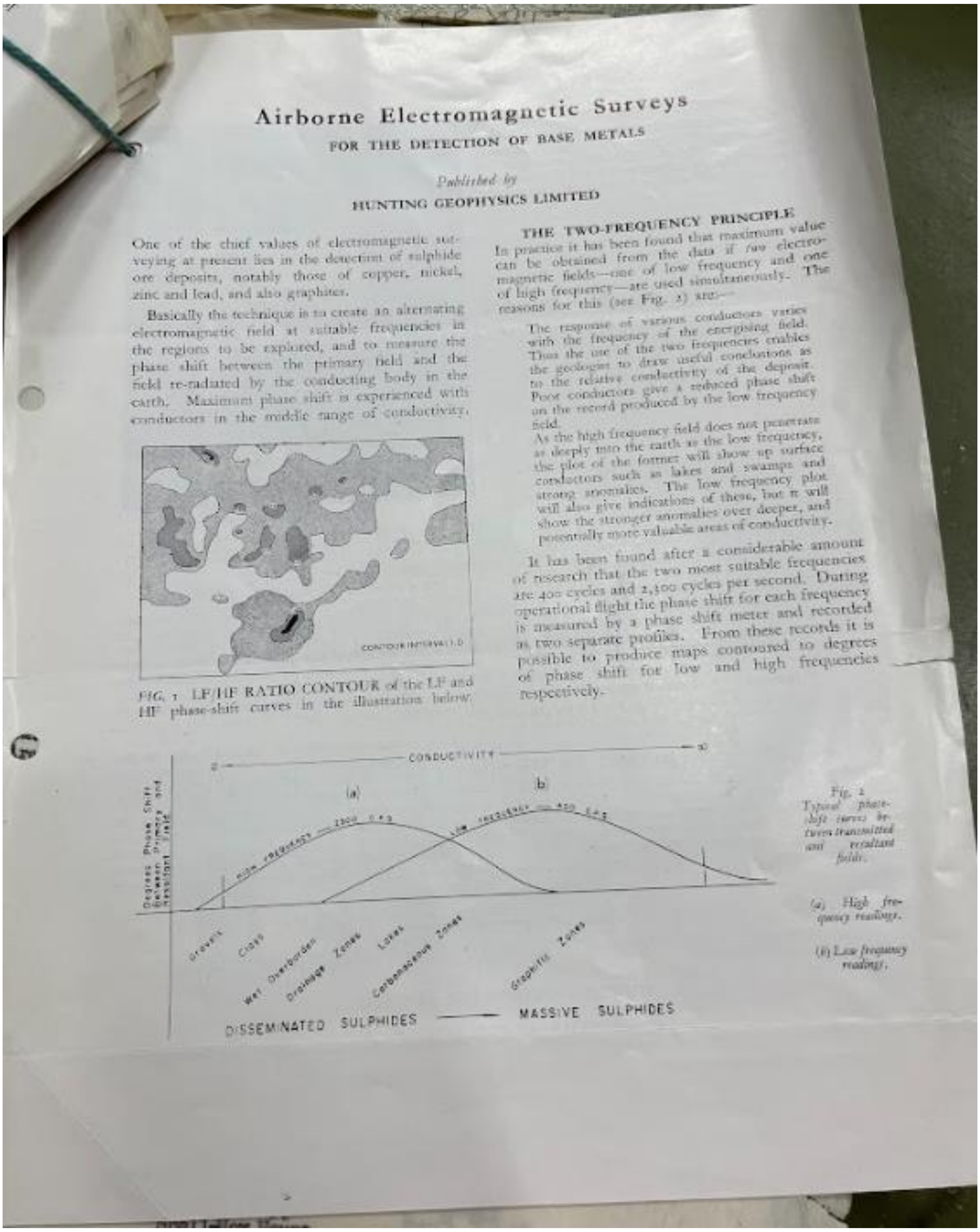
Also similar was the selection of target area. For the pilot survey, it was designed to cover the area between Stockport, Market Rosen in Lincolnshire, Luton, and Gloucester. The reason to choose the area was that this area

> includes a fair variety of flat and hilly country and a wide range of the kind of geological problems likely to be encountered in a survey of the whole

[500] 'Draft Letter to Mr. Sanderson of the Nuffield Foundation from Dr. Cawley', 16 February 1955, 1-2.

country; it is closely associated with the Geological Survey's programme of deep boring, and it has been wholly surveyed by gravity meter and partly surveyed by ground magnetometer. A pilot survey of this area should therefore permit a critical assessment to be made of the value of aeromagnetic surveying.[501]

[501] 'Draft Letter to Mr. Sanderson of the Nuffield Foundation from Dr. Cawley', 16 February 1955, 2.



Airborne Electromagnetic Surveys

FOR THE DETECTION OF BASE METALS

Published by

HUNTING GEOPHYSICS LIMITED

One of the chief values of electromagnetic surveying at present lies in the detection of sulphide ore deposits, notably those of copper, nickel, zinc and lead, and also graphites.

Basically the technique is to create an alternating electromagnetic field at suitable frequencies in the regions to be explored, and to measure the phase shift between the primary field and the field re-radiated by the conducting body in the earth. Maximum phase shift is experienced with conductors in the middle range of conductivity.

FIG. 1 LF/HF RATIO CONTOUR of the LF and HF phase-shift curves in the illustration below.

THE TWO-FREQUENCY PRINCIPLE

In practice it has been found that maximum value can be obtained from the data if *two* electromagnetic fields—one of low frequency and one of high frequency—are used simultaneously. The reasons for this (see Fig. 2) are:—

The response of various conductors varies with the frequency of the energising field. Thus the use of the two frequencies enables the geologist to draw useful conclusions as to the relative conductivity of the deposit. Poor conductors give a reduced phase shift on the record produced by the low frequency field.

As the high frequency field does not penetrate as deeply into the earth as the low frequency, the plot of the former will show up surface conductors such as lakes and swamps and strong anomalies. The low frequency plot will also give indications of these, but it will show the stronger anomalies over deeper, and potentially more valuable areas of conductivity.

It has been found after a considerable amount of research that the two most suitable frequencies are 400 cycles and 2,300 cycles per second. During operational flight the phase shift for each frequency is measured by a phase shift meter and recorded as two separate profiles. From these records it is possible to produce maps contoured to degrees of phase shift for low and high frequencies respectively.

Fig. 2 Typical phase-shift curves between transmitted and resultant fields.

(a) High frequency readings.

(b) Low frequency readings.

Figure 6.2. One page of a magazine article showing a simplified map of the airborne survey area. Hunting Geophysics Limited, "Airborne Electromagnetic Surveys," National Archives UK, DSIR 9/124 Aerial Magnetometer Survey of Great Britain, date unknown.

On the one hand, the rationale was the same for all the geophysical trials, that the chosen area should be explored already, and that it should provide representative and useful information. On the other hand, the considerable size of the area suggests that the Geological Survey was determined to push its geophysical explorations to an unprecedentedly larger scale.

These were the points that Cawley made in his original draft, and they are very plausible. However, more interesting are the corrections that were suggested by Smith, W. J. Pugh, who was Director of the Geological Survey and Museum at that time, and an unknown person (possibly Cawley himself as these corrections were marked on his original draft) respectively. These corrections highlight what the Geological Survey wanted to emphasise in the project and what might be attractive for the Nuffield Foundation.

Pugh asked for a few add-up sentences explaining the scientific meaning of an airborne magnetometer survey. While Cawley originally admitted in the draft that it was “uncertain whether its use would be justifiable in a country such as this where a great deal of geological information has already been obtained by normal methods of surveying, supplemented in special cases by boring,”[502] Pugh suggested that the airborne magnetometer survey had been proved of use somewhere else, possibly referring to other countries such as

---

[502] ‘Draft Letter to Mr. Sanderson of the Nuffield Foundation from Dr. Cawley’, 16 February 1955, 1,

Canada, and that it would "give information of general scientific interest, more particularly relating to the earth's magnetism and magnetization of rocks," so that the significance would go beyond providing economic data.[503] His summary was not only typical from a geological professional, but also applied to the Nuffield Foundation's expectation that their funded projects could benefit science as a general good.

Cawley's letter addressed to the Nuffield Foundation underwent several edits. One of these was adding "in the country" to say that the survey would be conducted domestically, perhaps to show the contrast between the survey in question and those in other countries mentioned above.[504] Another interesting edit is that the use of "geophysical" was once corrected from "geological," as was the case in the phrase the "method of geophysical surveying by airborne magnetometer."[505] Although changes in wording doesn't imply a change in methodology at the Geological Survey, it was still a suggestion that some people had noticed that there was a difference between geological methods

---

[503] W. J. Pugh to C. M. Cawley, 7 March 1955, National Archives UK, DSIR 9/124 Aerial Magnetometer Survey of Great Britain, Grant from Nuffield Foundation for Pilot Survey.

[504] 'Draft Letter to Mr. Sanderson of the Nuffield Foundation from Dr. Cawley', 16 February 1955, 1.

[505] 'Draft Letter to Mr. Sanderson of the Nuffield Foundation from Dr. Cawley', 16 February 1955, 1.

and geophysical ones, or between what had been done for a long time and what they were trying and learning.

There was no more suspense on the fate of the proposal. Cawley sent out the final version of the proposal to Sanderson on 10th March, and the trustees of the Nuffield Foundation discussed it at their 28th March meeting as planned. On the same day of the meeting, Sanderson was able to write to Cawley informally that the proposal was approved, and on the next day the Secretary of the Department of Scientific and Industrial Research received a formal letter from the trustees.

It turned out, though, that there was always someone who was not satisfied yet. As is mentioned earlier, Smith was asked for corrections on the proposal as well, and he actually suggested nothing but a firmer tone throughout the proposal. Although the proposal was for a pilot survey in a selected area, Smith meant that even a complete survey of the country could be expected. As he put it,

> As I mentioned to you, one of the questions which arose in my mind over this proposal generally was whether we ought to commit resources to it – whether our own or the Foundations – unless satisfied that there is a reasonable probability that funds will eventually be forthcoming to complete the whole survey if the pilot survey should prove the technique successful. I understand you to say that even without the complete

> survey the pilot survey would be worth doing, not only because of the information – or confirmation of existing assumptions – it might give in the two selected areas, but also because successful development of this technique would be justified whether or not the G.S.M. itself was able to make use of it. There is also the further point I suppose that any doubt we may have about completion of the survey (assuming the initial project to be successful) centres around the question of 'when' rather than 'whether'.[506]

Smith's attitude was not very helpful in assessing the proposal, but it did show an ambition to build up an innovative project that the Geological Survey would be proud of. Thus, with a similar insistence on independence, Smith suspected after learning the approval from the Nuffield Foundation, that what the Foundation was proposing was "different in an important respect from the arrangement envisaged in" the letter of 10th March. He then went on

> As I read it, what that letter does is simply to draw the Foundation's attention to an interesting piece work and ask them whether they would wish to finance it. A proposal to make a grant to D.S.I.R. has all the objections to which Mr. Hogg made reference in his minute of 19/2/55

[506] S. H. Smith to Dr. Cawley, 17 February 1955, National Archives UK, DSIR 9/124 Aerial Magnetometer Survey of Great Britain, Grant from Nuffield Foundation for Pilot Survey.

