The Cultural and Historical Geographies of Onshore Oil Exploration in the British East Midlands During the 20th Century

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Abstract

This thesis tells the hitherto neglected story of onshore oil exploration in the British East Midlands from 1908 to 1964. Drawing on a series of case studies it provides a regional historical geography, connecting science and industry to the exploratory field science of geology. During the period examined, two low key discoveries – Hardstoft, in Derbyshire (1919), and Eakring, in Nottinghamshire (1939) - altered Britain's energy prospects, supplementing coal with liquid mineral oil. Using archival research methods and oral testimonies, the thesis reveals how a diverse assemblage of earth scientists, oilfield technologies and techniques, institutions and private companies developed a regional laboratory for oil exploration. Liquid energy fuelled heated political debates over land nationalisation and private ownership rights, the science of subsurface quantification and governance, and the role of industry in exploration. Though small when compared with global consumption and production figures, oil discovered in the British East Midlands provided a time critical supply of oil during World War Two. It also facilitated technological advances in oilfield development, contributed towards a new arm of economic geology (geophysics) and encouraged earth scientists to think of territory as a three dimensional entity, extending beneath, as well as along the land surface.

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This thesis is dedicated to my Father, William Thomas Naylor (23rd August 1924 – 15th August 2004), who is shown below (left) standing next to his friend "Tiny" (right) at Welbeck Abbey, Nottinghamshire during World War Two.

"I am a thousand winds that blow".

Vaya Con Dios, Dad.

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Archive abbreviations

BPA:	British Petroleum Archive, University of Warwick
BGSA:	British Geological Survey Archive
CACCC:	Churchill Archives Centre, Churchill College
CEA:	Chatsworth Estate Archive
DWOM:	Dukes Wood Oil Museum
KUSCA:	Keele University Special Collections and Archives
TNA:	The National Archives, Kew
HLUNMSC:	Hallward Library, University of Nottingham, Manuscripts and Special Collections
PA:	Parliamentary Archive

Acronyms/definitions

Anticline	An upwardly convex geological structure comprising numerous layers, which increase with age towards the core. Such structures often contain hydrocarbon deposits.
AIOC	Anglo Iranian Oil Company, so named in 1935.
APOC	Anglo Persian Oil Company, and English founded in 1908 following the discovery of the Masjed Soleiman oilfield, Iran.
Barrel	A non-standardised unit of volume. 35 imperial gallons (159 litres) or 42 US gallons.
Bit	Tool at the end of the drill string responsible for cutting or crushing rock to bring to the surface.
Block	Topographic subdivision of an area for the purpose of licensing to a company for exploration/production rights.
Borehole	A deep, vertical or horizontal hole made into the ground in search of mineral deposits, commonly water and oil
British Petroleum	Formerly APOC, later AIOC and finally BP. A British multinational oil company with its Headquarters in London.
Cap rock	Impermeable rock which provides a seal preventing the migration of fluids, in particular hydrocarbons.
Crew	Personnel responsible for operating a drilling rig.
Derrick	Framework erected over a drill site to support/guide drilling machinery.
Directional drilling	Controlling the direction and deviation of a borehole from the surface in order to target a subsurface target.
Downhole	Term used to describe oilfield infrastructure (tools, equipment, and instruments) used for drilling and extraction process.
DORA	The Defence of the Realm Act (DORA), passed through parliament in 1914 governed the actions of the Britain public during World War One.
Drilling mud	A mixture of clay, water, or refined oil, and chemical additives pumped downhole. Used for cooling, lubrication, borehole support and movement of cuttings to the surface.
Drill string	Assemblage including drill pipe and associated drilling tools located at the bottom of the borehole.
Fault	A crack in the earth’s crust in which there has been an observable displacement.
Isopachyte	A contour line which represents rock of equal thickness over an area.

Licence	Issued as either an “exploration” or “production” licence. An exploration licence permits geological and geophysical surveying as well as the drilling of shallow wells. A production licence confers exclusive rights on the licensee to search and bore for and get petroleum.
Log	The collection of information in relation to the drilling and extraction process.
Migration	The movement of hydrocarbons from their source to a surrounding structure, often forming a hydrocarbon reservoir.
Nodding donkey	Also referred to as a pumping unit, pumpjack, beam pump or rocking horse, it is the power plant responsible for bringing hydrocarbons to the surface.
Percussive drilling	Repeated, high impact blows using a wedge-shaped boring tool pulverise the rock at the bottom of the borehole in order to be lifted to the surface.
PLUTO	A WWII operation involving the construction of Pipe-Lines Under The Ocean (PLUTO) to send oil under the English Channel to the allies in France.
Reservoir	A porous, permeable subsurface rock formation in which oil and gas are found.
Royalty	Fees received by the state for the production of minerals, including hydrocarbons, by the company licensed to produce.
Rotary drilling	A drilling process in which rock is cut or crushed via the circular motion of the drill bit, commonly rotated from the surface via the drill string.
Rate of Penetration (ROP)	Speed at which the drill bit advances through rock. Commonly measured in feet or meters per hour.
Secondary recovery	A process implemented to maintain reservoir pressure so as to sustain hydrocarbon extraction volumes. Examples commonly include well shooting, in which explosives are lowered into the bore hole and detonated to fracture the rock, or water injection, where water is injected to increase pressure and displace hydrocarbons towards producing wells.
Source rock	A rock sufficiently rich in organic matter as to be a source of hydrocarbons.
Specific gravity	The ratio of the density of a material to that of a reference substance, usually water.
Spud	The commencement of drilling a borehole.
Strata	Layers of sedimentary rock.

Stratigraphy	The study of the order and relative position of strata (rock layers) in the geological timescale.
Trap	An impermeable rock which stop hydrocarbons from migrating into surrounding structures, thus preserving them within a reservoir.

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Chapter 1 - Introduction

1.1 Introduction

This thesis aims to produce an historical and cultural geography of onshore oil exploration in the British East Midlands from 1908 to 1964. The belief that the national land mass of the UK might contain significant, commercially viable hydrocarbon reserves has been the source of scientific controversy for more than a century. An accidental oil discovery in a coal mine in Derbyshire in the mid-1800s led to the development of the oil shale industry in central Scotland as early as the 1850s. The systematic and commercial exploitation of onshore oilfields has taken place in a low profile and episodic manner since World War One, as a consequence of serious concerns that the nation's energy supplies might be exhausted during the latter phase of the war.

Determined by plate tectonics, the global distribution of oil deposits is more readily associated with deserts, Arctic tundra, offshore continental margins and river deltas, and not the vegetated, populated, quintessentially English East Midlands. This thesis, however, examines the early history of oil exploration and exploitation in the East Midlands oil province (also known as the Carboniferous Pennine Basin), a petroliferous area that "comprises a series of major Carboniferous rift basins" in the heart of Britain (Evans, *et al.*, 2011, p. 9). Providing only a small proportion of the total UK production, this modest rural industry provided a significant element of the UK's energy supplies during World War Two (Smith, 2002a).

This is the first serious analysis of a small but contentious rural industry and illustrates Britain's hesitant initial attempts to negotiate a pathway from a 19th century energy regime dominated by coal to a new era of oil. The dominance of oil within the UK's energy budget increased inexorably following the onset of North Sea production in 1964 and following the collapse of the domestic coal industry in 1948. However, the oil industry, an export industry since the 1980s is now on the brink of exhaustion. A reduction in oil refinery production in recent years has increased petroleum importation and decreased export, resulting in the "UK becoming a net importer of petroleum products for the first time since 1984" when the "miners' strike resulted in high demand for fuel oils for power generation to substitute for coal" (DECC, 2014b, p. 6).

This thesis examines the interactions between individuals, institutions and technologies within regional, national and international contexts, which became embroiled in a complex network which sought to overcome the technical and physical constraints inherent to exploring for and extracting a liquid target many thousands of feet below the surface of the earth. It considers the history of ideas and the way in which Britain attempted to diversify its energy regime through the geopolitics of oil in the early to mid-20th century. It also considers the life paths of a large number of individuals, drawing implicitly and explicitly from their national and international experiences, which brought them into contact with the natural world of oil, providing clues as to where oil might be located in Britain.

By considering the previously unexamined lifeworld of oil prior to the major offshore oil discoveries of the 1960s this thesis will contribute significantly to current and ongoing debates surrounding the country's energy supplies – debates which have, until recently, been primarily focused on the political and economic spheres of oil. It also makes a contribution to recent debates centred on "hydrocarbon cultures", which have, quite literally, fuelled late 20th century British modernity.

1.2 Aim and objectives of thesis

The aim of this thesis is to reconstruct a historical geography of onshore oil exploration in the British East Midlands from 1908 to 1964. An Actor Network Theory (ANT) inspired approach is deployed to argue that seemingly disparate assemblages, including people, places, technologies, private companies and research institutions, can create a regional, historical and industrial geography of onshore oil exploration. This mobilises biogeographical accounts of key protagonists, contemporary ideas relating to subsurface exploration, debates over the development of oil cultures and claims to scientific/technical advances in geology during the 20th century. Three empirical chapters are based around three periods of exploration activity. The following objectives cut across all of the empirical chapters and explore similar themes, as follows:

1. To identify key figures involved in onshore oil exploration in the British East Midlands from 1908 to 1964. In particular, investigating how geologists and other scientific experts stimulated political debates and initiated technological processes that resulted in the development of the Hardstoft, Derbyshire and Eakring, Nottinghamshire oilfields.

2. To investigate scientific techniques in relation to a number of cutting edge, 20th century oilfield technologies and how they shaped the geography of oil exploration and gave rise to a new arm of economic geology.

3. To examine the geopolitical, scientific and technical roles of formal, structured institutions that influenced this story.

1.3 Thesis structure

No study has ever attempted to explore the intricate hidden histories of onshore oil exploration in the British East Midlands. This thesis will reveal the bio-geographical accounts of key protagonists, the development of significant pieces of technology and progress in techniques, the establishment of research centres as well as and examining the wider implications of onshore oil exploration for the geosciences during the 20th century. This project draws on many archive collections from around the UK and some semi-structured interviews with former oilfield workers. It identifies three periods of exploration activity and involves two sites, Hardstoft in Derbyshire and Eakring in Nottinghamshire. This introduction is followed by a literature review (Chapter 2), methodology (Chapter 3) and three empirical Chapters, 4, 5 and 6 (which are arranged broadly chronologically), followed by a conclusion.

The literature review is split into five main sections. The first examines the notion of "cultures of exploration" within the exploratory field sciences of geography and geology during the 20th century. It examines the commercialisation of geological science post World War One and identifies the roles of geologists during episodes of conflict. The second section examines the recent cultural turn within the petroleum geosciences, and highlights the need for scholars to postulate the complete historiography of oil. The third section examines the ways by which geographers are beginning to engage with the notion of subsurface geographies, identifying that territory, as well as extending along the land surface, also extends above and below the ground. The fourth section places the thesis within the field of Science and Technology Studies (STS), outlining how a "softer" version of Bruno Latour's Actor Network Theory (ANT) is being used by geographers to examine how knowledge is created, mobilised, ordered and governed within complex networks, which incorporates people, objects and places. The final section examines the role of geobiographies in research and how, specifically, an individual's embodied experiences affect their motivations and actions.

Chapter 3 outlines the methodology and focuses on the sourcing of empirical material. It also offers a reflective account of archival research, before moving on to look at modes and methods of optimising the output generated from semi-structured interviews, which formed part of the research. Following on from this are the three empirical chapters. Chapter 4 is the first of three empirical chapters and covers the period 1908 to 1927. Onshore oil exploration activities began in this period, assisted by a major US oil company, on the surface anticlines of Carboniferous rocks in northern England and Scotland. Following a long and convoluted gestation, the Petroleum (Production) Act of 1918 granted companies access to explore for oil over small geological structures. This expedited exploration activities, culminating in the earliest commercially viable discoveries, beginning with Hardstoft No. 1, located on the Duke of Devonshire's estate in eastern Derbyshire in 1918.