> and to which Mr. Barnard referred in the penultimate sentence of his minute of 28/2/55. There is further subsidiary point that in this way we shall probably need a Supplementary Estimate as it is likely to cause gross expenditure to exceed the Parliamentary Estimate.
>
> Does it matter to Nuffield which way the project is handled? Could they not simply offer to carry out the pilot survey without involving D.S.I.R. in the receipt of a grant? We could offer to assist in the administration of the project if they wanted it. In view of our interest in the outcome I think it would be legitimate to provide such assistance without charge.[507]

The minutes that Smith mentioned here were exactly about the unclearness of the possibility whether the Treasury could set up a fund from its budget. Thus, Smith was very concerned to notice the departmental financial issue still existed, and was helpful to ask forma clarification. It was reasonable, and Sanderson replied with a yes quickly.

By the beginning of July 1955, preparations of the aerial magnetometer survey were settled. This was reflected in the Nuffield Foundation's annual report, where they included a section about "Aeromagnetic Surveys".[508] This

---

507 S. H. Smith to C. M. Cawley, 31 March 1955, National Archives UK, DSIR 9/124 Aerial Magnetometer Survey of Great Britain, Grant from Nuffield Foundation for Pilot Survey.

508 'COPY: Aeromagnetometer Surveys', n.d., National Archives UK, DSIR 9/124 Aerial Magnetometer Survey of Great Britain, Grant from Nuffield

short part of the report reiterated some of the points that had been agreed on in the past months: that the airborne magnetometer survey could provide “information of general scientific interest”, particularly “relating to the magnetization of rocks” and “about the deeper lying strata;” that the selected area for the pilot survey included “a variety of flat and hilly country and a wide range of the kinds of geological problem likely to be encountered in a survey of the whole country;” that the aeromagnetometer surveys were “closely associated with the Geological Survey’s programme of deep boring.”[509] Apart from these points, it also confirmed that the grant was made on “the recommendation of the Department of Scientific and Industrial Research,” and that the airborne magnetometer survey was a “method of geophysical surveying” that had developed for years.[510]

6.5 The Project Flies

In the annual report section, the timetable agreed aimed to complete flying “by early autumn” and other calculations and analysis “by the end of the year”.[511]

Foundation for Pilot Survey.

509 ‘COPY: Aeromagnetometer Surveys’.

510 ‘COPY: Aeromagnetometer Surveys’.

511 From 3 copies of what seems to be a final draft of the annual report section’, placed after Farrer-Brown’s letter to Cawley thanking him for returning the draft, 13th July 1955, n.d., National Archives UK, DSIR 9/124

By the end of July, all parties were in place and were reporting to the Geological Survey. On 25 July, T. E. Rowlands from Canadian Aero Service Corporation wrote a concise but surely cheerful letter to inform Bullerwell that

> We acknowledge, with thanks, todays receipt of the foil copies of Geological Sheets eleven and fifteen sent by registered post.
>
> Installation of the Magnetometer equipment is proceeding favourably, and we are at the stage where the wiring harness is being installed.[512]

These were the pieces of equipment from the Geological Survey. From other sources, Rowlands also reported that “a qualified engineering firm for the fabrication of the required bird looking [sic] device” had been arranged, and that he expected such device would be delivered in the next few days.[513]

The aeroplane, with its equipment installed, was ready to fly by the 17th of August 1955. It is also interesting to know that the commencement of the flight had been reported in *The Times*, as C. J. Stubblefield, Deputy Director of Geological Survey, reported to Farrer-Brown at Nuffield in a letter. About

---

Aerial Magnetometer Survey of Great Britain, Grant from Nuffield Foundation for Pilot Survey.

[512] T. E. Rowlands, ‘Attention Dr. W. Bullerwell’, 25 July 1955, National Archives UK, DSIR 9/124 Aerial Magnetometer Survey of Great Britain, Grant from Nuffield Foundation for Pilot Survey.

[513] Rowlands, ‘Attention Dr. W. Bullerwell’, 25 July 1955.

the progress, he also reported, that the Canadian Aero Service Ltd. had planned to complete all the flight tasks by 15th October, completing the first part of mapping by 7th November, and competing all the rest by 1st December.[514] They were expecting a confirmed timetable now, as all parties were racing for the provisional end by the end of the year, in spite of "weather, magnetic disturbances and other uncertainties."[515]

The next report came in on 10th September, where Stubblefield informed Farrer-Brown that the southern part of the selected area had been surveyed, which was "well ahead of the revised schedule."[516] And on 13th October, he was glad to report again, that "good progress has been maintained during the past few weeks," and that

> Practically all the flying required in the original contract has now been effected; subject to further inspection of records, only eighteen miles of re-flying in the northern area is still outstanding. In addition, however,

---

[514] C. J. Stubblefield to L. Farrer-Brown, 17 August 1955, National Archives UK, DSIR 9/124 Aerial Magnetometer Survey of Great Britain, Grant from Nuffield Foundation for Pilot Survey.

[515] Stubblefield to L. Farrer-Brown, 17 August 1955.

[516] C. J. Stubblefield, 'Aeromagnetic Survey', 10 September 1955, National Archives UK, DSIR 9/124 Aerial Magnetometer Survey of Great Britain, Grant from Nuffield Foundation for Pilot Survey.

about 300 miles of extra flying, designed to provide extra marginal control, have also been completed. The total mileage to date is 13,534.

We are now examining the data already obtained, with the object of deciding whether any additional mileage seems specially desirable. We believe that two limited areas will repay slightly more detailed study, but that the extra mileage involved will be small and the final cost of the survey is likely to be well within the original contract price, since the royalty fee has now been waived.

We have already seen the draft of the total force map for the southern area and the fair copy should be delivered to us within the next ten days. The map itself is quite pleasing and we believe that it will afford us the data which we require for the analysis of the method. Rapid progress is also being made in the drafting of the map for the northern area and Dr. Bullerwell hopes to be able to examine the greater part of it when he visits Derby today.[517]

As is fully quoted here, there are many unreserved expressions of delight in Stubblefield's letter, which had been rarely seen in the Geological Survey's correspondence and documents about its projects before. The aerial

517 C. J. Stubblefield, 'Aeromagnetic Survey', 13 October 1955, National Archives UK, DSIR 9/124 Aerial Magnetometer Survey of Great Britain, Grant from Nuffield Foundation for Pilot Survey.

magnetometer survey proceeded according to and even ahead of plan, and its outcome was already promising. Hence, there is argument that the project could be regarded by the Geological Survey as a success in their application of geophysical methods, and by historians as a rare one of (some may say first) such success.

6.6 Results

Flight magazine reported on the project in extensive length in November, which dug into the technical details of the equipment, and the report acts as a convincing example that the project had been a success. As *Flight* describes, the aircraft

> itself is comprehensively equipped for its survey role. The magnetometer, which measures the magnetic field, has its detector head fitted in the torpedo-shaped “bird” which, as shown in the photograph, is trailed at the end of a 100ft cable during runs. Inside the machine are mounted the other sections of the magnetometer installation, together with a continuous recorder; vertical continuous-strip 35 mm camera; radio altimeter and recorder; Decca Navigator Mk 8 receiver and Flight Log,

together with camera; an intervalometer; and the cable winding-in mechanism.[518]

Figure 6.3. The “Tornado-shaped ‘Bird’” where the detector head was fitted, as mentioned in the *Flight* magazine report. From: ‘Midlands Survey - by

[518] ‘Midlands Survey - by Airborne Magnetometer: Anglo-Canadian Co-Operation at Derby’, Flight, 4 November 1955, National Archives UK, DSIR 9/124 Aerial Magnetometer Survey of Great Britain, Grant from Nuffield Foundation for Pilot Survey, 718.

Airborne Magnetometer: Anglo-Canadian Co-Operation at Derby', *Flight*, 4 November 1955, 719. National Archives UK, DSIR 9/124.

As was the plan, the aircraft took off at Derby Airport to cover an area of 10,800 sq. miles stretching between Manchester in the north and Gloucester in the south. As the report continues, the area

> was covered by a network of east-west runs, 90 miles in length and spaced at one-mile intervals. Different techniques were employed for the northern and southern sections. In the former, a constant height of 1,000ft above the terrain was maintained (the radio altimeter and recorder being used), while in the southern area the procedure was to fly at a constant height of 1,900ft above sea level. These respective methods are discussed later; the relative heights were so chosen as to give good continuity of readings at the north/south boundary, which lay at an average altitude of 800ft.
>
> Visual navigation and photographic position-fixing were specified for the project, together with the experimental use of the Decca Navigator system for the latter function. Thus the normal procedure was for the pilot and navigator to use a one-inch Ordnance Survey map for navigation (permissible track error was only $\frac{1}{8}$ mile), a permanent record of the

> ground flown over being obtained by the use of the vertical mounted camera.[519]

The flight started with the southern part of the area, and both the geological and climatic conditions were pleasant, as

> in this sector, the basement rock is rarely exposed to the surface, and the effect of the topographical changes on the magnetic readings is not significant. With excellent weather, this half of the survey was carried out in less than a month Luton Airport was used as the operating base for part of this time.[520]

The northern sector of the Survey was completed with more difficulties as well as tasks, but still as scheduled. Pilots reported that “the area included the steep slopes of the Southern Pennines,” which, as has been mentioned in the report, required a different method to control the height:

> This method was required for two good geophysical reasons, however: a constant barometric height, if sufficient for suitable clearance over the high ground, would have given a lack of detail in the measurements take over lower ground; and, an accentuating factor, the magnetic basement if

---

[519] ‘Midlands Survey - by Airborne Magnetometer: Anglo-Canadian Co-Operation at Derby’, 718.

[520] ‘Midlands Survey - by Airborne Magnetometer: Anglo-Canadian Co-Operation at Derby’, 719.

> exposed to the surface more extensively in this area than in the northern sector.[521]

And meanwhile, the weather

> Deteriorated during this second half of the survey, which took longer than the first, but the total flying programme was completed, as scheduled, in the overall time of two months.[522]

The technical details above reveal a distinct focus of the airborne magnetic survey: the equipment. This is apparently different from reading or producing maps, as had been the case of the Geological Survey's traditional projects. Moreover, the airborne magnetometer project differed from the Geological Survey's previous projects in the allocation of staff, for the actual operators of the equipment were not geologists, but trained pilots from external companies ("Dick Wallis of Derby Aviation," the company that owned and operated the surveying aircraft, Anson G-AMDA)[523].

---

[521] 'Midlands Survey - by Airborne Magnetometer: Anglo-Canadian Co-Operation at Derby', 719.

[522] 'Midlands Survey - by Airborne Magnetometer: Anglo-Canadian Co-Operation at Derby', 719.

[523] 'Midlands Survey - by Airborne Magnetometer: Anglo-Canadian Co-Operation at Derby', 718.

The Geological Survey was not even the data processor after the flights, and the task was handled by the operating company's ground team at Derby Airport, led by data chief and navigator, William DesLaurier. As is learnt from the *Flight* report,

> The "raw material" consisted of the recorder rolls carrying the continuous traces of magnetometer reading and radio-altimeter height respectively; the film strip showing the track flown; and the appropriate section of the one-inch map which had been used for navigation. Also available was the continuous record of a ground magnetometer located outside the building, which would indicate any major disturbance in the regional field during flights (caused, for example, by magnetic storms).[524]

When the data processing began, the track shown on the film strip was transferred onto the one-inch map, with the intervals in flights in consideration. The magnetometer results were subtracted and refined by removing "spurious values obtained when flying over heavy D.C. supplies, or magnetic concentrations in large towns," and by coordinating with the intervals.[525] After

[524] 'Midlands Survey - by Airborne Magnetometer: Anglo-Canadian Co-Operation at Derby', 719.

[525] 'Midlands Survey - by Airborne Magnetometer: Anglo-Canadian Co-Operation at Derby', 719.

these steps, the results could be transferred onto a draft of the final map. In such a survey, the map,

> On a scale of $2\frac{2}{3}$ miles to the inch, was prepared for each of the two sections, for eventual reduction to the standard quarter-inch scale.[526]

Only after all these data processing steps did the Geological Survey get involved to study the results in the maps:

> the new maps will be compared, for example, with maps showing geological structure, gravitational-force variation, and variation of the vertical component of the earth's magnetic field (obtained from ground readings). Any correlation between the various "anomalies," or sharp distortions, will be noted, and in general a fuller picture of the nature of the country's basic geological structure will be obtained.[527]

And finally, the Geological Survey hoped

> to publish in due course the two new maps showing the total-force variation. A direct comparison of the time, effort and expenditure which would be involved in a comparable ground survey of this same area is not

[526] 'Midlands Survey - by Airborne Magnetometer: Anglo-Canadian Co-Operation at Derby', 719.

[527] 'Midlands Survey - by Airborne Magnetometer: Anglo-Canadian Co-Operation at Derby', 719.

> possible – valid readings by means of ground magnetometers in towns and cities, for example, would clearly be impracticable due to the many strong local distortions – but the advantage of the airborne method wherever time is a critical factor is obviously of great importance.[528]

Compared with its work on the gravity torsion balance in the 1920s, the Geological Survey showed more confidence on the outcome of the airborne magnetic survey. They knew how to handle the data collected in the survey, and their confidence was supported by a steadily expanding number of geophysical experts, as has been shown earlier in the chapter.

6.7 Conclusion

The airborne magnetic survey marked an innovative success for the Geological Survey. First of all, it was a fruitful application of the magnetometer, a geophysical instrument that the Survey had been interested since its early attempts in geophysics. The geophysics unit, led by Bullerwell, proved their ability and expertise to supervise a geophysical survey, introducing geophysics as an option for the Survey's work in the future.

---

[528] 'Midlands Survey - by Airborne Magnetometer: Anglo-Canadian Co-Operation at Derby', 719.

In addition, the Geological Survey had developed a clearer understanding of their role in research. When they operated the gravity torsion balance by themselves in the 1920s, their research method was largely based on their traditional way of reading the surface and drawing the map. During the airborne magnetic survey, the Geological Survey took the role of supervision and research, so that skilled pilots and navigators could conduct the survey in their stead. Such change was an inevitable requirement since the surveying equipment had become even more complicated; it also indicated that the Geological Survey geophysicists had combined their expertise in geophysics with the work of the Survey and developed a feasible way to apply their skills.

Last but not least, the success of the airborne magnetic survey reflected that scientific research was acknowledged as an important goal of the Geological Survey. The proposal of an airborne magnetic survey, from the beginning, was based on the view that the Geological Survey's work could have dual aims: as a source of economically relevant data and advice for business and government and as a producer of scientific research, in other words (as Clarke has noted of the DSIR), fundamental science with a practical aim. The acknowledged view allowed the Survey to investigate into topics such as the earth's magnetic field, which might not directly help the state development. It also paved the way for the Geological Survey to become a leading research institution in geosciences.

Chapter 7: Building up a New Team with Geophysical Abilities

Having tasted success in its geophysical magnetic survey, the Geological Survey showed a more welcoming attitude towards such useful and novel techniques. In 1966, the Geophysical Unit of the Survey used a proton magnetometer at sea. The proton magnetometer tested the earth's nuclear magnetic resonance and was usually used to detect minerals either on land or at sea. The Geological Survey used it in the marine way, "to investigate an anomaly in Loch Ewe and a sonic and magnetic package to carry out an extensive survey of the Moray Firth," and

> to complete the metamorphosis to marine activities the unit participated in a joint university project which covered areas of the Continental Shelf south and west of Ireland. In the same year, the first crustal seismic experiments were undertaken using massive marine explosions recorded by land-based seismometers.[529]

These projects were signs that the Survey's ability to manage and apply geophysical techniques in its field work was maturing. At the same time, the

---

[529] H. E. Wilson, *Down to Earth: One Hundred and Fifty Years of the British Geological Survey* (Edinburgh & London: Scottish Academic Press, 1985), 156.

Survey's geographical range of exploration expanded, and that its academic and professional connections were enhanced. Similarly, the 1960s was also the time when a Geochemistry Unit was borrowed from the Overseas Geological Surveys and remained active in geochronological studies.[530]

Geology more broadly saw a trend towards the application of more geophysical (and geochemical) techniques. For example, the *Journal of Geology* saw an increase in the number of publications about deep-sea sampling, hydrology in lakes, and chemical analysis of the component of minerals.

To conclude the Geological Survey's story of introducing geophysics into its work, this chapter will analyse an innovative recruitment by William Bullerwell, head of the Geophysical Unit at the Survey, to find out how geophysical expertise was integrated into the Survey's team, as well as extending its connection with universities. This chapter will also illustrate how the experience of Bullerwell's new cohort paralleled the transformation in the wider discipline of geology.

---

[530] Wilson, *Down to Earth: One Hundred and Fifty Years of the British Geological Survey*, 165.

7.1 Summer Intern for Geophysical Work

In July 1961, Bullerwell gathered 21 university students from across the country, offering them positions as Voluntary Workers at the Geological Survey for the geophysical work during the coming summer. Possibly, what he offered in the summer of 1961 might have been the first cohort of undergraduate voluntary jobs. Unclarity in his description of the job was inevitable. At that point, Bullerwell was not yet sure about their specific tasks, only indicating that:

> I presume that you will be joining the field party from your address in [blank, to be filled] The geophysical work at that time will be under the charge of [blank] who will send you the final arrangements for joining nearer to the commencement of the period. He will probably wish to arrange to collect you with one of our vehicles from a convenient point in [blank] round about [blank] on [blank].[531]

The 1962 proposal was clearer on candidates' criteria, that:

> The most suitable students are those who have done at least two years geology and reached at least intermediate standard in physics and mathematics. They should be prepared to work in all weathers, on

531 W. Bullerwell, 17 July 1961, British Geological Survey Archives, GSM/GL/BL/1, 1.

Sundays if necessary, and to take a share, after instruction, in preliminary computations in the evenings.[532]

Although without such a detailed requirement on candidates' backgrounds, Bullerwell's intention to recruit students with mathematical and physical backgrounds was well met by the 1961 candidates. There were 21 students in the cohort:

1. J. G. MacDonald, 11 Beaufort Drive, Glasgow. (Glasgow University)
2. R. R. Horme, Aberdeen University.
3. R. J. Howarth, 10 Grange Road, Highgate, N.6. (Bristol University)
4. I. C. Forgan, St. Andrews University.
5. C. W. M Clexton, University College, London.
6. T. P. Scoffin, Swansea University.

[532] Like what is assumed about unpaid internships nowadays, Bullerwell added that although "it is quite a strenuous life, an opportunity is offered to gain valuable experience not otherwise easy to obtain." Bullerwell, 'To Director, Geological Survey and Museum', 1962. It is still interesting to compare this with the 1961 letter, which says students "will require normal field clothes" for the work, packed lunches "are usually carried daily and you may consider it worthwhile to bring a vacuum flask and sandwich box." Bullerwell, 17 July 1961, 1.

7. T. J. Hayton, Potters Well, Durham. (The Dürham Colleges).

8. M. J. Robson, Edinburgh University.

9. D. J. Fettes, 60, Dee St., Aberdeen. (Aberdeen University).

10. J. Gray, Aberdeen University.

11. J. G. Sclater, Ashton, Dalkeith, Midlothian. (Edinburgh University)

12. R. Whitworth, Reading University.

13. R. Scott Donaldson, St. Andrews University.

14. A. C. Mather, 12 Burns Road, Aberdeen. (Aberdeen University)

15. D. G. G. Young, University College, Durham.

16. P. F. Barker, Imperial College, London.

17. E. J. W. Jones, University College, London.

18. F. G. [sic] Vine, St. John's Cambridge.

19. W. R. Cotton, 31, Woodvale Avenue, Bearden, Galsgow [sic]. (Glasgow University).

20. A. J. McKenzie, 48, Woodstock Road, Aberdeen. (Aberdeen University).

21. P. J. Carter, Nottingham University.[533]

The student volunteers were recruited based on recommendations from their universities. According to reference letters that Bullerwell gathered in prior to the list, students had submitted their applications to their individual departments, and the department faculty had selected and recommended outstanding candidates to Bullerwell. Inferred from details in these letters, the ideal candidates were expected to be in at least the second year of their study in Geology; a background in physics or relevant subjects might also be required. In some cases, this was not very common or easily reachable. For example, Alan Wood, Professor of Geology at University College of Wales, reported that he received only one application from a first-year student whose name was Hugh Jones. Jones had done an Advanced Level course in Geology and an Ordinary Level course in Mathematics before college, and he was studying "Subsidiary Geology, Subsidiary Geography, and Intermediate Physics at that time."[534] Although his professor nominated him as the only applicant from the university anyway, his name did not make it into the final list of interns. In other cases, students who were passionate about both geology and physics had arranged for other commitments, such as H. R. Spall, who was the only "second-year students who has the necessary

---

533 Bullerwell, 17 July 1961, 2.

534 Alan Wood to Dr. W. Bullerwell, 1 May 1961, British Geological Survey Archives, GSM/GL/BL/1.

standard in physics and mathematics." However, he had already planned "to go out with a geophysical field party from Birmingham University" and then "to work at British Museum," which made him unavailable for all the intern periods that the Geological Survey offered.[535]

These references clearly tell the academic backgrounds of the candidates, respectively:

> R. Whitworth: holding degree in geology, physics and mathematics, and applying for "special course in Geology" and specialising in geophysics.[536]

> David G. G. Young: achieved "2nd year honours geologist who took the 2nd year level of the qualifying examination in physics," who was "intelligent" according to his referee, M. H. P. Bott at Department of Geology at the Durham Colleges.[537]

> T. J. Hayton: holding "second year general degree with honours in Physics and Geology," highly praised by the Bott for working "hard and

---

535 J. H. Taylor, 'Voluntary Workers in Geophysics, Summer 1961', 3 May 1961, British Geological Survey Archives, GSM/GL/BL/1.