Chapter 5 examines the period from 1922 to 1939. Following developments in geophysical surveying techniques the British government passed the Petroleum (Production) Act 1934, which granted access to extensive surface territories and vested undiscovered onshore hydrocarbon ownership in the Crown. The legislation also established the licensing system for commercial onshore oil exploration and exploitation. Consequently the D'Arcy Exploration Company Ltd (D'Arcy) formed in 1914, a subsidiary of the Anglo Persian Oil Company (APOC), later the Anglo-Iranian Oil Company, (AIOC) and finally British Petroleum (BP) in 1954 carried out the first widespread, systematic search for oil across the UK. The result was D'Arcy geologists discovering the first of four fields in and around the village of Eakring on the brink of World War Two.

Chapter 6 covers the period from 1939 to 1964, during which significant quantities of oil were found at Eakring, Nottinghamshire, amid some secrecy, with the assistance of an American workforce provided by the Noble Drilling Corporation of Oklahoma. The oil provided a time-critical supply during World War Two and prompted D'Arcy to move its research and development division from London to Kirklington Hall in the village of Eakring, Nottinghamshire. As the epicentre of this new rural industry, D'Arcy's Kirklington Hall Research Station was a vital node in the global development of revolutionary oilfield techniques and technologies.

Following the three empirical chapters a conclusion outlines the main findings of the research, including empirical and theoretical contributions to geographical knowledge, limitations of the research and plans for future dissemination.

Chapter 2 – Review of literature

2.1 Introduction

This chapter provides a theoretical and historical framework in which to contextualise the thesis. It is divided into five sections. The first examines recent literature on 20th century exploration and the history of geology in the same period. Advances within sedimentology in particular are highlighted, as well as the role of geologists during World War One and World War Two, alongside advances in oilfield technologies. The second section examines a recent shift in the way oil histories are written, from traditional, celebratory accounts to cultural and ideological representations, which chronicle the lives of individuals and communities affected by oil exploration and extraction. These oil cultures have emerged largely from American research, which is to be extended to the British East Midlands during the course of this thesis.

The third section examines a recent, axiomatic assertion, that territory is a three-dimension entity, existing below, as well as above the land surface. The literature explores the notion of “verticality”, and in particular elucidates the British government’s approach to subsurface governance from the 19th century onwards, including the formation of the BGS in 1835. It goes on to identify how geology and geography became bifurcated at the beginning of the 19th century, as autonomous scientific institutions focused on representations of either topographic or geological territory.

The fourth section begins by postulating the importance of using a case study approach to situate knowledge production in the field. It goes on to examine how knowledge is circulated, by drawing on Bruno Latour’s Actor Network Theory (ANT), which advocates considering scientific networks as an assemblage of human and non-human actors. This theoretical approach underpins the empirical chapters of this thesis, as each identifies one or more human actor, as well as oilfield technologies and the role of research institutions and private companies.

The fifth and final section discusses geobiographies – an approach whereby emphasis is placed on the spatial life stories of subjects under investigation. The five sections highlighted above provide a conceptual framework to this thesis, which will be discussed in review sections at the end of Chapters 4, 5, and 6 and reported in the overall conclusion.

2.2 Exploration in the field: interrogating the earth above and below the earth’s surface

Modern cultures of exploration have focused on how exploration has been produced and consumed, as well as assessing how individuals and institutions alike have facilitated geographies of empire (Driver, 2001). Much of this literature relates to 18th and 19th century exploration, with little attention paid to the 20th century. This is highlighted by Driver, who argues that previous studies of exploration emphasise "Conrad's discontinuity" between the "geography militant" of the 19th century and the "geography triumphant" of the 20th century, whereby exploration had come to a close with all blank voids of the globe filled (Driver, 2000). While 20th century exploration might not conjure romantic images of heroic land and sea explorers, it is myopic to ignore significant scientific, cultural and social episodes in 20th century exploration, which has continued unabated, and unrecognised in increasingly hostile, often inaccessible areas, for example the north and south poles, tropical rain forests and the deep "ocean wilderness" (Kroll, 2008).

As discussed by Lowman, the 20th century witnessed an unparalleled surge in technologies, forming the foundations of scientific progress (Lowman, 1996). In the period from 1890 to 1910 alone there was the development of the radio, aviation, electronics, the automobile industry, the steel-frame skyscraper and steam turbine to name but a few, in an era of unprecedented scientific discoveries (Lowman, 1996). Within the solid-earth sciences, discrete "events" or "discoveries" were made throughout the century. A notable example, which will be examined in greater detail during Chapter 5, is the development of geophysics, which enabled earth scientists to delineate the physical boundaries and physical discontinuities of the mantle. According to Driver: "The large-scale organisation and mega-politics of twentieth-century scientific exploration, whether terrestrial, marine or interplanetary...suggest a direct lineage with the larger, more organised expeditions of earlier eras, for example European navigation of the 18th century and exploration of East African river and lake systems of the 19th century" (Driver, 2009, p. 244).

Such large scale expeditions were, according to Ryan and Naylor, constructed across spatial networks that "included not just individual explorers but scientific societies, government bodies, private organisations, publishers and patrons of various kinds" (Ryan and Naylor, 2009, p. 4). Developments in scientific instrumentation, in tandem with standardised data gathering techniques introduced during the 18th century onwards, drove forward exploration and geographical science (Driver, 2009). Beginning with sextants and barometers, human operators learnt how to use instruments to make observations and record precise scientific field data. Explorers were thus able to navigate the earth, produce maps, record geographical data and, crucially, compare data from remote places at scientific institutions or "truth spots". The late Victorian era witnessed a transformation in the ways by which science, industry and commerce was organised, produced and consumed.

Earlier in the Victorian era, science was approached from a philosophical perspective, with industrial applications of science seen as stymieing the pursuit of the gentlemanly elite. However, as stated by Driver, "such a lofty view obscured the large-scale social and economic shifts that were turning the vocation of science into a career: the era of specialism was at hand" (Driver, 2009, p. 246).

Specialisation and professionalisation, which will be discussed in due course in relation to geological science, challenged the traditional model of the explorer. Having mapped and surveyed the spaces and places opened up by earlier periods of exploration, the explorer was following the traditional paradigm. As Driver discusses, this view "mirrors the historical evolution of scientific inquiry, in which a descriptive, place based "natural philosophy "model is said to give way to systematic analysis, as the natural sciences moved from survey to experiment" (Driver, 2009, p. 246). However, as this thesis will reveal, "the practices of field work and mapping – essential features of the business of exploration, remain central to the pursuit of modern science, and not its [redundant] ancestors" (Driver, 2009, p. 247).

Most geological histories survey the intellectual landscape from above, whereas in this thesis I attempt to become what Torrens describes as "the mole-like historian interested in the detail and the hidden" (Torrens, 2002, p. iii). The discovery of stratiform minerals (of which oil is arguably the most important) is a complex process which involves understanding not only the behaviour of the target but also the interaction with the surrounding geological assemblage. Understanding the human elements of mineral prospecting and exploration conforms to a similar model, affording this thesis the opportunity to unravel a complex narrative which began during the early 20th century.

Oldroyd argues that the critical historiography of geological science gathered pace after World War Two, with historians attending to earlier, more distant and remote subjects first (Oldroyd, 2002). This is perhaps unsurprising, as the 18th and 19th centuries provide the foundations of geological science. The 20th century has only recently ended, and many of the key protagonists involved in technological innovation and scientific discovery are still alive. This creates potential stumbling blocks for researchers, who must consider ethical and moral issues, as well as intellectual property rights and data confidentiality. Examining events occurring beyond living memory enables critical analysis and perspective; however, it closes the door on much of the 20th century – a period in which "much more geology has been done…than in the whole of previous human history" (Oldroyd, 2002, p. 2).

Science and technology has, historically, had a major impact on the outcome of conflicts throughout the 20th century. Relating specifically to geological science, Kiersch and Underwood, Jr argue that "the geological characteristics of contested terrain have influenced the outcome of battles and wars since individuals, tribal groups, and nations began vying for power and control" (Kiersch and Underwood, Jr, 1998, p. 5). However, they continue, "only when the relatively new science and profession of geology evolved in the late 18th and early 19th centuries did those with some understanding of geology begin to have a direct influence on military planning and operations" (Kiersch and Underwood, Jr, 1998, p. 5).

According to Guth (1998, p. 1), “in warfare, military geologists pursue five main categories of work: tactical and strategic terrain analysis, fortifications and tunnelling, resource acquisition, defence installation, and field construction and logistics”. During World War One, for example, geologists from the BGS were involved in hydrogeological surveys to locate water on the western front. They also prepared geological maps of Belgium, reported on the topography and geological character of the ground in Belgium and Northern France, located water supplies in the Dardanelles (Turkey), advised on sites of aerodromes, analysed samples of concrete from German defences, advised on the suitability of sand for making concrete, produced maps and reports relating to mineral supplies (allied and enemy), experimented with different materials for use as bearings for aeroplane compasses, selected certain quartz crystals for use in anti-submarine operations, produced reports on caves for the storage of munitions and offered scientific insights at various committee meetings relating to mineral resources (BGS World War One Exhibition, January 2014).

During World War One, military mining proliferated, resulting in a complex maze of entrenchments, which deepened as the war progressed. At the height of mine warfare in 1916, the British engaged a total of 25,000 men who worked underground (Rose and Rosenbaum, 1998). The siting of subsurface excavations became a staple occupation of the military geologists of World War One, providing sanctuary at depth for thousands of troops via “dugouts, subways and other subsurface excavations” (Rose and Rosenbaum, 1998, p. 33). This military tactic required geologists to gather geological field data, including the stratigraphic position of the Eocene “blue clay” of Flanders and the location and behaviour of water tables. The single largest offensive manoeuvre was the undermining of 16km of the Messines-Wytschaete Ridge, along which were planted 19 massive mines into the Flanders blue clay, totalling 450,000kg of high explosives, which were detonated in sequence on 7th June 1917.

As well as offensive military strategy, geologists also compiled specialist geotechnical maps, identified soils and underlying strata and produced some of the earliest hydrogeological maps in Europe. In total, the British drilled 470 borings for water behind the western front during World War One, while the Americans formed the 26th Engineers - a specialist water supply regiment, consisting of 1,434 men and 51 officers to drill for potable water (Pittman, 1998). Military geologists operating during World War One also supported engineering works including fortifications and roads, and were employed to predict likely battlefield conditions, extrapolating data from a range of sources, including soil and geology maps. Mine warfare also led French physicists to invent the geophone, a device similar to a stethoscope, which could “hear” enemy advances via the vibrations transmitted through the ground.

The geophone, used in military mining activities during World War One was part of a larger revolution in seismic imaging techniques during the first half of the 20th century, which ultimately resulted in the successful discovery of concealed oil deposits, having “no obvious surface structure or seep" (Smith, 1995, p. 14). Reddy provides a chronological account of developments in refraction and reflection seismic from the 1850s to just after World War Two, arguing that "the practical use of seismic waves to explore shallower depths for minerals and oil took shape during the mid-nineteenth century" following the successful discovery of salt domes using artificial seismic waves (Reddy, 2012, p. 75). Reddy highlights several moments in the development of geophysics, which begin in 1851 when Robert Mallet of the USA developed a basic seismograph, which consisted of a bowl of mercury that reflected a spot of light in the shape of a cross hair, observed via a telescope, to measure the velocity of artificial seismic waves in granites and loose sand. In 1878, H. L. Abbot used several Mallet type seismographs to measure the velocity of seismic waves following the detonation of 50,000lb of explosives. These experiments were improved upon by Milne and Gray several years later, who again used explosive charges, this time in Japan, to create ground vibrations.