536 To Dr. W. Bullerwell, April 1961, British Geological Survey Archives, GSM/GL/BL/1.

537 M. H. P. Bott to Dr. Bullerwell, 4 May 1961, British Geological Survey Archives, GSM/GL/BL/1.

conscientiously," as well as Young.[538]

F. J. Vine: with strong academic record in geology, physics, mineralogy and crystallography, and mathematics. His referee reported that he was expected to "do well in Part I Nat. Sci. Tripos" in that summer, and next year he would "do Part II Mineralogy and Petrology, offering one paper in Geology."[539]

Ian C. Forgan: with 3 years geology, 22 years chemistry, and First B.Sc. Physics and Mathematics. He was "a good worker," "pleasant, quiet, Scots lad, without any annoying idiosyncrasies."[540]

Scott R. Donaldson: having graduated with "an Ordinary B.Sc. degree this year, proposing to be a Science teacher," 3 "years Geology and Chemistry," and "First B.Sc. Physics and Mathematics." He was "conscientious, reliable, and mature" with "great physical stamina" as an ex-Commando and "a high degree of initiative."[541]

Peter J. Carter: having read "Geology, Mathematics and Chemistry" and

---

538 Bott to Dr. Bullerwell, 4 May 1961.

539 To Dr. W. Bullerwell, 24 April 1961, British Geological Survey Archives, GSM/GL/BL/1.

540 C. F. Davidson to Dr. W. Bullerwell, 14 April 1961, British Geological Survey Archives, GSM/GL/BL/1.

541 Davidson to Dr. W. Bullerwell, 14 April 1961.

was now reading “Honours Geology,” being “a good student, energetic and interested.” His referee reported that he worked well independently and had “plenty of stamina.”[542]

J. G. MacDonald, W. R. Cotton, and D. F. Paterson: all at the end of their third year “of the Honours in Geology,” and having completed “a subsidiary course in either Mathematics or Physics or both.” The three applicants were listed in a sequence of “in order of merit,” and Paterson did not make it into the final list.[543]

C. W. M. Claxton: law student who switched to science. He received “the equivalent of First Class marks in Physics and Chemistry at Advanced Level, and the equivalent of Second Class in Pure Mathematics,” with “ancillary subjects” in “two-years Chemistry and one-year Zoology.” He was referred as a “good all-round man, keen to add to his experience.”[544]

E. J. W. Jones: doing “two-years Physics ancillary” and taking “one-year Mathematics course as an additional voluntary subject in order to improve his prospects of taking up geophysics as a postgraduate

---

542 ‘Voluntary Workers in Geophysics Summer 1961’, 5 May 1961, British Geological Survey Archives, GSM/GL/BL/1.

543 To Dr. W. Bullerwell, 10 May 1961, British Geological Survey Archives, GSM/GL/BL/1.

544 S. E. Hollingworth to W. Bullerwell, April 1961, British Geological Survey Archives, GSM/GL/BL/1.

course." He had "first-class calibre" for "Advance Level subjects" in mathematics, "Pure and Applied," physics, and chemistry, despite only one year's experience in geology.[545]

Douglas J. Fetters, James Gray, Arthur C. Mather, and Alastair John McKenzie: all to have "degree examination in advance physics" in the coming June.[546]

Terence Peter Scoffin: first year Honours in geology, having pursued Advanced Level school course in pure mathematics, physics, and chemistry and college Subsidiary courses in geology, physics, and chemistry, all with very good performance. His referee, F. H. T. Rhodes at University of Wales notes that Scoffin was "a student of real promise" and "potentially a first-class Honours man." He was "friendly, co-operative, conscientious and adaptable," and "anxious to follow a career in geophysics."[547]

J. G. Sclater: having completed one year of geology, three years of physics, "two of Mathematics and one of Applied Mathematics." He started as "a prospective Honours Geologist" and then transferred to

---

545 Hollingworth to W. Bullerwell, April 1961.

546 A. Kerr Pringle to Dr. W. Bullerwell, 27 April 1961, British Geological Survey Archives, GSM/GL/BL/1.

547 F. H. T. Rhodeso Dr. W. Bullerwell, 2 May 1961, British Geological Survey Archives, GSM/GL/BL/1.

physics. He was recommended as “a pleasant and interested man,” with a good record in one year in Geology and Merit Certificates in most of his classes.[548]

Martin J. Robson: completing two years of Geology, two years of Chemistry, and one year of Physics. He was “a capable man, particularly in the field.”[549]

R. J. Howarth: having passed “‘A’ level G.C.E. in Mathematics, Physics and Chemistry,” been awarded George Alfred Wills Entrance Scholarship, and completed Stage I Geology and subsidiary Physics. He was planning to take Pure Mathematics along with his second year of Honours Geology, an example of his “unbound” “interest and enthusiasm” and that he was not worried “about any physical hardships on which he might be called to experience.”[550]

There were also several candidates who were not selected as summer interns:

---

548 F. H. Stewart to Dr. W. Bullerwell, 28 March 1961, British Geological Survey Archives, GSM/GL/BL/1.

549 F. H. Stewart to Dr. Bullerwell, 8 May 1961, British Geological Survey Archives, GSM/GL/BL/1.

550 W. F. Whittard to Director, Geological Survey and Museum, 21 April 1961, British Geological Survey Archives, GSM/GL/BL/1.

George Law: having graduated, applying for permanent jobs in geophysics and having co-worked with Canadian Aero-Service previously.[551]

James Jack: also having worked with Canada Aero-Service before.[552]

David Gould: completing three years of Geology, two of Chemistry, and one of Mathematics. He did not study Physics as University but “took it up to Bursary Competition standard at school.” He was “considerably more capable than Sclater” as geology is concerned.[553]

The reason for Law and Jack not being selected was obvious: the reference mentioned nothing about their degree background, and thus there was no evidence that their study had any relevance to geology or physics. Gould’s case is more interesting, especially considering that he was described as “considerably more capable than Sclater,” who won the internship.[554] Compared with most of his competitors, there is a lack of college-level education in physics in his background, but this does not explain why Carter made it into the final list. Unless he was spared due to other commitments for

---

551 A. Kerr Pringle to Dr. W. Bullerwell, 20 May 1961, British Geological Survey Archives, GSM/GL/BL/1, 1-2.

552 Pringle to Dr. W. Bullerwell, 20 May 1961, 2.

553 F. H. Stewart to Dr. W. Bullerwell, 5 May 1961, British Geological Survey Archives, GSM/GL/BL/1.

554 Stewart to Dr. W. Bullerwell, 5 May 1961.

the summer that were not indicated in the reference, his referee's word that he was "something of an oddity" (despite being "very pleasant and definitely bright student") might have been a concern. Still, apart from the odd case, Bullerwell had recruited a team of students, many of whom had a physics education.

Bullerwell's standard matched the job. His draft letter on recruitment in 1962 gave its readers more details about what a summer programme at the Survey was designed to be like. The 1962 summer internship programme was designed in a similar way to the one of 1961. Successful candidates had 4 periods on survey's settled calendar to choose from if they were based in English Office, or 2 to choose from if they were in Shetland Isles, while joining for "the whole of one or more of these periods" were preferred.[555] Their job during the summer would closely abide with the Survey's agenda, stated in the proposal as:

> During the surveys in the Shetlands, gravity, magnetic and electrical methods will be used, commencing on the mainland of Shetland and extending northwards to Yell and Unst during the second period. Details of the geophysical work to be undertaken in England have not yet been finalised, but it is likely that areas in the Mendips, central England and

555 W. Bullerwell to Director of Geological Survey and Museum, 1962, British Geological Survey Archives, GSM/GL/BL/1.

northern England will be surveyed.[556]

Many of the 1961 summer interns had a long career path in geology. Some interns brought their surveying experience into industry. James Gray received first class honours for his undergraduate study and the Mitchell Prize for Mineralogy.[557] He worked for a Canadian mining company after graduation and earned an MSc degree in 1965 for research on ore deposits. After a short period as Assistant Lecturer in Glasgow, Gray worked mainly in industry, first as Geologist in engineering companies, and later he established his own geological consultancy and site investigation company, the Grampian Soil Surveys for almost thirty years.[558] Arthur Mather coordinated and managed council projects.[559] Alastair McKinzie worked as a Mineral Geologist at Robertson Research International, and then taught as Senior Lecturer at University of the West of Scotland until retirement.[560]

Other students have clear records of professional memberships, publications,

---

556 W. Bullerwell to Director of Geological Survey and Museum, 1962, British Geological Survey Archives, GSM/GL/BL/1.

557 Anne Wilkins, 'James Gray, 1941-2005', *The Geological Survey*, n.d., https://www.geolsoc.org.uk/en/About/History/Obituaries%202001%20onwards/Obituaries%202005/James%20Gray%201941-2005.

558 Wilkins, 'James Gray, 1941-2005'.

559 'Arthur Mather', *LinkedIn*, n.d., https://www.linkedin.com/in/arthur-mather-6590a456/.

560 'Alastair McKenzie', *Facebook*, n.d., https://www.facebook.com/alastair.mckenzie.524/.

or institution affiliations in academia, although in different disciplines. Some of them stayed close to rocks instead of data: Terence P. Scoffin remained at Swansea after college and completed his PhD study on the sedimentology of the Wenlock Limestone in 1965. Sedimentation remained his main research interest as he developed his academic career across universities, as post-doctoral fellow at Liverpool and as lecturer at Edinburgh. He investigated sedimentation in shallow seas and was also an expert in the carbonate process and reefs, having published a textbook on carbonate sediments and rocks;[561] Douglas J. Fettes remained in close contact with Scottish geology. He was a member of Edinburgh Geological Society since 1969, became its Scientific Editor in 1972, and acted as Vice-President during 1982-86.[562] His research was focused on metamorphic rocks in Scotland, and he was the compiler of the Metamorphic Map of Europe for its UK section. His connection with the Geological Survey continued as Honorary Research Associate at the British Geological Survey.[563]

---

561 Larry Thomas, 'Terence Peter (Terry) Scoffin, 1941-2002', *The Geological Survey*, https://www.geolsoc.org.uk/en/About/History/Obituaries%202001%20onwards/Obituaries%202003/Terence%20Peter%20Terry%20Scoffin%201941-2002.

562 'EGS Officers and Council Members - Historical List', *Edinburgh Geological Society*, n.d., https://www.edinburghgeolsoc.org/home/officers-and-council-historical/#toggle-id-2.

563 D. Fettes and J. Desmons, eds., 'Frontmatter', in *Metamorphic Rocks: A Classification and Glossary of Terms* (Cambirdge: Cambridge University

Others played with graphs, charts, and numbers: David G. G. Young continued to study geophysics at Durham, and his doctoral thesis was submitted there in 1965, focused on gravitational and magnetic survey results of the north Irish Sea.[564] The thesis was based on magnetic maps published by the Geological Survey. Martin Robson studied for his PhD at Kingston University in Physical Chemistry;[565] John Sclater continued to study for a PhD degree at Cambridge. He now works as Professor at Scripps Institution of Oceanography, with research interest in Tectonics and Structural Geology and Marine Geology and Geophysics;[566] Richard J. Howarth continued studying at Bristol for a PhD degree, after which he was a post-doctoral researcher at Shell (specifically at its Indonesian offshoot Bataafse Petroleum Maatschappij at that time) in the Netherlands and then at Imperial College London, where he studied the statistical and computing methods in geochemical surveys. He started teaching at imperial College in 1972. Having undertaken consulting

---

Press, 2007), https://assets.cambridge.org/97805218/68105/frontmatter/9780521868105_frontmatter.pdf.

564 Young, David. G. G. (1965) *Gravity and magnetic investigations of the deep structure of the north Irish Sea*, Durham theses, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/9216/.

565 'Martin Robson', n.d., https://www.linkedin.com/in/martinrobson1/.

566 'John Sclater', *Scripps Institution of Oceanography, UC San Diego*, n.d., https://jsclater.scrippsprofiles.ucsd.edu.

roles with BP, Howarth is now Honorary Professor in Mathematical Geology at University College London.[567]

There was also an E. J. Jones who co-authored with G. Y. Craig a popular book titled “A Geological Miscellany.” It would be interesting if they are the same person, but there is not yet any evidence that the author is the same as the intern that we are talking about.

Perhaps the most eminent geologist among all the 1961 summer interns was F. J. Vine, who continued his study in geophysics as a PhD student as Cambridge, and cooperated with his supervisor, Drummond Matthews, to considerably develop the plate tectonics theory, a topic that gained them international fame, based on new research that the Juan de Fuca Ridge out of Vancouver Island had magnetic field anomalies which suggested a constant rate of spreading on the sea floor. Since then, Vine and his colleagues at Lamont Geological Observatory at Columbia University received more data from the south Pacific and Iceland, which confirmed their sea floor spreading hypothesis about Juan de Fuca Ridge.[568]

---

[567] ‘Richard J. Howarth’, *ResearchGate*, n.d., https://www.researchgate.net/profile/Richard-Howarth.

[568] Frederick J. Vine, ‘Reversals of Fortune’, in *Plate Tectonics: An Insider’s History of the Modern Theory of the Earth*, ed. Naomi Oreskes (Boulder: Westview Press, 2003), 47-48.

7.2 Vine and Geophysics

Vine’s experience shows how a student in the late 1950s and the 1960s in geology could develop an interest in geophysics and make it a career.

Having participated in many surveys across oceans in his later career, Vine’s summer internship with the Geological Survey in 1961 became relatively unimportant, and it is difficult to find out what exactly he did during the internship (as is the case for the other interns – we only have the recommendations and the final list). His contribution to the plate tectonics theory was loosely connected to the Geological Survey’s work in geophysics, and the validity of his hypothesis was based on the observation and analysis of “the reality of three phenomena: sea floor spreading, reversals of the earth’s magnetic field, and the importance of remnant magnetism in the oceanic crust,”[569] but he had to reach out to the other side of the north Atlantic to find more evidence, which only came in 1965, when he was no longer a student. In his Cambridge years, Vine was a member of the university’s geological society – the Sedgwick Club – at Cambridge. It was to the society that he gave a talk about his sea floor hypothesis for the first time, when he was the President for the summer term of 1962, and, as the

---

[569] Vine, ‘Reversals of Fortune’, 46.

President, was expected to give a speech. The topic of his presidential speech had long been his interest: Hess' hypothesis that new crust was born from mantle activities at ocean ridges. Vine said that the topic was "a natural choice" for him,

> in that Harry Hess' range of interests closely paralleled my own, and I had been inspired both by is papers and by his talk a few months earlier. The address was therefore something that I enjoyed preparing. In addition, it was useful review for my finals, which by then were very imminent. In the talk I summarized Hess' work and ideas on layered igneous intrusions, on the mineralogy and crystallography of pyroxenes, on the alteration of ultrabasic rocks and in marine geology, emphasizing the connections between them. I assumed that most or all of my audience had been present at the meeting in January, and the talk was intended therefore to provide the background to the development of Hess' current ideas. As a consequence I only made brief mention of the substance of his January talk.[570]

It was also at the talk that Vine met and discussed the topic with his future supervisor, Matthews. As Vine remembers, Matthews was present at the talk, and

---

[570] Vine, 'Reversals of Fortune', 52.

> it soon became clear during the discussion that followed that they had not been present at Hess' talk in January. This was their first encounter with the concept of sea floor spreading. Someone, quite possibly Drum [Drummond Matthews] or Tony [Tony Laughton], asked whether I thought that the north-south 'grain' of linear magnetic anomalies recently discovered in the northeast Pacific might be related to sea floor spreading.[571]

What Vine called the "Hess' talk in January" was Hess' guest talk at the 10th Inter-University Geological Congress, entitled "Impermanence of the Ocean Floor." Vine participated in the organisation of the conference. As a student in Geology with particular interest in Mineralogy and Petrology who had studied Physics and Mathematics in his first two years as an undergraduate, Vine had become familiar with Hess' work, because he thought Hess' "ranged over mineralogy, petrology, tectonics, geophysics, and marine geology."[572] His background was unique. At that time, the Department of Geodesy and Geophysics at Cambridge, where Vine worked on his PhD, was for research students only, and geophysics was not a degree subject. There was "very little geophysics in other, related courses such as geology" either.[573] Having said so, Vine was unique not because he was a geologist who understood physics,

[571] Vine, 'Reversals of Fortune', 53.
[572] Vine, 'Reversals of Fortune', 51.
[573] Vine, 'Reversals of Fortune', 50.

but a physicist who enjoyed geology! By the time he joined the Department of Geodesy and Geophysics in 1962, the Department

> Consisted almost entirely of theoreticians (mathematical physicists) and applied physicists, who built new instruments. The one exception was Dr. Drummond H. Matthews, a geologist with a background similar to my own, who had entered the department as a graduate student in January 1958.[574]

As a consequence, Vine worked with Matthews. They worked on the "interpretation of magnetic data" in the Department where

> There was at least one graduate student working on each of the main geophysical techniques, such as gravity, heat flow, refraction seismics, magnetics, and so on. There was a 'vacancy' in the magnetic area and it was entirely appropriate that Drum Matthews should supervise me, not only because of our similar backgrounds, but also because he was involved in the acquisition of magnetic data at the time and had measured the magnetic properties of some basaltic rocks dredged from the ocean floor as part of his Ph.D. thesis.[575]

When he decided to take geology as one of his Natural Sciences subjects,

---

[574] Vine, 'Reversals of Fortune', 52.

[575] Vine, 'Reversals of Fortune', 52.

Vine did not expect that he would come across such a landscape-changing theory as soon as he started his career. As he recalls in different interviews, he was sure about taking Physics and Mathematics. When asking him about every subject one by one, K. G. Budden, his director of studies at Cambridge, stopped at Geology and simply asked whether he liked the open air and fieldwork. For Vine, who had walked on geographical excursions since school, the answer was yes, and hence he went to study Geology.[576]

Geology was indeed about fieldwork. For him as an undergraduate, laboratory work was a little dull, involving demonstrations and materials such as rocks, minerals, and maps to be set out; field trips were enjoyable every year: Vine remembers the the island of Arran in his first year, Pembrokeshire in the second, and Skye in the third, "mainly for igneous and metamorphic petrology."[577]

Vine's transition from geography at school to geology and then geophysics at university reflects a wider pattern. As geophysics became more and more involved in geological work, Vine could sense that the subjects that used to mingle together started to differentiate. At the beginning it was geography, which he could not choose as one of his Natural Sciences subjects. Vine

---

576 Fred Vine, An Oral History of British Science, interview by Paul Merchant, *National Life Stories*, n.d., http://sounds.bl.uk/related-content/TRANSCRIPTS/021T-C1379X0025XX-0000A0.pdf, 52.

577 Vine, An Oral History of British Science, 93-94.

remembers that, although his interest started with geography at school,

> it wasn't within the natural sciences faculty as it were. And I mean that's an interesting point because it meant there was – I forget which faculty geography was in, I suppose arts or something but of course there is this overlap with geography, and in terms of geology and physical geography and geomorphology and hydrology, I mean it's one of the things we've – we solved here with environmental sciences in that we broke down this barrier, I mean it essentially started off in – in historic terms as geology and geography, environmental sciences and it ballooned into something, arguably fantastically different in a way but still covering the environmental sciences probably in a more modern way. And also there is this social geography side which obviously separates off and you couldn't really include that – although they call it social science and they would like to think it is a science and in some senses it is a science, but it's not a hard science [laughs] in the way that other sciences are so.

It was also at this topic that Vine commented that geophysics and geology should come together and that made the "big breakthroughs" that he had witnessed in his career:

> I think particularly by the '60s with the existing of the traditional universities that they'd become so structured, so fragmented in terms of narrow departments and – and relatively narrow faculties that the – the

> structure had – had become very very bad and I mean I recognised at an early stage and a lot of people did that – that interdisciplinary research was terribly important and that the breakthroughs typically came by applying one science to another and that sort of thing, and of course since then it has – you know, we've got biophysics, we've got biochemistry, we've got, you know, geophysics and geology have come together and this is where the big breakthroughs have been. I mean almost inevitably really because you've got these central sciences, maths in a sense is the most central science and then you've got physics and chemistry and – and they're very rigorous and – and they increasingly have been applied to the – to biology and geology and so on.

His second year of Geology was a good example of this tentative and incomplete interdisciplinary mixing with a "small geophysics component of" petrology.[578] Maurice Hill and Teddy [Edward] Bullard taught the course, both of whom worked at the Department of Geodesy and Geophysics where, as mentioned above; they talked mainly about physics and mathematics. Vine remembers that Hill

> did sort of geophysical techniques I think essentially, the sort of thing I mentioned earlier about gravity magnetics, seismology and explained some of the techniques. And then Teddy Bullard did a section [laughs]

---

578 Vine, An Oral History of British Science, 85.

> which was just fantastic, I mean you know, this guy was so inspirational.[579]

And Bullard,

> was inspirational because he just started talking off the cuff, I mean he didn't – he had a syllabus about recent developments in geophysics sort of thing and this was fantastically exciting, you know, everything they did turned up something new which was roughly true, you know, they put a – they did – and partly because they'd just – only just devised the instruments, you know, which is – it's technology led very largely, but they just had to deploy a magnetometer and a buoy off the western approaches or something, got some fascinating data which they weren't expecting, you know, and they just – well not so many years earlier he and people at Woods Hole had developed a – a probe that could measure heat flow from – through the ocean floor and this sort of thing, you know, and they were just beginning to get all these mag – this magnetic data off – off the west coast of the US showing magnetic lineations and it seemed to me as though anything you did turned to gold, you know, you came up with some [laughs] – not surprisingly because we knew so little about the oceans and so this whole course was just, you know, such a contrast to everything else, it was just a complete [laughs]

[579] Vine, An Oral History of British Science, 85.

inspiration.[580]

As he talks about Bullard, Vine also has a chance to describe the relations between geology and geophysics in his Cambridge years: “they were quite separate.”[581] As he comments,

> it was very unfortunate and you had this physical separation of about two miles almost with Madingley Rise out – out in the big – well not now I mean they’ve built the new Cavendish out there in Madingley Road, but then you – but then you had the Cavendish and all the other sciences were pretty well – all the other sciences were on the – on the Downing site, down on the Downing Street. But it was worse [laughs] than the physical separation because – well I mean the interdepartmental rivalry was ridiculous, again I – presumably I haven’t mentioned it on this tape, you had geology and the Sedgwick Museum as part of the Downing site buildings there, adjacent to geology you had mineralogy, petrology and crystallography, right, continuous building. At one point just before we became undergraduates the doors between the two were locked because [laughs] – because of the antipathy between the heads of department, I mean it was that ridiculous, you know, this departmentalism.[582]

---

580 Vine, An Oral History of British Science, 85-86.

581 Vine, An Oral History of British Science, 86.

582 Vine, An Oral History of British Science, 86-87.

As was the case of Bullard, geophysics over geology had become the new trend, in the same way that physics was regarded superior to other "stamp-collecting" disciplines. On the other hand, Vine notes that Hess' work, which was a breakthrough, was actually no less stamp collecting, that Hess' daily job was about

> how mountains are formed, was that Harry Hess, his – his day job almost, you know, or his rigorous basic work was in mineralogy and petrology and he – in particular he studied the – what was it, the pyroxenes I think was the main minerals he studied and then he also studied serpentinites.[583]

According to Vine's comments, by the 1960s, geophysics had become an integral, if not more useful, part of geology. It allowed geologists to investigate into questions which would otherwise be unapproachable; meanwhile, geology, with the touchable evidence that it gathered, was still a subject where earth scientists could get inspirations.

7.3 Conclusion

This chapter shows how the Geological Survey developed in geophysics after

583 Vine, An Oral History of British Science, 101.

its first success. Through an internship programme, the Survey attracted a cohort of promising students, many of whom pursued a career in geology. Among these students, Vine became quite a significant figure, and his path to geophysics reflects the development of the discipline at that time.