Field practice was complemented by the theory of seismic wave transmission, developed by Wiechert and Zoeppitz in 1907, who "gave solutions to the problems of seismic wave propagation, refraction and reflection" (Reddy, 2012, p. 76). By the end of the first decade of the 20th century, early investigators had "built instruments to pick up tremors, and to record and time them…developed an entirely adequate theory of wave propagation…[and] suggested practical uses of the method" (Reddy, 2012, p. 76). In 1914, for example, Reginald Fessenden used reflected and refracted sound waves for locating mineral bodies. Reddy argues that "World War I provided the impetus for the introduction of seismology to mineral exploration" (Reddy, 2012, p. 75). For example, German Scientist Dr L. Mintrop invented a portable seismograph to detect the location of allied artillery. By using three devices to capture vibrational data, Mintrop could triangulate the exact location of distant artillery and thus direct offensive attacking fire to destroy it. Following World War One Mintrop reversed this process, setting off explosions at known distances in order to conduct "refraction profiling for locating the depth and type of subsurface formations" (Reddy, 2012, p. 77). Successful field tests led Mintrop to form Seismos, the world's first seismic exploration company, which was contracted under the Gulf Production Company to locate likely oil reservoirs. As discussed by Reddy, during the 1920s, the Geophysical Research Corporation, headed by J. C. Kracher, revised early designs of seismographs, utilising electrical, rather than mechanical devices, which were far more accurate. In the late 1930s and 40s, subsequent developments were made to both the apparatus and the technique, "increasing the stability of the equipment used" (Reddy, 2012, p. 77).

World War One massively increased the global demand for oil, which "provided the impetus for the introduction of seismology to mineral exploration" (Reddy, 2012, p. 75). As a consequence, the geosciences witnessed a rapid period of specialisation, driven by engineers and technicians, who developed sensitive scientific instrumentation, and by the oil companies, who supplied funding and provided test sites for exploration. Over the course of the 20th century, the field of geophysical imaging became fragmented through specialisation, resulting in separate branches, which included electrical resistivity tomography, ground penetrating radar, induced polarization and seismic tomography and reflection seismology. As elucidated by Reddy, increasing specialisation meant that "all major theoretical components of classical physics can be applied to geophysical exploration" (Reddy, 2012, p. 75).

Smith argues that "early petroleum exploration usually entailed field mapping by drilling surface anticlines, in sedimentary rocks, preferably near oil seepages" (Smith, 1995, p. 14). A focus on sedimentary rocks resulted in further specialist branches within the geological sciences during the 20th century – significantly in sedimentology. Seibold and Seibold state that from the late 19th century, sedimentary rocks were studied due to the fossils they contained, enabling geologists to work out geological sequencing. With the introduction of thin sections and microscopical investigation, the composition of sedimentary rocks began to receive increasing attention, spawning the beginnings of micropalaeontology (Seibold and Seibold, 2002). The "founder of sedimentary petrography" Henry Clifton Sorby (1826-1908) published widely on metrological aspects from as early as 1850, leading to quantitative ideas, descriptive texts and later, actualistic concepts (Seibold and Seibold, 2002).

In 1895, Roentgen serendipitously discovered x-rays, marking a milestone in physics. Clearly a significant discovery in medicine, x-rays were, during the 20th century, applied to mineralogy, petrology, and geochemistry. At the turn of the 20th century, mineralogy was a largely descriptive science, used only to indicate composition and general physical properties. However, the work by Laue, W. H and W. L. Bragg (father and son) shifted mineralogy, through x-ray diffraction to a "precise, quantitative, and testable" science (Lowman, 1996, p. 487). X-ray diffraction facilitated the identification of minerals and revealed their respective structures. This in turn, "[proved] invaluable in many geochemical problems, such as the partitioning of trace elements, formation of hydrothermal ore deposits, and others" (Lowman, 1996, p. 487).

As the 20th century unfolded, increasing hydrocarbon demand shifted the emphasis in sedimentology from single grain analysis to the ultimate understanding of complex sedimentary basins, which "can stand as a multidisciplinary and increasingly quantitative method in earth sciences…leading to integrative models" (Seibold and Seibold, 2002, p. 245). The analysis of fine grains necessitated an understanding of microscopic organisms, which are sensitive to sorting and form the organic components of sediments, critical in the formation of black shales and thus significant to petroleum geologists exploring for hydrocarbons. Such phenomena required input from biologists and chemists, resulting in the formation of specialist fields in geochemistry and palaeontology. During World War One, progress in sedimentology declined, owing to the severing of international links and the focus on applied geology. However, following World War One it "expanded gradually, into a plethora of fields – geochemical, pedological, geophysical, biological or mathematical aspects, and applied sedimentology (Seibold and Seibold, 2002, p. 241).

Moving to World War Two, geologists were employed to collect and evaluate geological data, produce specialist maps of mineral and water resources, undertake ground truth and terrain evaluation studies, plan military strategies and supervise on field operations. The evaluation of ground-water resources, and subsequent water well drilling in North Africa and the Middle East in particular, became a key strategic operation, upon which the movement of entire armies depended. As well as operations on the ground, geologists were also engaged in intelligence operations, notably air reconnaissance, interpreting aerial photographs to locate military targets and plan bombing missions. As discussed by Butler, following the war the Geological Museum (now part of the Natural History Museum) organised a temporary exhibition detailing the contributions of British geologists to the war effort (Butler, 1947). They included, amongst others, projects associated with ground-water supply, mining of resource materials (iron, non-ferrous metals such as lead and zinc, and coal) as well as projects that utilised the subsurface to construct bomb-proof structures. Military geology became an area of growing professional practice during World War Two, bringing “about the proliferation of applied geology on a scale hitherto unimagined (Kiersch and Underwood, Jr 1998, p. 23). On the allied side, prior to the Normandy landings, geologists served as part of prelanding parties to provide ground truth reconnaissance to assess, for example, the physical characteristics of beaches for vehicular trafficability, as well as the depth of coastal inlets, which would provide “entrances” for landing heavy cargo.

Significantly, geology and engineering amalgamated to become a specialism known as military engineering geology. The German army and navy, for example, utilised “geological guidance when planning and constructing major field works, whether fortifications, underground installations and factories, airfields, military bases, or secret command facilities (Kiersch and Underwood, Jr, p. 14). The German Navy were guided by geologists prior to, and during the construction of bomb-proof submarine pens on the northern coast of Norway. The U. S. response to the threat of U-boat attack was to established geodetic networks in coastal areas from 1942 to 1943 to assist in monitoring their position.

The application of military geology resulted in the formation of specialist departments during World War Two. For example the German Army had three top-level, geology-related agencies (Smith and Black, 1946). The largest, and most well-known, being the Mil-Geo, which provided the German Army with scale 1:500,000 and later 1:200,000 “handbooks on the countries in Europe, Asia, North Africa, and ultimately on the countries in the Indian Ocean region” (Kiersch and Underwood, 1998, p. 14). A detailed understanding of the wide ranging hazardous physical processes, inherent to the markedly different elemental battle grounds of World War Two became essential to both the Germans and the allies. “From the frozen waters of the Arctic to the equatorial jungles", geological expertise, alongside other specialisms, for example hydrology and soil science, forged a strong alliance between geology, geography and landscape during World War Two (Kiersch and Underwood, 1998, p. 18).

Following World War Two, petroleum geologists located the Leduc oilfield in Alberta, leading to extensive research into carbonate formation. As had been the case in sedimentology prior to World War One, the trend was to firstly analyse thin sections and ascertain rock composition - the minutiae - in order to build a larger picture of continental environments (Seibold and Seibold, 2002). Armed with such knowledge, geologists could transpose findings to their search for tectonic traps, and reservoir and source rocks in distant locations. For example, geologists employed by SHELL, utilised single grain analysis acquired from studies into the dunes and wadies of the deserts of the Near East, to assist in the "understanding of the Dutch and North Sea gas fields with their Permian reservoir rocks" (Seibold and Seibold, 2002, p. 244).

In parallel with 20th century advancements in geological science, the operational aspects of oilfield technologies also progressed throughout the 20th century to meet the requirements of the Western world's oil prodigal culture. Early oilfield drilling was performed using percussive methods, which was slow, and pulverised geological samples, making it difficult to draw conclusions on downhole conditions. At the turn of the 20th century, however, rotary drilling methods became popular, significantly increasing the Rate of Penetration (ROP) and offering the ability to extract geological core samples. Until 1909, rotary drilling systems employed a "fishtail" drill bit, which worked well in loose formations, however, this proved ineffective when attempting to drill through medium to hard-rock formations (Baker Hughes, 2009). Consequently, oil exploration was limited to shallow depths. In 1909, however, Howard Hughes Sr patented a two-cone rotary rock bit, which revolutionised oilfield drilling. Giving far greater ROP, and able to withstand the rigours of drilling through hard-rock formations, the two-cone bit provided access to previously inaccessible oil deposits at great depth below the earth's surface (Baker Hughes, 2009). While the system has been improved since, the basic principle remains the same, being the most widely used system today.

Having developed an efficient drill bit, engineers next turned their attention to maximising oilfield development, by increasing the efficiency, flexibility, accessibility and speed of drilling. During the 1930s, rudimentary attempts were made to drill "multilateral" wells, which, by definition, "is a single well with one or more wellbore branches radiating from the main borehole" (Bosworth, *et al*., 1998, p. 14). Such wells are able to thoroughly drain reservoirs both vertically and horizontally, "improve[ing] recovery from multiple zones by commingling production". Early attempts proved unsuccessful, however, in 1953 oil well "66/45", located in the Bashkiria field near Boshkortostan, Russia, became the world's first multilateral well. In total, nine separate well "deviations" were drilled, increasing access to the main oil-producing zone by 5.5 times, and overall production by 17-fold, at a cost of just "1.5 times that of conventional well" (Bosworth, *et al*., 1998, p. 14).

Notwithstanding its economic value, petroleum, existing in its fluid state has advanced the science of geology perhaps more than any other resource on earth. Geology is not solely a solid state science – its principles, processes and mechanics are shaped by fluids and vice versa. Petroleum's mobility within the subsurface and widespread existence has meant few places on Earth have escaped the drill. As discussed by Hedberg, petroleum geosciences advanced the pioneering work of stratigraphers like William Smith and gave geologists a medium to apply rock property data, thus creating a new arm of economic geology (Hedberg, 1973). Structures such as unconformities, which were previously seen as academically interesting peculiarities, became significant indicators of petroleum productivity.

Unlike coal, metal ores and minerals, the exploration, and exploitation of petroleum is only practicable at the surface, creating distance between the geologist and the target. As discussed by Hedberg, by "sucking" oil through small holes located often thousands of feet underground, oil exploration has provided millions of individual stratigraphic records. (Hedberg, 1973). Once interpreted, this geological data can be used as an heuristic device, becoming the geologist's "spirit level" to decipher the heterogeneous subsurface environment. Oilfield technologies, in particular rotary drilling (which opened up the potentialities of horizontal drilling) developed in tandem with geophysics during the early part of the 20th century. By undertaking geophysical surveys prior to drilling (initially gravity and magnetic surveying, seismic refraction and finally seismic reflection) earth scientists were able to explore more subtle, concealed oil traps.

As stated by Smith, "since about 1960 exploration has diversified, reflecting wide-ranging technological innovations…extending into progressively deeper offshore and inhospitable areas" (Smith, 1995, p. 14). Offshore exploration and production in the 1960s onwards (either by way of peiers e.g. Caspian or offshore rigs and platforms) generated millions of ocean drilling results, which significantly increased our understanding of plate tectonics. By the 1980s, work by a French team led by Alpern, Tissot and Welte resulted in petroleum system-seismic imaging-geochemistry (Smith, 1995). This in turn led to the abandonment of large areas for exploration, and a focus more on reservoir analogues, characterisation from core and outcrops and the production of sedimentological models.