Chapter 8: Conclusion

This thesis investigates the British Geological Survey's effort to introduce geophysical techniques into its work in the 1920s to 1950s. The reason for the Survey's effort was, at the beginning, a need for more efficient method to identify the geological structures and to make maps, and then a demand for more information and knowledge about the country. Gravitational and magnetic surveys were the main techniques that the Survey explored in those decades, and the programme to gain data using the instruments in question marked arguably the Geological Survey's first attempts in geophysics and, in the case of the airborne magnetic survey, the first unambiguously successful one. As the Survey explored deeper into the field (no pun intended), the role it played also changed. Having served the country for a century as an information provider and an advisor, the Geological Survey, along with its tests with geophysics, sought for more opportunities to conduct scientific research that was not directly connect to economic demands.

Chapter 2 explains that the change of the Geological Survey's role always had its counterpart in the government, expressed through the Geological Survey Board. At the time around the Survey's centennial, the prevailing view was that the Survey played an important part in serving the country's developmental needs with its reliable information on the country's geology.

Such a view confirmed that the Survey would be an irreplaceable and thus permanent organisation, but also limited its function in a way that was not yet noticed at that time. In Chapter 3 which follows, we can see that, when the Survey discussed and submitted its proposal for research programme using a Eötvös torsion balance in the 1920s, it shared the same motive with the Board, that the Survey was encouraged to initiate an agenda for new techniques as long as it enhanced its function to collect and publish geological information.

Chapter 4 shows how the Second World War was an opportunity for the Geological Survey to explore more subdisciplines of geology. The Geological Survey changed its goal first, and it was expressed by its scientific staff that the Survey should be allowed to do research in the same way as and in connection with universities and academic institutions. In Chapter 5, we can see that the government was not yet in agreement with this view; after all, as a post-war personnel plan was developing between departments, there was no time to consider whether the Geological Survey would be taking on any new, radically different projects. After the war, as is in Chapter 6, the Survey and the government became consistent again on delivering a geophysical project, with the recognition that the project would largely benefit the research capability of the Survey.

The Geological Survey Board, in spite of an emphasis on the practical use of the Geological Survey, did not set any real obstacles in the projects above. It accomplished its mission to improve the communication between scientific organisations and the government well. On the other hand, case studies show that finance had been the vital concern in every project of the Survey. A scarcity in funding for equipment would easily cut off a geophysical proposal.

When the revolutionary plate tectonics theory came into being, the Geological Survey's experience in geophysics allowed its staff understand what was happening and thus allowed the Survey's endeavour to become a leading research institution. Peter Allan, when looking back at the end of the twentieth century, says that the Survey was experiencing a transition since the 1980s, in the way that the Survey manages and analyses the information that it acquires: "It is the passage of the BGS from being a geological survey, whose primary concern was the traditional one of carrying out geoscience surveys to one more concerned with knowledge management and dissemination that defines this period as one of transition."[584] In fact, since the Geological Survey's role in the airborne magnetic project was mainly examining the data, the transition that Allen refers to could be seen to have started much earlier.

As existing literature has been incomplete about the range and local causes

---

[584] Peter Allen, 'Chapter 20 A Geological Survey in Transition', in *A Geological Survey in Transition* (Keyworth: British Geological Survey, 2003), https://earthwise.bgs.ac.uk/index.php/A_geological_survey_in_transition.

of the changes that happened to geology, or the earth sciences, in the twentieth century, the story of the Geological Survey offers one way to explore answers to the questions of what geology means as it evolves over time: why and how did it become more interdisciplinary. As the Geological Survey tested geophysical instruments for its geological work, it had to acquire a cohort of expertise to support further explorations, and the cohort would bring in a more diverse background than physics alone. Furthermore, some of this cohort carried away knowledge skills and experiences into other disciplines and interdisciplines. In this way, the development of modern geology gathers various streams of skills and perspectives – fieldwork, calculation, making analogue graphs, etc., but does not necessarily collect them by specific knowledges.

Put under another lens, the story of Geological Survey in this thesis sheds lights on the oil industry’s influence. To begin with, the oil industry, mostly in the United States, applied geophysical techniques in search of new deposits, and, in the United Kingdom, the cooperation with the oil industry supported the Geological Survey’s test and purchase of the gravity torsion balance, arguably their first geophysical instrument. John Cadman and the Anglo-Persian Oil Company showed a keen interest in finding oil with a torsion balance before the Geological Survey, extended this invitation and showed the Geological Survey its use, and played an advisory role as the Geological Survey made its own agenda with a torsion balance.

The connection between industry and the university-based geologists strengthened throughout the Second World War, and the Geological Survey's continuous effort to map the fuel deposits in the country provided valuable data for postwar planning. One of the tasks that the Survey faced was to fill the knowledge gap that had been left by their and private drilling projects. Meanwhile, the oil industry which had spent much of its time overseas across the empire now showed an interest in resources in Britain. On the one hand, there were noticeably more enquiries about the country's fuel reserve, even coalfields. On the other hand, some important figures, whether in consultative positions or academic roles, had experience with oil companies. The Geological Survey Board membership provides good examples that illustrate such backgrounds.

Literature about the Geological Survey in the twentieth century has been scarce, and, apart from two Directors' memoirs, there is not yet a detailed account of the history of the Geological Survey. This thesis should be able to make a small contribution to change the situation, and should encourage historians to explore further into other aspects of the story. For example, the role and programmes of the Overseas Geological Survey would make a good topic for a historical study of expertise, diplomacy and global history. Historians may also be interested in the broader context of each projects and make the projects here into case studies to reflect another aspect of the era.

For curation and museums, this thesis will be helpful if someone would like to identify geological equipment and instruments used in twentieth century Britain. These objects reflect the path along which earlier generations of geologists and geophysicists explored nature of rocks, sediments and the land beneath our feet.

I would also be happy to see a fellow researcher pick up the fieldwork in these case studies, and make another thesis along with other excursions and expeditions. As existing literature shows, research on the significance of geological fieldwork is far from complete; what this thesis mentions is only a small piece of it as well. I assume that the numerous excursions and expeditions that the Geological Survey or geologists organised would provide more clues about how the geological technology developed in the field, about the job of geologists, and, again, about the meaning of geology.

Bibliography

Unpublished Sources

CAB 126/20 Establishment of Geologists in the Geological Survey and Museum for TA purposes, National Archives;

DSIR 9/28 Centenary Committee: Constitution, National Archives;

DSIR 9/29 Centenary Committee: meetings; minutes etc, National Archives;

DSIR 9/34 Geophysics: financial provision, National Archives;

DSIR 9/109 Report, Aug. 9, 1933, National Archives;

DSIR 9/110 Future Organisation, National Archives;

DSIR 9/111 Report on desirability of a general programme of boring, National Archives;

DSIR 9/112 Minutes of meetings, National Archives;

DSIR 9/124 Aerial magnetometer survey of Great Britain: Nuffield Foundation grant, National Archives;

DSIR 36/1396 Geological survey: mainly GSRC papers (some relating to the Australian Geophysical Expedition) on the usage of different geophysical

instruments, National Archives;

WO 195/259 Geophysics Sub-Committee: terms of reference and constitution, National Archives;

WO 195/265 Geophysics Sub-Committee: 2nd report, National Archives;

WO 195/646 Geophysics Sub-Committee: 3rd report, National Archives;

GSM/GL/Bl/1 Minutes and letters on the work of the Geophysics Dept, British Geological Survey Archives;

GSM/PY/A/18, British Geological Survey Archives.

Published References

Adams, Frank D. 'Further Note on the Earliest Use of the Word "Geology"'. *GSA Bulletin* 44, no. 4 (1933): 821–26. https://doi.org/10.1130/GSAB-44-821.

Adler, Antony. *Neptune's Laboratory: Fantasy, Fear, and Science at Sea*. Cambridge & London: Harvard University Press, 2019.

Agar, Jon. *Science and Spectacle: The Work of Jodrell Bank in Post-War British Culture*. Amsterdam: Harwood Academic, 1998.

Allen, Peter. ‘Chapter 20 A Geological Survey in Transition’. In *A Geological Survey in Transition*. Keyworth: British Geological Survey, 2003. https://earthwise.bgs.ac.uk/index.php/A_geological_survey_in_transition.

Anderson, Katherine. ‘An “Experimental” Instrument: Testing the Torsion Balance in Britain, Canada and Australia’. *Annals of Science* 76, no. 1 (2019): 58–86. https://doi.org/10.1080/00033790.2019.1578897.

Appleton, Edward V. ‘Science, Government and Industry in Britain’. *Bulletin of the Atomic Scientists* 2, no. 11–12 (1946): 2–5.

Aronova, Elena. ‘Geophysical Datascapes of the Cold War: Politics and Practices of the World Data Centers in the 1950s and 1960s’. *Osiris* 32, no. 1 (2017): 307–27.

Bailey, Edward. *Geological Survey of Great Britain*. London: Thomas Murby & Co., 1952.

Baker, Victor R. ‘Interdisciplinarity and the Earth Sciences: Transcending Limitations of the Knowledge Paradigm’. In *The Oxford Handbook of Interdisciplinarity*, edited by Robert Frodeman. Oxford: Oxford University Press, 2017. 10.1093/oxfordhb/9780198733522.013.8.

Bate, David G., and Andrew L. Morrison. ‘Some Aspects of the British Geological Survey’s Contribution to the War Effort at the Western Front, 1914-1918’. *Proceedings of the Geologists’ Association* 129, no. 1 (2018): 3–11.

Bateman, Alan Mara. ‘The Eötvös Torsion Balance’. *Economic Geology* 19, no. 1 (1 January 1924): 84–86. https://doi.org/10.2113/gsecongeo.19.1.84.

Bowie, S. H. U. ‘Obituary Notices - Charles Finlay Davidson, O.B.E., D.Sc., F.R.S.E., M.I.M.M.’ *Proceedings of the Geological Society of Glasgow*, 1969, 2–3.

Bullard, Edward Crisp. ‘Gerald Ponsonby Lenox-Conyngham, 1866-1956’. *Biographical Memoirs of Fellows of the Royal Society* 3 (1 January 1997): 129–40. https://doi.org/10.1098/rsbm.1957.0009.

Butel, Paul. *The Atlantic*. London & New York: Routledge, 2002.

Cannon, Susan Fate. *Science in Culture: The Early Victorian Period*. Folkestone: Dawson, 1978.

Carlsson-Hyslop, Anna. ‘How the Liverpool Tidal Institute Was Established: Industry, Navy and Academia’. *History of Geo-and Space Sciences* 11, no. 2 (2020): 139–56.

———. ‘Patronage and Practice in British Oceanography: The Mixed Patronage of Storm Surge Science at the Liverpool Tidal Institute, 1919–1959’. *Historical Studies in the Natural Sciences* 46, no. 3 (2016): 270–312.

Clark, Ronald W. *A Biography of the Nuffield Foundation*. London: Longman, 1972.

Clarke, Sabine. ‘Pure Science with a Practical Aim: The Meanings of Fundamental Research in Britain, circa 1916–1950’. *Isis* 101, no. 2 (2010): 285–311.

Corfield, Stephen M. ‘The First Oil Exploration Campaign in the UK, 1918-1922’. *Geological Society Special Publication* 465 (2018): 39–52. https://doi.org/10.1144/SP465.11.

Culshaw, M. G., K. J. Northmore, and DM McCann. ‘A Short History of Engineering Geology and Geophysics at the British Geological Survey’. In *Engineering Geology for Society and Territory-Volume 7*, 257–60. Springer, 2014.

Davidson, Charles F. ‘II.—The Archæan Rocks of the Rodil District, South Harris, Outer Hebrides’. *Earth and Environmental Science Transactions of The Royal Society of Edinburgh* 61, no. 1 (1944): 71–112. https://doi.org/10.1017/S0080456800018056.

Doel, Ronald E. ‘Constituting the Postwar Earth Sciences: The Military’s Influence on the Environmental Sciences in the USA after 1945’. *Social Studies of Science* 33, no. 5 (2003): 635–66.

Dunham, K. C. ‘Arthur Holmes 1890-1965’. *Biographical Memoirs of Fellows of the Royal Society* 12 (1966): 290–310.

Dunham, Kingsley Charles. ‘William Bullerwell, 27 September 1916 - 25 November 1977’. In *Biographical Memoirs of Fellows of the Royal Society*, 24:1–13. London: Royal Society, 1978. https://doi.org/10.1098/rsbm.1978.0001.

Edgerton, David. ‘Liberal Militarism and the British State’. *New Left Review* 185, no. I (1991): 138–69.

———. *Science, Technology and the British Industrial ‘Decline’, 1870-1970*. Cambridge: Cambridge University Press, 1996.

———. ‘Time, Money, and History’. *Isis* 103, no. 2 (2012): 316–27.

———. *Warfare State: Britain, 1920–1970*. Cambridge University Press, 2005.

Edgerton, David E. H., and Sally M Horrocks. ‘British Industrial Research and Development before 1945 1’. *The Economic History Review* 47, no. 2 (1994): 213–38.

Edinburgh Geological Society. 'EGS Officers and Council Members - Historical List', n.d. https://www.edinburghgeolsoc.org/home/officers-and-council-historical/#toggle-id-2.

Everitt, CWF, and JC Belshé. 'Palaeomagnetism of the British Carboniferous System'. *Philosophical Magazine* 5, no. 55 (1960): 675–85.

F., E. R. 'Book Review of The "Eötvös" Torsion Balance. Pp. 90. (London: L. Oertling, Ltd., n.d.) 21s'. *Nature* 118, no. 2968 (1926): 406. https://doi.org/10.1038/118406a0.

Facebook. 'Alastair McKenzie', n.d. https://www.facebook.com/alastair.mckenzie.524/.

Fettes, D., and J. Desmons, eds. 'Frontmatter'. In *Metamorphic Rocks: A Classification and Glossary of Terms*. Cambirdge: Cambridge University Press, 2007. https://assets.cambridge.org/97805218/68105/frontmatter/9780521868105_frontmatter.pdf.

Flett, John S. (John Smith). *The First Hundred Years of the Geological Survey of Great Britain, 1835-1935*. London: H. M. Stationery Office, 1937.

Frankel, Henry R. *The Continental Drift Controversy Volume 1: Wegener and the Early Debate*. Vol. 1. Cambridge: Cambridge University Press, 2012. https://doi.org/10.1017/9780511842368.

Freeman, Donald B. *The Pacific*. London & New York: Routledge, 2013.

Furon. 'Earth Sciences'. In *The Beginning of Modern Science, from 1450 to 1800*, edited by Rene Taton, translated by A. J. Pomerans, 565–85. London: Thames & Hudson, 1964.

'Geological Survey (Scottish Office) Mr. T. H. Whitehead'. *Nature* 156, no. 3973 (1 December 1945): 743–743. https://doi.org/10.1038/156743b0.

'Geology at Birmingham: Prof. L. J. Wills'. *Nature* 164, no. 4159 (1 July 1949): 96–96. https://doi.org/10.1038/164096a0.

'Geology at Glasgow: Prof. A. E. Trueman, F.R.S.' *Nature* 158, no. 4009 (1 August 1946): 299–299. https://doi.org/10.1038/158299a0.

Glen, William. *The Mass-Extinction Debates: How Science Works in a Crisis*. Stanford: Stanford University Press, 1994.

———. *The Road to Jaramillo: Critical Years of the Revolution in Earth Science*. Stanford University Press, 1982.

Godin, Benoît, and Désirée Schauz. 'The Changing Identity of Research: A Cultural and Conceptual History'. *History of Science* 54, no. 3 (2016): 276–306.

Gohau, Gabriel. *A History of Geology*. New Brunswick & London: Rutgers University Press, 1990.

Good, Gregory A. 'Vision of a Global Physics: The Carnegie Institution and the First World Magnetic Survey'. In *History of Geophysics: Volume 5–The Earth, the Heavens and the Carnegie Institution of Washington*, edited by Gregory A. Good, 29–36. American Geophysical Union, 1994. https://doi-org.libproxy.ucl.ac.uk/10.1029/HG005p0021.

Goodeve, Charles Frederick. 'Frank Edward Smith, 1876-1970'. *Biographical Memoirs of Fellows of the Royal Society* 18 (1 January 1997): 525–48. https://doi.org/10.1098/rsbm.1972.0019.

Gowing, Margaret. *Britain and Atomic Energy, 1939-1945*. London: Macmillan & Co Ltd, 1964.

Hallam, A. (Anthony). *Great Geological Controversies*. Oxford: Oxford University Press, 1983.

Heggie, Vanessa. 'Why Isn't Exploration a Science?' *Isis* 105, no. 2 (2014): 318–34.

Heim, Carol E. ‘Government Research Establishments, State Capacity and Distribution of Industry Policy in Britain’. *Regional Studies* 22, no. 5 (1988): 375–86.

‘Herman Shaw’. *Physics Today* 3, no. 7 (1950): 39–40. https://doi.org/10.1063/1.3066962.

Hough, Susan. *The Great Quake Debate: The Crusader, the Skeptic, and the Rise of Modern Seismology*. Seattle: University of Washington Press, 2020.

Howarth, Richard. J. ‘Gravity Surveying in Early Geophysics. II. From Mountains to Salt Domes’. *Earth Sciences History* 26, no. 2 (2007): 229–61. https://doi.org/10.17704/eshi.26.2.f04281625w2w7614.

Hsü, Kenneth Jinghwa. *Challenger at Sea: A Ship That Revolutionized Earth Science*. Princeton: Princeton University Press, 2014.

Hutchinson, Eric. ‘Scientists as an Inferior Class: The Early Years of the DSIR’. *Minerva* 8, no. 3 (1970): 396–411.

Kohler, Robert E. *Landscapes and Labscapes: Exploring the Lab-Field Border in Biology*. Chicago & London: University of Chicago Press, 2002.

Launius, Roger D. ‘Toward the Poles: A Historiography of Scientific Exploration during the International Polar Years and the International Geophysical Year’. In *Globalizing Polar Science: Reconsidering the International Polar and*

Geophysical Years, edited by Roger Launius, James Fleming, and David DeVorkin, 47–81. Springer, 2010.

LinkedIn. ‘Arthur Mather’, n.d. https://www.linkedin.com/in/arthur-mather-6590a456/.

LinkedIn. ‘Martin Robson’, n.d. https://www.linkedin.com/in/martinrobson1/.

Livingstone, David N. *Putting Science in Its Place: Geographies of Scientific Knowledge*. Chicago: University of Chicago press, 2010.

‘Lord Balfour in His Relation to Science’. *Nature* 127, no. 3194 (1 January 1931): 87–87. https://doi.org/10.1038/127087a0.

Lovell, Bernard. *The Story of Jodrell Bank*. Oxford: Oxford University Press, 1968.

M. T. M. O. ‘Review of Field and Colliery Surveying: A Textbook for Students of Mining and Civil Engineering Surveying by T. A. O’Donohue and T. G. Bocking’. *Science Progress in the Twentieth Century (1919-1933)* 24, no. 94 (1929): 365–365.

MacLeod, Roy M. ‘Scientists, Government and Organised Research in Great Britain 1914-16’. *Minerva* 8, no. 3 (1970): 454–57.

Mather, John D. ‘War as a Catalyst for Change: Groundwater Studies in the Geological Survey of Great Britain Before 1950 and the Impact of Two World

Wars'. *Geological Society, London, Special Publications* 362, no. 1 (1 January 2012): 139–60. https://doi.org/10.1144/SP362.8.

McKenzie, Dan Peter. 'Edward Crisp Bullard, 21 September 1907 - 3 April 1980'. *Biographical Memoirs of Fellows of the Royal Society* 33 (1 January 1997): 65–98. https://doi.org/10.1098/rsbm.1987.0004.

Melville, Harry. *The Department of Scientific and Industrial Research*. Allen and Unwin, 1962.

Menard, Henry William. *The Ocean of Truth: A Personal History of Global Tectonics*. Princeton University Press, 2014.

Mills, E. L. 'Editorial What Is History of Oceanography'. *History of Oceanography*, no. 2 (1990): 2.

Moseley, Russell. 'Government Science and the Royal Society: The Control of the National Physical Laboratory in the Inter-War Years'. *Notes and Records of the Royal Society of London* 35, no. 2 (1980): 167–93.

———. 'The Origins and Early Years of the National Physical Laboratory: A Chapter in the Pre-History of British Science Policy'. *Minerva* 16, no. 2 (1978): 222–50.

Mowery, David C. ‘Firm Structure, Government Policy, and the Organization of Industrial Research: Great Britain and the United States, 1900-1950’. *The Business History Review*, 1984, 504–31.

Muller, A., D.W. Müller, K.J. Hsü, J.S. McKenzie, J.A. McKenzie, H.J. Weissert, and Eidgenössische Technische Hochschule Zürich Geologisches Institut. *Controversies in Modern Geology: Evolution of Geological Theories in Sedimentology, Earth History and Tectonics*. Academic Press, 1991. https://books.google.co.uk/books?id=crYSAQAAIAAJ.

Naylor, Simon. ‘Fieldwork and the Geographical Career: T. Griffith Taylor and the Exploration of Australia’. In *New Spaces of Exploration: Geographies of Discovery in the Twentieth Century*, edited by Simon Naylor and James R Ryan, 105–24. London & New York: I. B. Tauris, 2010.

Naylor, Simon, and James R Ryan. *New Spaces of Exploration: Geographies of Discovery in the Twentieth Century*. London & New York: I. B. Tauris, 2010.

Nickles, Thomas. ‘Scientific Revolutions’. In *The Stanford Encyclopedia of Philosophy (Winter 2017 Edition)*, edited by Edward N. Zalta. Stanford: The Metaphysics Research Lab, Center for the Study of Language and Information, Stanford University, n.d. https://plato.stanford.edu/archives/win2017/entries/scientific-revolutions/.

Odishaw, Hugh. ‘The International Geophysical Year and World Politics’. *Journal of International Affairs* 13, no. 1 (1959): 47–56.

Oldroyd, David R. *The Highland Controversy: Constructing Geological Knowledge through Fieldwork in Nineteeth-Century Britain*. Chicago: University of Chicago Press, 1990.

———. *Thinking about the Earth: A History of Ideas in Geology*. London: Athlone, 1996.

Oreskes, Naomi. *Science on a Mission: How Military Funding Shaped What We Do and Don’t Know about the Ocean*. Chicago & London: University of Chicago Press, 2021.

———. *The Rejection of Continental Drift: Theory and Method in American Earth Science*. New York: Oxford University Press, 1999.

Oreskes, Naomi, and Ronald Doel. ‘The Physics and Chemistry of the Earth’. In *The Cambridge History of Science: Volume 5: The Modern Physical and Mathematical Sciences*, edited by Mary Jo Nye, 5:538–58. The Cambridge History of Science. Cambridge: Cambridge University Press, 2002. https://doi.org/10.1017/CHOL9780521571999.030.