Improvements in computers and thus data analysis subsequently resulted in the production of complex three-dimensional seismic models, allowing scientists to visualise deep buried oil deposits. With "conventional" oil reserves being depleted during the mid to late 20th century, geologists began assessing "unconventional" hydrocarbon prospects. For example Smith discusses the recognition of unusual trapping methods, artificial fracturing of sandstones, search for over pressured reservoirs, increasing depths of wells and production from older rocks, amongst others (Smith, 1995, p. 14). Further developments in horizontal drilling and hydraulic fracturing up to the end of the 20th century bring us to our current position regarding hydrocarbon exploration in the 21st century.

2.3: Oil cultures

In May 2012 the *Journal of American Studies* published a "special issue on oil cultures", combining a series of essays from the humanities, which have attempted to reveal the myriad ways that oil has impacted upon American aesthetic practices, cultural forms, and public discourses since the 19th century (Barrett and Worden, 2012, p. 269). In light of peak oil output and recent environmental and ecological disasters (notably the Deepwater Horizon blowout on 20th April 2010) the editors argue it is now appropriate to examine the practices, motivations and conflicts that made the dominance of oil possible.

Until recently, oil histories have focused on the totality of oil, namely, the economic and political (see Clo, 2000; Parra, 2010; Yergin, 2012) dimensions of the industry (Appel, *et al*., 2015). There has also been a preoccupation with the seven sisters, the major international oil companies and the major producing countries (see Sampson, 2009; Yergin, 1990). As stated by Partanen, currently "the twelve biggest oil producers account for around two-thirds of all oil production" (Partanen, *et al*., 2014, p. 129). In 2014 the largest three oil producers included Saudi Arabia (543.4 million tons) the Russian Federation (534.1 million tons) and the US (519.9 million tons) (BP, 2015, p. 10). In the same year the UK produced just 39.7 million tons, representing 0.9% of total global oil production, against consumption of 1.6% of global production (BP, 2015, p. 9-10), which indicates reliance on energy importation. In 2008 the UK produced only 1.2 million tons of oil from onshore fields, indicating the relative insignificance of UK onshore oil when compared to the five largest global oilfields (Ghawar, Saudi Arabia; Burgan, Kuwait; Safaniya, Saudi Arabia; Rumaila, Iraq; West Qurna, Iraq) which hold c. 13 – 70 billion in remaining reserves (Cunningham, 2014, np).

The oil and gas industry is one of the largest, most technically complex and cash rich industries in the world, presenting a daunting prospect for the researcher, who may well suffer from intellectual vertigo (Appel, *et al*., 2015, pp 5-9). The task is further complicated by the secretised nature of the industry and apparent in archival collections, which can make knowing the truth difficult (Barry, 2015). Valued at several trillion dollars and involving numerous actors and agents, it is problematic to attempt to define its limits, since oil is considered to underpin modern cultures and is embroiled in our modern way of life. By concentrating on specific field sites the thesis remains focused on the British East Midlands, unpacking the secrets of a long forgotten period in Britain's oil culture.

British-born historian Timothy Mitchell, whose earlier works on Egypt - *Colonising Egypt* (1991) and The *Rule of Experts: Egypt, technopolitics and modernity* (2002) have been widely cited by historical-political geographers, has developed key themes with reference to oil. According to Mitchell, the shift from coal to oil (which he claims took place definitively in the wake of the Great Depression of the 1930s and was facilitated in large part by that economic collapse) was connected to the development of a particular form of democracy in the West, a form of governance in which the management of the economy, facilitated by a professional cadre of economic experts, became the primary responsibility of the state. According to Mitchell, the rise of oil, with its "fluid and transportable properties" produced a new kind of global politics, so much so that democracy, in its modern formulation, might actually be defined [in a similar way] oil – scarce in some places, abundant in others (Mitchell, 2011, p. 44). Using French theorist Jacques Rancière's work on democracy as his inspiration, Mitchell argues that oil created both the possibility of modern democracy while at the same time defining its limits. Mitchell's book has a global geopolitical perspective; however, it provides an historical interpretation of the rise of oil cultures which relate directly to this thesis.

Establishing global energy nodes involved the triangulation of agreements between the oil companies, the host governments and the industrialised consumer states. Located in areas considered to be politically unstable and economically backward, oil rich countries lacked the technical expertise, market awareness or financial backing needed to exploit the vast subsurface deposits. The oil industry, therefore, was dominated and shaped by a small group of oil companies. Known as the 'Severn Majors' (the collective name given to the main oil companies – Exxon, Mobil, Royal Dutch/Shell, Chevron, Texaco, British Petroleum), these vertically integrated companies "simultaneously owned, produced and transported crude oil and oil products" (Van de Graff, 2014, p. 491). BP was British owned, Royal Dutch/Shell was Anglo-Dutch, while the remaining five were all American-owned. Through numerous "formal cartel agreements, the seven majors restricted the supply of petroleum and controlled oil prices on world markets" (Van de Graff, 2014, p. 491). By the 1940s, this oligopolistic market structure was causing severe tensions between the East (producers) and West (consumers).

This inequality was accompanied by an ill feeling of monopolisation amongst the Eastern host states, who felt that the exploration and exploitation of hydrocarbon reserves was an example of neo-colonialism, following on from the imperialist expansion of the 19th century (Bina, 2013, p. 151). Many concessional agreements with Eastern host countries covered vast areas of a producer's territories and were often owned by a single oil company. Furthermore, the agreements lasted for many years, often extending into decades, for example in Venezuela where a 1950 agreement lasted until 1983/84 (Parra, 2003, p. 10). Aware of the political and economic instabilities of host countries, oil companies, and by proxy the governments of the

Western states, sought to secure returns on their investments, and, ultimately, oil security through the rigorous terms of the concessional system.

Towards the end of the 1940s, the oligopolistic system was showing signs of collapse. In parallel with the demise of colonial power, Eastern oil-exporters began to negotiate increasingly favourable terms in order to capture a larger share of oil profits. Systematically, oil producing countries forced the oil majors into "renegotiations of royalties, taxation and cost cost-sharing schemes" (Van de Graff, 2014, p. 491). Ultimately, these strategies culminated in a series of nationalisations in the mid to late 1970s as the East began to regain control of the oil within its boundaries. Without their own supplies of oil, the Western consumer countries therefore became increasingly dependent on the undemocratic Middle East (Mitchell, 2011).

The three empirical chapters of this thesis systematically examine the aforementioned themes of political and economic instability as well as fears of monopolisation. They also critically examine the spatial and temporal issues which underpin the rationale as to why Britain required a secure domestic supply of oil in the early decades of the 20th century. In doing so the thesis reveals a nucleus of geological experts, whose international involvements in securing oil in the Middle East (and indeed elsewhere throughout the world) were transposed to the problems of securing a British based supply of oil, partly in the wake of diminishing colonial power within oil producing countries. Chapter 6 in particular examines the ramifications of geopolitical unrest in the Middle East, which ultimately resulted in the establishment of British Petroleum's research headquarters in Eakring, Nottinghamshire during the early 1940s.

Oil histories tend to build on and affirm existing knowledge, rather than offer fresh outlooks and perspectives. Earlier studies have often been funded by the oil companies themselves, leading to sympathetic omissions of micro scale phenomena (Salas, 2009). According to Mitchell, oil is often seen in purely economic terms, failing to consider the "processes by which a wider world obtains the energy that drives its material and technical life" (Mitchell, 2011, p. 2). For Mitchell, social, political and economic relationships are "engineered out of the flows of energy" (Mitchell, 2011, p. 5). By considering the interwoven complexities of the British onshore oil industry from the grassroots, this thesis will uncover the "epistemological and material mechanisms through which oil came to establish its contemporary political power" (Knox, 2015, p. 309).

The social and cultural impacts of oil capitalism are discussed by Hanna Musiol in her analysis of the Osage community in Oklahoma, which became the richest community in the world through the sharing of profits from oil mineral wealth in the early 20th century, (Petro) modernity, she argues, had severe implications for the Osages, bringing instability and destabilisation to their culture (Musiol, 2012). Oil modernity can bring "solidity" - social stability at the macro level but "liquidity" - uncertainty and fragmentation at the community level. These differing states of cultural fluidity may, Musiol asserts, exist simultaneously within "different geopolitical spaces" ultimately leading to the liquidity of the micro undermining the solidity of the state (Musiol, 2012, p. 359). The juxtaposition of solidity and liquidity is applicable to much of early 20th century British debate on coal to oil modernity. Just as coal had replaced wind, water and wood energy in the 18th century, the notion of oil replacing coal sparked conflict and controversy over supply shortages and national security. Coal was physically and metaphorically "solid", whereas oil's liquidity extended to supply, control, distribution and scientific understanding.

The 2012 special addition of the *Journal of American Studies* led to Barrett and Worden's book, *Oil Culture*, which draws together a series of essays that investigate the cultural discussions that have, in recent years, begun to examine the oil culture nexus, considering oil as both a natural resource and trope (Barrett and Worden, 2014). The 20 essays, categorised under five sub-headings, serve to propose oil's dominance as part of a cultural, rather than economic or physical necessity. Allan Stoekl's foreword elucidates that:

"Oil is natural in the sense that no one put it there in the ground: it is the result of natural processes, the arrested decomposition of plant and organic matter over millions of years". And yet, the upstream and downstream processing, which includes the pumping, the refining, the grading, the distribution, the use in transport, manufacture, heating, the generation of electricity – is fully cultural "…oil is the ultimate natural-cultural artefact" (Stoekl 2014, xii).

Oil, in its raw, natural, viscous state, located deep within the earth's crust where it cannot be seen, is largely taken for granted. We are all aware of oil, however, which "gives oil a curious valence in the cultural imagination – it is foundational and ever present, yet it is also secreted away" (Barrett and Worsden, 2014, p. xvii). The political, economic, scientific and technical aspects of the oil industry are important, yes, however, as Stoekl states, "we need to do more: we need to understand, given the centrality of oil, its weird natural/cultural status, what oil has been in history, and what will be: politically, culturally, aesthetically, historically" (Stoekl, 2014, p. xiv).

The historiography of British oil has, until now tended to focus on the North Sea oil and gas industry, for example Alex Kemp's *The Official History of North Sea Oil* (Volumes I and II), Bill Mackie's *The Oilmen: The North Sea Tigers* and Cresswell's *Conversations with North Sea Oil Moguls* (Kemp, 2004a/b; Mackie, 2004; Simons, 2005). British oil policy and Britain's relationship with international oil companies has also been examined, for example see McBeth's *British Oil Policy 1919-1939* and Charles More's *Black Gold: Britain and Oil in the Twentieth Century* (McBeth, 1985; More, 2009). The Shetland Islands has received attention also, with John Button's (1979), *Shetland Way of Oil: Reactions of a Small Community to Big Business* chronicling the discovery of oil which was, at the time hailed as the UK's second Industrial Revolution, placing Shetland at the centre of a new economic geography for Britain (Byron, 1983).

Of the period examined during this thesis, only one text, *The Secret of Sherwood Forest: Production in England during World War II* investigates in any great detail, the events which unfolded in Eakring, Nottinghamshire during World War Two (Woodward and Woodward, 1973). This book was constructed using the archive collections of private American companies, and through the oral testimonies of individuals. However, the book is written from a triumphant perspective, seeing the episode through an American lens, which undermines the significance I assign to the British experts who discovered, and latterly developed the Nottinghamshire oilfields.

2.4 Vertical geopolitics: territory in the third dimension

Exploration has historically been held as a horizontal, flat, lateral pursuit which "ignores the vertical dimension and tends to look across rather than to cut through the landscape" (Weizmann, 2012, p. 3). Naylor and Ryan's 2009 collection of 20th century exploratory case studies includes a chapter by Fraser MacDonald on space exploration. As a precursor to rocket propulsion, MacDonald discusses the role of the hot air balloon in providing a bird's eye view of the earth for primitive remote sensing, thus approaching notions of vertical territory from above (MacDonald, 2010, pp. 196-221). Aside from Bruce Braun, who has discussed the vertical geographies of geology and governmentality in Victorian Canada, and Simon Naylor, who has looked at the developing role of geology in Cornwall, few historical studies have emphasised the intimate relationship between the exploratory sciences of geology and geography (Braun, 2000; Naylor, 2011). Geographers have traversed the earth for centuries, exploring and documenting the intimate relationship between people and place along the land surface.

Space exploration has a well-documented 20th century history, becoming deeply embedded in western discourse through such authors as H. G. Wells, Herman Oberth, Luigi Gussalli, Konstantin and Tsiolkovsky, as well by the British Interplanetary Society (BIS), which published a proposed manned mission to the moon. In relation to the latter, Oliver Dunnett, has investigated the institutional and cultural developments of the BIS in order to assess how cultural geography has begun to reengage with 20th century outer space as a field of enquiry (Dunnett, 2011).

Whilst space exploration has received attention from a plethora of perspectives, curiously, the geographies of exploration within the earth's atmosphere, and in particular in the subsurface has received little attention from geographers. Traditionally, exploration tied to the terra has advanced from the exterior to the interior of surface territories using natural features in the landscape to locate new spaces and places (Naylor and Ryan, 2009). Traditional cartographies aim to recreate topographic, political and economic boundaries using features found at the land's surface, rather than looking through the landscape in the third dimension. As stated by architect Eyal Weizman, the tendency to map in a single plane has historically been determined by military and political spatialities (Weizman, 2002). Nation states have, Weizman asserts, quantified place in terms of two dimensional maps and plans, assuming claims to surface territories are mirrored in the subsurface. This, however, is clearly not the case (Weizman, 2002).

In recent years[1], scholars have begun investigating conceptualisations of 'verticality' in relation to power, sovereignty and territory, rightly asserting "territory [is] now in 3D!" (Bridge, 2013). For example, as highlighted by Weizman "frontiers are deep, shifting, fragmented and elastic [and] not limited to the edges of political space but…throughout its depth" (Weizman, 2012, p. 4). These subsurface geographies are "ripe for exploration, exploitation, and, inevitably, controversy and preservation" (Kroll, 2008, p. 194). In attempting to tackle these broad themes, critical geographers have investigated subjects such as warfare, surveillance, urban design and planning, and the ordering of vertical territory. Vertical geopolitics is concerned with spatial aspects existing beyond the traditional flat map of the world (Mahony, 2013, np). Mahony (2013, np) argues the notion of vertical geopolitics is receiving increased media attention due to new technologies of surveillance and violence, including the military use of drones to gather intelligence or carry out assassinations.

Recent studies of vertical geographies have tended to focus on air space (the up) rather than the subsurface (the down). Adey, for example, has looked at how the airplane has affected human development over the last century, creating aerialised societies or "aerealites" (Adey, 2010). Using a series of case studies Adey demonstrates how the mobilisation of humans into above ground spaces has shaped society, from effects on the human body at an individual level, to concerns relating to modern day international terrorism at the geopolitical level (Adey, 2010).

Adey, *et al.*, show how verticality is today at the heart of modern warfare, security and politics with new wars fought from the sky using increasingly advanced technologies (Adey, *et al.*, 2011). As examined by Bishop, the air and the subsurface have become intimately entwined over the last few decades (Bishop, 2011). Modern weaponry is now capable of destroying almost all surface buildings, forcing individuals underground where such weaponry becomes ineffective. Military tactics now seek to overcome the limits of underground impregnability using high tech remote sensing and imagery. For example, Bishop discusses how the American Defence Advanced Research Projects Agency (DARPA) has developed a defence initiative called "Transparent Earth" which is able to read subsurface geographies. Bishop asserts "more

[1] For example, on 8th December 2010 a conference entitled "Vertical Geographies" was held at Royal Holloway University of London Department of Geography which drew together a plethora of themes ranging from aerial surveillance to atmospheric sciences and urban design.

than half a century of advanced satellite episcopy has rendered the surface of the earth consistently and constantly visible and resulted in the concomitant defensive move to underground weapons systems, battlements and sites" (Bishop, 2011, p. 272) .

Weizman provides perhaps the best starting point to understand vertical geographies in the subsurface. Using the Israeli-Palestinian conflict as his case study, Weizman demonstrates how the battle over the West Bank is a three-dimensional struggle involving the built and natural environment (Weizman, 2002). Using the Oslo Interim Accord as one particular example, Weizman explains how "the Palestinian authority was given control over isolated territorial "islands", but Israel retained control over the airspace above them and the sub-terrain beneath" (Weizman, 2002, np). This political arrangement created "homogenised enclaves located next to, within, above or below each other…layered with strategic, religious and political strata" (Weizman, 2002, np). This resulted in the formation of intricate new frontiers, each one adding their own agnostic potentialities to an increasingly bisected landscape.

Elden argues that territories, understood from a geographical perspective, have historically ignored the height and depth aspect of space (Elden, 2013). The world, states Elden, "Does not just exist simply at the surface, nor should our theorisations of it; security goes up and down; space is volumetric" (Elden, 2013, p. 15). Historically, the subsurface has played an important role in the movement of people and the establishment of administrative systems for the governance of vertical territory. Scott discusses the implications of mining in the development of "colonial underground" during the 16th century, calling for increased attention to subterranean spaces as arenas of European imperial and colonial expansion (Scott, 2008, p. 1853). The geological qualities of the subsurface were ultimately responsible for the establishment of communities, thus giving surface landscapes colonial meaning. As fossil fuel consumption increased during the 17th, 18th and 19th centuries, exploration increasingly incorporated vertical as well as lateral territory.

"Underground geography" (subterranean geography) was in fact referred to in the 18th century (Ellenberger, 1999). Then known as "mineralogical geography", it was "absolutely necessary to imagine in a rational manner the architecture of the internal structure and to visualise the disposition of things at depth and in three-dimensions" (Ellenberger, 1999, p. 47). Scott draws attention to this period, using a mining plan and petition presented in Lima, Peru in 1790 to demonstrate how Spanish American cartographic cultures have overlooked mining maps, which, Scott argues, brought enlightened order and reform to Peru's mining spaces (Scott, 2015, p. 7). In Britain, territory began to incorporate vertical spaces, as surveyors, mineral agents, landowners, entrepreneurs and scientists began to investigate Earth's inner architecture, reconfiguring the field site into places in which to objectively and empirically record scientific truths (Braun, 2000). Large scale construction projects including canal and railway building during the late 18th and 19th centuries opened up vast swathes of vertical territory, allowing the likes of William Smith and Georges Cuvier to "[recognise] and [interpret] the physical, biological, and chemical properties of strata" thus creating geographically as well as geologically sited epistemological field sites (Embry, 2010, p. 35).

Geology and geography became institutionalised and intellectually divided during the late 18th and early 19th centuries as autonomous agencies (Ordnance Survey, 1791; Geological Society of London 1807; Royal Geographical Society, 1830; British Geological Survey, 1835) were created with the remit of either surface (geography) or subsurface (geology) cartographic production. However, mapping Earth's inner architecture brought frequent interdisciplinary intersections. Taken together, geography and geology aim to provide Earth's x, y, z coordinates. As discussed by Elden, tied to territory is "ownership, exchange and use value, distribution, partition, division [which collectively give rise to] notions of jurisdiction, authority, sovereignty, superiority [and] administration" (Elden, 2013, p. 1).

Understanding the spatial extent of the underground depends upon the effectiveness of technical advances in geological science. Drawing on Foucault and Martin Heidegger to illustrate the political-technical dimension of territory, Elden argues that developments in geometry "[made] possible large-scale cartographic and land-surveying projects that contributed to the modern sense of territory" (Elden, 2013, p. 1). As well as two dimensional cartographies, advances in maths and geometry led to the production of three-dimensional models for educational and economic purposes. For example, cabinet maker turned surveyor Thomas Sopwith (1803-1879), famed for his 1834 book *A treatise on isometric drawing as applicable to geological and mining plans* drew accurate geological and mine plans in three-dimensions in the early 19th century. His models, made during the late 1830s and 1840s, were valuable inscriptions, being "some of the most sublime of three-dimensional geological teaching aids of all time (Turner, 2011, p. 1).

The role of geology, and the geologist, in British society evolved as industrial needs demanded. Western science discourse was a reflection of prevailing Whiggish tradition, which had a "tenacious hold on science as individuals attempted to discover and record facts for prosperity and progress" (Gohau, 1990, p. 5). Numerous geological field excursions brought "verticality" to the attention of the state, enabling a better understanding of the qualities of subsurface territory, which in turn optimised resource extraction. According to Braun, "At the end of the nineteenth century the physical spaces daily transformed by mining were intricately intertwined with the epistemological spaces opened up by the discourse of geology" (Braun, 2000, p. 14).

Like geography, geology is concerned with the ordering and mapping or 'geo-coding' of space and the production of knowledge, which was central to the formation of modern government (O'Tualhail, 1996; Pickles, 2004; Rose-Redwood, 2006). By the 19th century the state had become governmentalised and "developed an ensemble formed by institutions, procedures, analyses and reflections…the calculation of tactics” (Foucault, 1991, p. 102). Part of this process involved the establishment of the Ordnance Survey (OS), which was formed in 1791 and charged with producing maps on a scale of one-inch to the mile of the British Isles. From the late 18th century the British Government began to recognise that the growth of the British Empire depended on the proper use of geological resources, in particular the staple minerals iron and coal.

Britain’s prevailing laissez-faire politics in Victorian Britain meant private enterprise was responsible for rudimentary, site specific geological mapping (Bate, 2010). Impetus for a state-controlled British Geological Survey was provided by Henry Thomas De la Beche, who secured funding from the Board of Ordnance to map the geology of Devon on a scale of one-inch to the mile. The resulting eight maps (producing from 1832 to 1835) formed the basis on which to formulate an argument for a comprehensive nationwide survey. De la Beche’s vision of a state-funded geological survey was bolstered by the Geological Society of London (established in 1807) and Lt. Col. Thomas Colby, Superintendent of the Ordnance Trigonometrical Survey who sought to increase the utility of geographical maps by adding geological data (Bate, 2010). At a rudimentary level the production of accurate geological maps necessitated the production of accurate topographic base maps – a prerequisite still central to modern geological mapping.

The BGS, established in 1835 thanks to the vision of De la Beche, created a model of subsurface exploration that was emulated throughout the world (Cook and Allen, 1992; Bate, 2010). It became a powerful instrument to enable the state to view its vertical geographies, so that it could make rational decisions on how to manage and control the vertical as well as lateral territory contained within its boundaries (Murdoch and Ward, 1997). In Britain, from the mid-19th century onwards planar divisions of the earth began to be supplanted by three-dimensional boundary representations cutting through sovereign blocks of territory, “[redefining] the relationship between sovereignty and space” (Weizman, 2002, p. 108). By re-visioning cartographic production from the second to third dimension a holographic representation of territory is created, enabling earth scientists to better understand the qualities of territory and the location of valuable mineral deposits including coal, iron ores and ultimately oil.