‘Prof. A. O. Rankine, O.B.E., F.R.S.’ *Nature* 139, no. 3524 (1 May 1937): 830–830. https://doi.org/10.1038/139830b0.

‘Professor H. L. Hawkins’. *Nature* 221, no. 5177 (1 January 1969): 294–294. https://doi.org/10.1038/221294a0.

Read, H. H. (Herbert Harold). *The Granite Controversy: Geological Addresses Illustrating the Evolution of a Disputant*. London: Murby, 1957.

Reidy, Michael S., Gary R. Kroll, and Erik M. Conway. *Exploration and Science: Social Impact and Interaction*. Santa Barbara: ABC-CLIO, 2007.

ResearchGate. ‘Richard J. Howarth’, n.d. https://www.researchgate.net/profile/Richard-Howarth.

Robertson, Alex J. *The Bleak Midwinter 1947*. Manchester: Manchester University Press, 1987.

Robinson, Sam. ‘Scientific Imaginaries and Science Diplomacy: The Case of Ocean Exploitation’. *Centaurus* 63, no. 1 (2021): 150–70.

Rogers, Steven Leslie, Sam Giles, Natasha Joanne Dowey, Sarah E. Greene, Rehemat Bhatia, Katrien van Landeghem, and Chris King. ‘“you Just Look at Rocks, and Have Beards” Perceptions of Geology from the UK: A Qualitative Analysis from an Online Survey’, 2023. *Earth ArXiv*. https://doi.org/10.31223/X5MD4N.

Rose Edward P. F. ‘Groundwater as a Military Resource: Pioneering British Military Well Boring and Hydrogeology in World War I’. *Geological Society,* *London, Special Publications* 362, no. 1 (1 January 2012): 49–72. https://doi.org/10.1144/SP362.4.

Rose, Edward P.F. 'Geologists and the Army in Nineteenth Century Britain: A Scientific and Educational Symbiosis?' *Proceedings of the Geologists' Association* 107, no. 2 (1 January 1996): 129–41. https://doi.org/10.1016/S0016-7878(96)80006-X.

Rose, E.P.F., and M.S. Rosenbaum. 'British Military Geologists: The Formative Years to the End of the First World War'. *Proceedings of the Geologists' Association* 104, no. 1 (1 January 1993): 41–49. https://doi.org/10.1016/S0016-7878(08)80153-8.

Rose, Steven P. R.. 'Organising for Science in Britain: How Far Is There Still to Go?' *Minerva* 5, no. 4 (1967): 578–81.

Rozwadowski, Helen M. *Fathoming the Ocean: The Discovery and Exploration of the Deep Sea*. Cambridge & London: Harvard University Press, 2005.

———. *Vast Expanses: A History of the Oceans*. London: Reaktion Books, 2018.

Rudwick, Martin J. S. *The Great Devonian Controversy: The Shaping of Scientific Knowledge among Gentlemanly Specialists*. Chicago: University Of Chicago Press, 1985.

Ryan, James R., and Simon Naylor. ‘Exploration and the Twentieth Century’. In *New Spaces of Exploration: Geographies of Discovery in the Twentieth Century*, edited by Simon Naylor and James R Ryan, 1–22. London & New York: I. B. Tauris, 2010.

Rybar, Stephen. ‘The Eötvös Torsion Balance and Its Application to the Finding of Mineral Deposits’. *Economic Geology* 18, no. 7 (1 October 1923): 639–62. https://doi.org/10.2113/gsecongeo.18.7.639.

Schofield, Robert E. ‘Histories of Scientific Societies: Needs and Opportunities for Research’. *History of Science* 2, no. 1 (1963): 70–83.

Scripps Institution of Oceanography, UC San Diego. ‘John Sclater’, n.d. https://jsclater.scrippsprofiles.ucsd.edu.

Secord, James A. *Controversy in Victorian Geology: The Cambrian-Silurian Dispute*. Princeton: Princeton University Press, 1986.

———. ‘The Geological Survey of Great Britain as a Research School, 1839–1855’. *History of Science* 24, no. 3 (1986): 223–75.

Servos, John W. ‘To Explore the Borderland: The Foundation of the Geophysical Laboratory of the Carnegie Institution of Washington’. *Historical Studies in the Physical Sciences* 14, no. 1 (1983): 147–85. https://doi.org/10.2307/27757528.

Shaw, H., and E. Lancaster-Jones. ‘Application of the Eötvös Torsion Balance to the Investigation of Local Gravitational Fields’. *Proceedings of the Physical Society of London* 35, no. 1 (1922): 204–12. https://doi.org/10.1088/1478-7814/35/1/327.

———. ‘The Eötvös Torsion Balance’. *Proceedings of the Physical Society of London* 35, no. 1 (1922): 151–66. https://doi.org/10.1088/1478-7814/35/1/319.

———. ‘The Eötvös Torsion Balance and Its Use in the Field’. *Nature* 111, no. 2799 (1923): 849–51. https://doi.org/10.1038/111849a0.

Shulman, Peter A. ‘“Science Can Never Demobilize”: The United States Navy and Petroleum Geology, 1898-1924’. *History and Technology* 19, no. 4 (2003): 365–85. https://doi.org/10.1080/0734151032000181095.

Smith, Frank Edward. ‘John Cadman, Baron Cadman, 1877 - 1941’. *Obituary Notices of Fellows of the Royal Society* 3, no. 10 (1 January 1997): 915–27. https://doi.org/10.1098/rsbm.1941.0042.

Stephens, J. V. *Wells and Springs of Derbyshire*. Memoirs of the Geological Survey (Water Supply). London: His Majesty’s Stationery Office, 1929.

Strahan, A., T. V. Holmes, H. Dewey, C. H. Cunnington, W. B. R. King, W. C. Simmons, and D. A. Wray. *On the Thickness of Strata in the Counties of*

England and Wales Exclusive of Rocks Older than the Permian. London: His Majesty's Stationery Office, 1916.

Stroikos, Dimitrios. 'Engineering World Society? Scientists, Internationalism, and the Advent of the Space Age'. *International Politics* 55, no. 1 (2018): 73–90.

Stubblefield, Cyril James. 'George Hoole Mitchell, 31 December 1902 - 11 March 1976'. *Biographical Memoirs of Fellows of the Royal Society* 23 (1 January 1997): 367–83. https://doi.org/10.1098/rsbm.1977.0014.

Summerhayes, Colin P. 'International Collaboration in Antarctica: The International Polar Years, the International Geophysical Year, and the Scientific Committee on Antarctic Research'. *The Polar Record* 44, no. 4 (2008): 321–34.

Sutherland, Gordon. 'Government and Science in Britain and the US'. *Bulletin of the Atomic Scientists* 24, no. 4 (1968): 20–28.

Swenarton, Mark. 'Rammed Earth Revival: Technological Innovation and Government Policy in Britain, 1905-1925'. *Construction History* 19 (2003): 107.

Thomas, Larry. 'Terence Peter (Terry) Scoffin, 1941-2002'. *The Geological Survey*, https://www.geolsoc.org.uk/en/About/History/Obituaries%202001%20onwards/Obituaries%202003/Terence%20Peter%20Terry%20Scoffin%201941-2002.

Thomas, Nicola J., and Jude Hill. ‘Explorations in the Libyan Desert: William J. Harding King’. In *New Spaces of Exploration: Geographies of Discovery in the Twentieth Century*, edited by Simon Naylor and James R Ryan, 78–104. London & New York: I. B. Tauris, 2010.

Tizard, Henry Thomas. ‘Nevil Vincent Sidgwick, 1873-1952’. *Obituary Notices of Fellows of the Royal Society* 9 (1954): 236–58.

Torrens, H. S. ‘Southwell, Sir (Charles Archibald) Philip (1894–1981), Petroleum Geologist and Industrialist’, 23 September 2004. https://doi.org/10.1093/ref:odnb/47970.

Varcoe, Ian. *Organizing for Science in Britain: A Case-Study*. Oxford University Press, 1974.

———. ‘Scientists, Government and Organised Research in Great Britain 1914–16: The Early History of the DSIR’. *Minerva* 8, no. 1 (1970): 192–216.

———. ‘The DSIR: A Study in the Growth of Organized Science’, 1972.

Varcoe, Ivan. ‘Co-Operative Research Associations in British Industry, 1918–34’. *Minerva* 19, no. 3 (1981): 433–63.

Vernon, Keith. ‘Locating Industrial Research: Universities, Firms and the State, 1916–39’. In *Participating in the Knowledge Society*, 79–91. Springer, 2005.

Vetter, Jeremy. *Field Life*. University of Pittsburgh Press, 2016. https://doi.org/10.2307/j.ctt1gxxqcp.

Vig, Norman J. *Science and Technology in British Politics*. Elsevier, 2013.

Vine, Fred. An Oral History of British Science. Interview by Paul Merchant. National Life Stories, n.d. http://sounds.bl.uk/related-content/TRANSCRIPTS/021T-C1379X0025XX-0000A0.pdf.

Vine, Frederick J. ‘Reversals of Fortune’. In *Plate Tectonics: An Insider’s History of the Modern Theory of the Earth*, edited by Naomi Oreskes, 46–66. Boulder: Westview Press, 2003.

W. B. H. ‘Sir Richard Threlfall, 1861 - 1932’. *Obituary Notices of Fellows of the Royal Society* 1, no. 1 (1 January 1997): 45–53. https://doi.org/10.1098/rsbm.1932.0010.

Whitehead, Mark. *State, Science and the Skies: Governmentalities of the British Atmosphere*. Vol. 64. John Wiley & Sons, 2011.

Whitehead, T. H. ‘Dr. R. W. Pocock’. *Nature* 174, no. 4424 (1 August 1954): 294–95. https://doi.org/10.1038/174294c0.

Wilkie, Tom. *British Science and Politics since 1945*. Oxford: Blackwell, 1991.

Wilkins, Anne. 'James Gray, 1941-2005'. *The Geological Survey*, n.d. https://www.geolsoc.org.uk/en/About/History/Obituaries%202001%20onwards/Obituaries%202005/James%20Gray%201941-2005.

Williams, Carol. *Madingley Rise and Early Geophysics at Cambridge*. Antique Collectors' Club, 2010.

Williamson, Fiona, and Janković. 'A Question of Scale: Making Meteorological Knowledge and Nation in Imperial Asia'. *History of Meteorology* 9 (2020): 1–9.

Wilson, H. E. *Down to Earth: One Hundred and Fifty Years of the British Geological Survey*. Edinburgh & London: Scottish Academic Press, 1985.

Wise, M. Norton, ed. *The Values of Precision*. Princeton University Press, 1995. https://doi.org/10.2307/j.ctv14163t2.

Wood, Robert Muir. *The Dark Side of the Earth*. London: Allen & Unwin, 1985.

Yergin, Daniel. *The Prize: The Epic Quest for Oil, Money & Power*. London: Simon & Schuster, 1993.

Yoder, H. S., Jr. 'Development and Promotion of the Initial Scientific Program for the Geophysical Laboratory'. In *History of Geophysics: Volume 5–The Earth, the Heavens and the Carnegie Institution of Washington*, edited by Gregory A. Good, 21–28. American Geophysical Union, 1994. https://doi-org.libproxy.ucl.ac.uk/10.1029/HG005p0021.

Young, David G. G. ‘Gravity and Magnetic Investigations of the Deep Structure of the North Irish Sea’. Doctoral Thesis, Durham University, 1965. http://etheses.dur.ac.uk/9216/.