According to Crawford (2002), late nineteenth-century scientific enterprise contributed to the rise of the nation-state in Europe. Scientific internationalism, Crawford (2002), argues, occurred when economic relations, transport and communications began to transgress national boundaries. Doel (1997, p. 400) elucidates that geological science was still orientated towards “applied problems in surveying and mining” at the start of the 20th century and claims that “neither ‘geophysics nor the earth sciences’ connoted a distinct field of research nor a common set of instrumental techniques”. Crawford (2002), argues that the founding of the Nobel Prize in 1901 signalled the age of scientific internationalism. In the same year Emil Wichert established the Geophysichalisches Institut in Göttingen, Germany. In England, Cambridge University began to apply physico-mathematical approaches to geology, with resulting in developments within geophysics (Doel, 1997).

The amalgamation of disciplines in geological science during the 20th century gave rise to new branches of science. Good (2002, p. 229), argues that following World War two, specialisation within geology increased and with this came "distinct research areas…over several decades: the geodynamo theory and the study of the core-mantle boundary; palaeomagnetism and its growing connection to geology; the production of induced fields in Earth's crust; and, among others, the electromagnetic phenomena of the upper atmosphere and near space". As stated by Oldroyd (2002, p. 4), "submersibles and aeroplanes became useful tools in the progress of geology, complementing the hammer, microscope, field survey, instruments, etc." These technological advances, in addition to the increasing use of computers, gave rise to the fusion of formerly disparate specialisms including meteorology, oceanography, seismology geodesy and geophysics (Good, 2002). These developments had a profoundly spatial dimension, along a vertical axis, with space science and aeronomy looking beyond planet earth, to the Moon and planets (Oldroyd, 2002). The earth sciences, geophysics in particular, were marked by a move towards collaboration and knowledge exchange in a new age of scientific internationalism.

On 28th July 1919 the International Research Council formalised the International Union of Geodosy and Geophysics (IUGG) "as an international, non-governmental, non-profit organisation" (Ismail-Zadeh and Beer, 2009, p. 493). This was followed by the American Geophysical Union "European Geosciences Union and the Asia Oceania Geosciences Society" amongst others (Ismail-Zadeh and Beer, 2009, p. 493). These institutions were primarily interested in understanding the location and interplay between boundary layers existing within and between the earth's crust and atmosphere. The most important episode in the internationalism of geophysical science occurred from July 1957 to December 1958. This 18 month window coincided with elevated sunspot activity, during which over 30,000 scientists from over 70 countries established research stations to record earth science processes. The post war era saw earth scientists attempt to reconnect scientific networks. This was of particular importance for geophysics, where close consultation and interdisciplinarity "were prerequisites in [a] field which knows no national boundaries" (Nicolet, 1982, p. 222).

The International Geophysical Year (IGY) aimed to study…"all the physical forces on our planet" by conducting research across 11 earth science disciplines (including gravity, geomagnetism and seismology) collecting geophysical data which was subsequently assembled in World Data Centres (Martin, 1957, p. 7). The IGY resulted in the discovery of Van Allen radiation belts, improved understanding of space exploration as well as Arctic and Antarctic polar regions and, importantly, gave rise to the theory of plate tectonics which became extremely important in the exploration of hydrocarbons at continental margins.

Moving to the 21st century, developments in sophisticated computer modelling programmes have shifted the emphasis and ethos of cartographic institutions from mapping to modelling, unifying surface and subsurface phenomena (Smith, 2005). Moreover, modelling programmes allowed geologists to analyse, interrogate, manipulate, interpret and evaluate subsurface spaces using features such as vertical exaggeration, exploded views, unit isolation and section slices. In this way, they can recreate underground geographies in distant computer modelling suites and reconfigure static, two dimensional geology maps into three-dimensional block units representing Earth's inner architecture (Ford, *et al*., 2010). Computer modelling must be considered as the logical successor to traditional geological cartographies. The geology/geography interface presents a new and exciting opportunity for geographers to apply the principles, processes and philosophies of geographic discourse to the ordering and governance of subsurface space.

2.5 Actor Network Theory (ANT) and case study approaches

This thesis draws together a series of case studies and examines how key individuals operating within the British East Midlands circulated, translated and mobilised petroleum geoscience. By examining how earth scientists moved within and between scientific institutions, political centres, landed estates and company board rooms the thesis chronicles the events that latterly extended petroleum geoscience beyond the confines of the two field sites examined to gain intellectual provenance at the national and international levels.

The British East Midlands have acted as a place where scientific truth was validated and where local credibility in the global field of petroleum geoscience was produced and maintained (Ophir and Shapin, 1991). By shedding light on the anthropology of science and technology the thesis aims to reveal the spatialities of scientific practice and demonstrate how "the place of knowledge [was] fully imbricated within networks of power relations" (Powell, 2007, p. 312). Scientific observers are not merely solitary actors picking ideas from the ether in a world where science is pragmatically universal. Rather, Ophir and Shapin (1991) argue, meaning is situated and ideas tied to places, space and time. The architecture of places, they intimate, can by understood by studying "historical actors' practical activities in context" (Ophir and Shapin, 1998, p. 6).

Shapin, writing in 1998, argued that we were then more than two decades into the "geographical" turn within science studies, which is today providing rich interdisciplinary perspectives on the spatialisation of science and indeed the spaces science itself creates. Central to this "geographical sensibility towards science" is, Shapin argues, "[needing] to understand not only how knowledge is made in specific places but also how transactions occur between places" (Shapin, 1998, pp. 6-7).

The two most prominent historical geographers emphasising the importance of geographies of science today are David Livingstone and Charles Withers. Livingstone argues geography shapes the conduct and context of science (Livingstone, 2003). For Livingstone, geography affects whether or not knowledge claims are accepted or rejected, how scientific methods and apparatus are standardised and how ideas are circulated – indeed, he argues, "the spectrum of scales from particular sites through regional settings to national environments, the "where?" of scientific activity matters a good deal" (Livingstone, 2003, p. 3).

Science is a mobile and fluctuating entity which reflects local, regional or national phenomena. Livingstone argues that the meaning of science "takes shape in response to spatial forces at every scale of analysis – from the macropolitical geography of national regions to the microsocial geography of local cultures" (Livingstone, 2003, p. 4). In the East Midlands, the presence of anticlines – geological features in the landscape often indicating areas of petroliferous potential – led to scientific enquiries based on the transposition of exploratory paradigms from America and Iran (Smith, 2002a).

Geographies of science have been studied in various ways, for example Ogborn and Withers have examined 18th century (Georgian) geographies, adding to a growing literature on 18th century studies questioning themes relating to space, place, scale and territory (Ogborn and Withers, 2004). Withers has studied how the Enlightenment can be understood geographically, arguing that the geographical aspect - the "where," has often evaded "historians, literary scholars and others [in preference for the] "what," "when" and "why" (Withers, 2007, p. xi).

Moving into the 19th and early 20th century, Withers has also explored the urban and regional settings in which the BAAS held its annual meetings, as it aimed to promote civic science as a cultural good (Withers, 2010). In 2011, Livingstone and Withers edited a volume, drawing together a broad and diverse array of essays examining the geographies of 19th century science, including the geographies of civic science, of museums, the spaces of London science, the distribution and circulation of French science books, and the significance of museums in the formation of material culture and identity. As intimated by Elliott (2009, p. 5) "the special qualities of civic science exemplified by museums, libraries, botanical gardens and mechanics' institutes" have revealed the importance of civic science within the urban scientific culture of 19th century Britain in helping "[foster] local, regional and national identities".

The purpose of Withers and Livingstone's volume is, they argue, to demonstrate how science is spatialised as "mappable locations…each site [being embedded] in wider systems of meaning, authority and identity" (Livingstone and Withers, 2011, p.5). Withers argues that "science everywhere bears the imprint of local circumstances" (Withers, 2010, p. 4). Science is "not a standard enterprise…it reflects local conditions in its making. [Moreover it reflects and directs] particular social and political interests in those localities" (Withers, 2010, p. 4). This is supported by Naylor who argues that historical geographers have shown how "place plays a major role in the development of particular sorts of science, not to mention the developments of particular sorts of scientists" (Naylor, 2005, p. 5).

Focussing on Cornwall, which at the time had the world's largest copper ore output, Naylor later shows how, in the 19th century, geological cartographies became valuable tools to visually depict deposits in the subsurface, as well as project land ownership both above and below the ground (Naylor, 2011). They were, therefore, "valuable tools in the enhancement of the capital value of the land" (Freeman, 2004, p. 123). Naylor argues that the Royal Geological Society of Cornwall (RGSC), the first provincial geological society in Britain, encouraged its members (gentlemanly elites who had a significant bearing on the content of the maps produced) to map the region, providing some of the earliest regional geology maps of Britain. These maps added to 19th century visual cultures, becoming an "important part of science's complex visual economy" (Naylor, 2011, p. 345). Cornwall's early geology maps also expressed "proprietorship - over places and resources [guiding] the reader around an enclosed and owned landscape; they were texts that spoke to others and excluded others" (Naylor, 2011, p. 346). Moreover, they "were employed to express proprietorship and authority over economic and intellectual territories" (Naylor, 2011, p. 346).

In his monograph *The Derby Philosophers*, historical geographer Paul Elliott "tries to 'place' Derby scientific culture within its national and international contexts" (Elliott, 2009, p. 3). Elliott discusses how geological study in Derbyshire was stimulated in various ways, including industrial activity, mineral extraction (in particular lead), agriculture and manufacturing, fossil and mineral collecting, a growing tourism trade, the Derbyshire springs and "Wonders of the Peaks tradition". As a consequence, "by the 1820s, with its varied geological and topographical character, Derbyshire was one of the most comprehensively surveyed and studied counties in Britain" (Elliott, 2009, p. 192).

Scientists from Derbyshire thus translated the geological qualities of the region into a "space of governmentality", a place that was interrogated in order to provide empirical geological evidence to support geological theories and to produce geological specimens for collecting and facilitating targeted mineral exploration/exploitation. By promoting geological study the Derby philosophers bridged "the interface between national and provincial science" (Elliott, 2009, p. 192). Significantly, the area's unique geology framed it as being different to its neighbours and was a key driver behind the commercialisation of geology in Britain in the 19th century (Walker, 2003, p. 12). The region's uniqueness attracted geologists to join the Literary and Philosophical Society, give lectures and donate works which resulted in an extensive collection housed within the Philosophical Society Library (Elliott, 2009). This burgeoning literature and detailed scientific understanding would latterly be interpreted by earth scientists searching for domestic oil long into the 20th century.

As elucidated by Shapin, "the grand narrative of inherent scientific universality deflected attention away from place (Shapin, 1995, p. 306). In order to obviate mundane, localist perspectives, Simon Schaffer encourages us to "distinguish between the process of "localisation", through which local techniques get to work at sites like labs via the concentration of widely distributed resources, and "spatialisation", through which techniques which are efficacious within the lab, manage to travel beyond it" (Schaffer, 1991, p. 190). Elliot discusses how the study of individual places can enrich sweeping generalisations, though he warns that "so-called local history, cannot be studied without constant attention to international as well as national events" (Elliott, 2009, p. 3).

In recent years geographers have begun to analyse how "individual agency, the one-off action, the local become sites for a consideration of wider issues, using the particular to explore broader societal and historiographical themes" (Short and Godfrey, 2007, p. 46). This approach could present a naïve regionalism; however, a focus on small scale case studies can demonstrate how scale develops into the "manufacture [of] things like economics, empires, institutions, discourses, knowledges", for Naylor, small scale case studies are "as good a starting point for our investigations as any" (Naylor, 2008, p. 266).

The interconnected cases I investigate during the course of this thesis ultimately enable a "historical geography of geographical knowledge" to emerge (Withers, 2001, p. 1). As previously stated, case studies run concordantly through this thesis. A "case" defines an event(s) which changes history, and is conditional on its relative position in a sequence of interrelated cases (Bearman, *et al*., 2003). By combining individual cases, a population of events transformed a narrative into a network of flowing causation. Case study approaches can be traced back to social anthropologists, whose methodological approach was/is to isolate, analyse and interpret small social fields or sub groups contained within a larger social system.

Since the 1990s there has been a move to rethink the history of geography using the field site to shed light on the "repositories of meaning that facilitate communication" (Driver, 1995; Livingstone, 2003, p. 4) through the permeable membranes of scale. Micro historiographical analysis enables the examination of intricate relationships between people and places, mobilising the hidden histories of Britain's hydrocarbon culture and presenting the grass roots developments behind the corporate facades of the multinational oil companies.

Geographers are placing increasing emphasis on the field site, "[developing] reflexive interpretations of the spatialised knowledges and embodied protocols concealed within geography's field cultures, be they academic or amateur in origin" (Lorimer, 2003a, p. 201). Micro-historical analysis, when applied to the oil industry, provides a means of understanding the "strategy from below" through the collective configurations of actors, nature and society, which give rise to governable domains (Valdivia, 2008; Lovbrand, *et al*., 2009).

By understanding the ways in which people and places interact at the micro scale, we are given the opportunity to map new trajectories of place and practice. As Withers points out, "If we are to understand in a particular historical context the spaces in which geography, however understood, has been produced, consumed and negotiated, we should not uncritically privilege the academic in considering the sites of its making and consumption" (Withers, 1999, p. 46). Lorimer (2003a, p. 200), argues that micro histories..."allow [an individual] to uncover in the transient experience an intricate network of geographical knowledge and action, while exploring traditions of field practice in an identifiable period from geography's past – that of the regional episode".

By tracing the development of a succession of field sites, the thesis will identify key constituent assemblages, which taken in collaboration, result in macro-phenomena. Investigating the local provides a contemporary perspective combining myopic detailing with panoramic projections of cause and effects (Short and Godfrey, 2007). Moreover, it addresses a fundamental question of geographers - how and why does knowledge circulate? Knowledge in transit is increasingly becoming a governing concern in the studies of science, for example Secord argues "It is not so much a question of seeing how knowledge transcends the local circumstances of its production but instead of seeing how every local situation has within it connections with and possibilities for interaction with other settings" (Secord, 2004b, p. 664).

This notion of actors and actants, based on the study of heterogeneous social and technical relationships developed within Science and Technology Studies (STS) during the 1980s. Bruno Latour, Michel Callon and John Law used the "relational thought of philosopher of science, Michael Serres and the materialised post-structuralism of philosophers Michel Foucault and Gilles Deleuze" to form Actor Network Theory (ANT) (Gregory, *et al.*, 2011, p. 6). Combining conceptual approaches, ANT is an analytical approach that seeks to trace the associations and relationships of heterogeneous elements through a network (Gregory, *et al.*, 2011). It serves to examine how human and non-human actants are arranged, constructed and maintained. Conceptually, ANT offers a toolbox of concepts, which, when brought to bear on empirical studies, can reveal how order and disorder emerged in a "more-than-human world" (Müller and Schurr, 2016, p. 226). ANT assumes no priori distinction between technical and non-technical. Emerging from the achievements of disparate, distributed achievements, ANT proposes that the association of human and non-human actants as a whole is more than the sum of its parts (Müller and Schurr, 2016, p. 217).

ANT places subjects (human and non-human) and characteristics of a network under scrutiny. According to Müller (2015, p. 30), it conceives that atoms (micro) to governments (macro), all "stand on equal ontological footing to begin with (and that) the associations established between them make the difference of whether one becomes more powerful than another". ANT attempts to breathe life into inanimate objects and provides them with agency within a network. In order to put forth his notion of agency, Latour uses the example of scientist Louis Pasteur in his book *The pasteurization of France* (Latour, 1993). As discussed by Dunnett (2012), Latour shows how Pasteur brought "culture" and "nature" under one roof as he conducted experiments into animal vaccinations. By re-locating parts of the farm into the laboratory for testing, Latour demonstrates the hybridity of the scientific network and the flow of knowledge from one location to another. As the subject of Pasteur's research, bacteria are given agency, as "human beings are not the sole purveyors of agency in our world: objects such as Pasture's bacteria are given agency, just as the scientists who have produced them" (Dunnett, 2011, p. 46).

As discussed by Gregory *et al*., (2009, p. 7), agency is a consequence of the "relational effect that is the outcome of the assemblage of all sorts of social and material bits and pieces". As a mobile liquid energy, located often thousands of feet below the land surface, the physical and chemical characteristics of oil gives it unique spatial agency, requiring multiple human and non-human actants to locate and extract it. For example, understanding the spatial location of oil within the subsurface means scientific results, derived from the actions of humans using pieces of oilfield equipment must be taken to 'centres of calculation', such as the BGS in the form of 'inscriptions' – graphs, tables, maps, physical samples and so forth for post field analysis. Scientific research, generated through the use of scientific instruments (non-human) can, through the marshalling of human actors, 'localise the global' and 'redistribute the local' (Latour, 2005).

ANT states that knowledge production occurs through what Bruno Latour (1987, p. 223), terms "cycles of accumulations". Using cartography as one case study, Latour shows how one explorer will be sent into the field to gather information on a new region using a range of scientific apparatus before returning to a 'centre of calculation' - a venue in which knowledge production is deposited - for example the laboratory or parliamentary office with a map of said region. When a new explorer is sent into the field to gather additional knowledge he/she will use the previous map as the bedrock for new studies. On the explorer's return additional scientific lithologies will have been added, thus creating 'cycles of accumulation'. The map, which becomes known as an 'inscription' is generated using 'inscription devices', which Latour and Woolgar (1979, p.51) state are "any item of apparatus or particular configuration of such items which can transform a material substance into a figure or diagram". These inscriptions/inscription devices become enrolled into the network as active "actants" holding equal importance within the burgeoning network as their human operators.

A 'cycle of accumulation' is a profoundly geographical process insofar as the geoscience praxis associates technologies with a place, such as a field site, laboratory or scientific research institution. To be oil-dependent is to be globally connected. Developments in oilfield technologies have, throughout the 20th century been largely responsible for our understanding of the subsurface, creating multiple social, cultural, economic, political and scientific networks. Exploiting oil reserves involves human operators using high tech geophysical equipment to analyse, interpret and interrogate data as well as direct and locate drill bits, strings and casings. The drill string itself can be viewed as a vital "actant" linking human and non-human 'actors' in a complex and entangled web of relationships which form a network. These actor networks are, therefore, the mobilising forces behind actions and developments, rather than humans or non-humans treated in isolation (Gregory, *et al*., 2011). Oilfield technologies (drill strings in particular) located in distant territories, either on land or at sea serve as umbilical cords linking surface with subsurface worlds and tying the technoscience of the oilfield (local) to the fundamental wants and demands of 21st century society (global).

Concepts such as *cycles of accumulation* and *inscriptions* allow empirical research to "make sense of the formation of associations" (Müller, 2015, p. 31). They also dovetail with the episodic nature of oil exploration in the British East Midlands, in particular the sedimentation of knowledge accrued and later revisited over the period examined. As the thesis moves from one case study to the next a legacy of geographic/geological knowledge becomes transposed onto the next case. The end product of oil exploration is, quite obviously, oil. It is of crucial importance, however, not to forget the layers of inscriptions and cycles of accumulation that lead to oil finds. As Jones (2005, p.3) argues "while much attention is being paid to scientific representation at the final level, the intermediate process of scientific representation – the making of inscriptions through photographing, editing, tabulating, or simulating – is often overlooked".

The exploration and extraction of coal during the 17th, 18th and 19th centuries was carried out by colliers able to physically access deposits at relatively shallow depths. In the 20th century, the vastly magnified depths at which oil tends to be found, led to advances in geophysical methods, including magnetic, electrical, and gravitational (Doel, 1997), to probe the earth to remotely locate oil-bearing structures. The first and most notable gravitational probe was the torsion balance, "devised by the Hungarian experimental physicist Baron Roland von Eötvös" (Doel, 1997, p. 401). Offering increased instrumental sensitivity, the first gravimetric survey was undertaken in Czechoslovakia in 1915, followed by surveys in the US in 1924, before the widespread adoption of the gravimeter in around 1930 to 1935 (Eckhardt, 1940). Its widespread implementation made the torsion balance a vital link in the assemblage of geological knowledge production and an 'agent' operating within a hybridised, co-constitutional network of human and non-human actants.

As oil technoscience intensified over the 20th century, increasing numbers of earth scientists became engulfed within a rapidly extending oil-network, drawing scientists (human agents) once located at the periphery of the network, into the core, which subsequently grew more advanced. As discussed by Castree, *et al*., (2013) "while humans possess unique attributes and are able to construct their own linguistic, symbolic, and physical worlds, Latour [insists] they are also continually dependant on a myriad of non-human 'actants' for their daily survival and for new ventures'. This thesis will trace the processes by which these associations are built, maintained and severed (Müller and Schurr, 2016, p. 218; Callon, 1986). These processes are inextricably linked to human actions, aspirations and desires. The following section, therefore, will investigate how geobiographies can add sensitivity to ANT, acknowledging that socio-material relations often emerge through the individual or collective emotions of human protagonists.

2.6 Geobiographies

This thesis sheds light on the professional lives of a series of previously unknown and largely ignored individuals, whose collective experiences resulted in the discovery and subsequent political, scientific and technical development of onshore oil exploration and exploitation in the British East Midlands, over a period of almost 60 years. By drawing together their spatial life-stories – recollections of place from memory – a complex regional oil biography emerges. Collective life-stories may be described as geobiographies which, according to Karjalainen, are the expression of the courses of life as they relate to the places lived", each being "deeply personal and complexly memory-laden" (Karjalainen, 2003, pp. 87-88). Thomas suggests "there is a need to cast biography in geographical terms and not to shy away from reconstructing the experience of individual lives within both a historical and geographical context" (Thomas, 2004, p. 498).

McGeachan, *et al*., argue that:

"Attending to the spatialities of a life also encourages a stronger focus on what might be called the more-than-human assemblages which constitute that life. Thinking about subjects through particular spaces or places can help to draw out the influences of the other factors and agents…A geographical focus on biography reveals that the sites of a life are never hermetically sealed but always composite, hybrid spaces, which extend spatially and temporally from their settings in lines which interweave. Lives are spatial, so their telling should reflect and embrace this. The lives of subjects are also thoroughly entwined with the lives and biographies of other things, and this too, should, where appropriate, be a feature of life-writing" (McGeachan, *et al*., 2012 pp. 178-179).

Daniels and Nash explore the intertwined relationship between biography and geography, arguing that "the arts of geography and biography appear closely connected; life histories are also, to coin a phrase, life geographies" (Daniels and Nash, 2004, p. 49). Geography and biography, Daniels and Nash (2004, p. 49) argue, share a long tradition, such that by the "end of the 18th century exploration had become established as a mode of autobiography, in journeys of observation and introspection, in pursuit of knowledge and self-knowledge." They also draw attention to 19th century geobiographies, when biographical dictionaries served as "monuments to late 19th century liberal nationalism" and demonstrate how "life history, plotted as "a story of self-reflection and self-improvement, has been deployed as a method of social investigation and reform, becoming a paradigm of early 20th century American urban sociology" (Daniels and Nash, 2004, p. 49). It is important to "situate individuals under consideration within their wider worldly context" (McGeachan, *at al*., 2012, p. 170). This is corroborated by Hayden Lorimer, who states that rather than narrate a subjects life as a "fixed arc that begins, happens and ends", we should "narrate subjects entire life histories as a "more mobile [biogeography] told through different episodes or moments happening within the longer context of a life" (Lorimer, 2003b, p. 283).

Examining the dynamics of a life encourages biographers to move away from the traditional "linear-jigsaw approach" which privileges a particular trajectory and often places a spotlight on a certain aspect of a life (Thomas, 2004, p. 499). In doing so it is important to examine the social networks of individuals. Nicola Thomas, for example, has examined the friendship networks of Lady Curzon and found that her life and identity were shaped by the various dynamic social networks in which she was engaged (Thomas, 2004). Thomas argues "By placing Mary Curzon within her friendship network it is hoped that the specificity of biography can be combined with a greater engagement with the wider social, economic, political and cultural context in which Mary lived, conveyed through her own writings and those of her circle" (Thomas, 2004, p. 500).

Driver and Baigent suggest "As biographers, we might understandably be drawn to idiosyncratic, imaginative and oppositional figures…but it is equally important to tell the life stories of the apparently more conventional and indeed low-profile men and women" (Driver and Baigent, 2007, p. 102). In critiquing Ron Johnston's article on the treatment of geographers in the Oxford Dictionary of National Biography (ODNB), Driver and Baigent call for a greater number of literary biographies that open up the field of geography and capitalise on the "insights into the collective biography of particular groups and cohorts" provided by the electronic dictionary (Driver and Baigent, 2007, p. 102). Used in the manner in which Driver and Baigent (2007) suggest, the ODNB can become an important geobiographical tool, with the biographies of individuals being used to establish the wider connections between people, places and technologies within the British East Midlands.

Brian Frehner also uses a humanistic approach, examining how the physical location of oil resulted in the professionalisation of geology in America. From early "folk" using divining rods to "practical men" and finally academically trained geologists who refined their skills by surveying geological formations (Frehner, 2011). Frehner also traces the development of university courses and state-wide geological surveys by recounting the contributions made by geologists such as Tom Slick, Charles Gould and Henry L. Doherty. The two aforementioned studies focus on oil exploration in America, the histories of which are well documented within wider world histories of the industry.

2.7 Conclusion

This literature review has examined five bodies of material, which form the conceptual framework of this thesis: - 20th century exploration and developments in geological science, oil cultures, vertical geographies, ANT, case studies approaches and geobiographies. No study has ever attempted to investigate the role of the British East Midlands in the global arena of oilfield development. By paying attention to the local and micro-geographical scale this thesis seeks to fill the void which currently exists in the history of British onshore oil exploration.

An ANT inspired approach, based on notions of non-human and human 'agency', is used to investigate how oil exploration was mobilised by these actants within the British East Midlands. The role of geobiographies and, in particular, oil cultures represents an emerging body of literature that asserts that energy history is entwined not only with material necessity and oil capitalism, but also with cultural history. It is important to note that such discourse pays no attention to Britain's onshore oil industry (the American oil industry receives the greatest scrutiny), hence this thesis makes an important contribution to the geographies of oil exploration, practice of geological field science and significance of the British East Midlands in contemporary oil histories.

Chapter 3: Methodology

3.1 Introduction

This chapter lays out the methodological framework of this thesis and has four further sections. The first section investigates historical archival research methods, highlighting the strengths and weaknesses of qualitative research methods within historical geography. This is followed by a reflective critical discussion on each of the nine archive collections studied during the project. Section two explores oral testimonies as a research method, highlighting the techniques used to analyse interviews, as well as outlining strengths and possible limitations.

The last section begins by examining the characteristics of the study area using the BGSs ARC GIS 9 software to visually represent the main lithologies present in and around Hardstoft, Derbyshire and Eakring, Nottinghamshire. It then moves on to provide a brief overview of petroleum systems, in particular identifying a number of geological prerequisites required to preserve commercial oil accumulations. It is followed by a conclusion, which summarises the chapter.

The overarching aim of the chapter is to assess how and why a combination of inter-textual methods and oral testimonies align with the broader conceptual framework identified within the literature review, and specific aim and objectives outlined in Chapter 1. It also situates hydrocarbon exploration within the British East Midlands.

3.2 Historical and archival research methods

This research draws on the well-established methods of historical and cultural geography and economic, social and cultural history, but also required familiarity with the techniques and practices of geological survey and mapping consistent with research on the history of the natural and geological sciences in the 20th century. The approach taken throughout the course of this thesis was to engage with a range of sources, in order to provide a rich, lively geographical enquiry, in line with the “cultural turn” and poststructuralist approaches reviewed during the course of the literature review. Such changes have, according to Gagen, *et al.*, “resulted in the development of new methodological vocabularies among new generations of historical and cultural geographers” (Gagen, *et al.*, 2007. p. 2).

As discussed by Black (2010, p. 466), research using historical and archival sources falls within one of two categories; source or problem-orientated research. Unlike source-orientated research, which focuses on a single source, for example a diary, problem-orientated research “involves defining a research question through conceptual and theoretical reasoning before the initial engagement with archives and historical sources”. Having defined a series of research questions I began reviewing pertinent secondary sources, as well as identifying likely sources of primary archival data. Here it was important to consider the distinction between primary and secondary data. As stated by Black (2010, p. 468), "primary data are generally taken to mean raw data in an unprinted or unpublished form, usually located in a record office or archive. Secondary data are generally understood to have been transformed from their raw state, often collated, classified and/or tabulated for publication". This thesis has utilised a variety of primary resources, including letters, diaries, parliamentary debates, personal journals, photographs, and maps.

As stated by Gaillet and Eble (2016, p. 5) "primary materials can often help tell a story or document a past or current act, place, movement, culture, or community". They add resolution to our understanding of past events and can be used to show the actions and scientific rationality of individuals operating within a particular situation and circumstance, many of whom may otherwise have gone unnoticed. Primary sources are defined by Gaillet and Eble (2016) as being factual in nature, purporting the results of scientific discoveries or experiments. Written during or very close to an event or time period, they provide original, first-hand accounts given by the human actors operating at a particular point in time. At the point at which they were written, the intended target audience would have been limited to those closely associated to the research or discovery, for instance the Duke of Devonshire's private papers were intended only to be seen by his mineral agents and solicitors – those with a close, vested interest.

As discussed by Ogborn (2010, p. 91), different sources will answer different sorts of questions, [while] some questions are more easily answered than others". Therefore, in order to build a representative account of past events, this research also drew on secondary published sources contemporary to the episodes investigated. According to White (2010, p. 75), secondary "data may be seen as providing an 'extensive' basis and context for a more 'intensive' investigation", which came during archival data analysis. Contemporary secondary sources included books, geological memoires, obituaries and peer reviewed journal articles. These sources cut across scales and provided "plausible sources of evidence" (White, 2010, p. 75).

Primary and secondary data sources differ significantly. Secondary sources have undergone manipulation and filtering by the author(s) and are intended for widespread circulation, for example amongst the scientific community or the general public. As discussed by Gaillet and Eble (2016, p. 6), secondary sources are centred on the analysis and interpretation of primary data and provide a "second-hand account of a historical event". Secondary sources used within this thesis included proceedings from conferences, newspaper articles and the published results of research. By analysing primary and secondary data this research identified linkages between sources "not only to deepen the analysis of interesting research questions but also to cross-check and validate different forms of historical knowledge" (Black, 2010, p. 481).

This project first involved an initial review of modern published literature on Britain's onshore oil potential and on the relevant economic, political and cultural context. A report compiled by Harvey and Gray, first published in 2007, but revised in 2013, entitled "The Hydrocarbon Prospectivity of Britain's Onshore Basins" provided an initial starting point. As part of this review I undertook a systematic analysis of key protagonists, using the Oxford Dictionary of National Biography, where possible, as well as obituaries and secondary sources. This initial phase of research was extremely important, as it provided an historical setting for the thesis. According to Kearns, understanding the historical context allows us to relate…abstract ideas into situated details" (Kearns, 2007, p. 11). Our knowledge about those contexts is, Kearns argues, "likewise derived from experiences and readings, themselves informed by other theoretical priorities" (Kearns, 2007, p. 11).

The reconstruction of the historical geography of onshore hydrocarbon exploration and exploitation in the British East Midlands from 1908 to 1964 was constructed via the previously unused materials from nine British collections. Table 3.1 provides a summary of archives used and materials consulted during the construction of this thesis. Chapter 4 utilised four archive collections, while chapters 5 and 6 utilised three and six collection respectively. The BP Archive, uniquely, cut across all three chapters, while the BGS collections and Hallward Library, University of Nottingham, Manuscripts and Special Collections cut across two chapters. The Chatsworth Estate Archive, Parliamentary Archive, Churchill Archives Centre, Churchill College, The National Archives, Kew, Keele University Special Collections and Archives and Dukes Wood Oil Museum were all confined to individual chapters.

Archival research involved subjecting printed and written texts to textual analysis and interpretation to reveal negotiations of power between key protagonists and institutions (Gagen, 2007). In interrogating these traces I looked for their geographical dimensions, in particular, the development of onshore oil exploration, the movements of key protagonists from one locality to another and production and consumption of geoscience within the British East Midlands (Kearns, 2007). Keighren, suggests that archival research reveals "the personal and everyday detail…which …invariably deals in an important record of the professional practice of geography" and in the case of this thesis, geological science (Keighren, 2007, p. 48). Keighren goes on to argue that scholarly tradition tends to focus on the explanatory, rather than the facilitative aspects of an individual's life. However, as this thesis reveals, the facilitative, which enabled particular engagements with hydrocarbon exploration within the British East Midlands, "can also afford useful illumination, serving more than vignettes" (Keighren, 2007, p. 53)

Table 3.1: Summary of archives and materials consulted per chapter.

Archive	Items viewed	Chapter 4	Chapter 5	Chapter 6
British Petroleum Archive, University of Warwick	13	ArcRef 68964	ArcRef 41067 ArcRef 44067 ArcRef 44191 ArcRef 44196 ArcRef 44197 ArcRef 44199 ArcRef 44201	ArcRef 111344 ArcRef 44191 ArcRef 113250 ArcRef 44199 ArcRef 70893 ArcRef 44201 ArcRef 44197 ArcRef 44206
British Geological Survey Archive	9	GSM/XG/0/1. IGS2/857 GSM/XG/0/1. IGS2/862	GSM/XG/0/1.IGS2/857 GSM/XG/0/1.19S2/858 GSM/XG/0/1.19S2/859 GSM/XG/0/1.19S2/869 GSM/PY/A/10 GSM/PY/A/12 GSM/PY/A/13 GSM/PY/A/17	
Chatsworth Estate Archive	8	All items consulted		
Hallward Library, University of Nottingham, Manuscripts and Special Collections	6		43.5.93/A.5 1931-36 43.5.93/A.7 1938-1940 43.5.93/A.130 1935-1937 43.5.93/B.1	43.5.93/A.8 1944-1945 43.5.93/A.10 1950s.
Churchill Archives Centre, Churchill College	4			All items consulted
Parliamentary Archive	2	BL/83/6/28. LG/F/32/5/6		
The National Archives, Kew	2			POWE 33/538 POWE 33/1738
Keele University Special Collections and Archives	1			Philip Southwell: unpublished autobiography dated 1980.UGSD102, 1-18.
Dukes Wood Oil Museum	1			Original conveyance dated 5th June 1940.
Total No. archives used per chapter		**4**	**3**	**6**

Source: *Andrew Naylor, June 2016.*

As stated by Mayhew, it is important to consider textual sources not simply as “data sources”, “but as themselves historically embedded products whose modes of authoring, production, dissemination and reception are vital sources of insight to the historical geographer” (Mayhew, 2007, p. 25). When undertaking archival research, it was important to realise that a). the “author” of a given document was not a single figure, but part of a larger network and that b). the message being conveyed had its own context. Mayhew argues that “evidence itself is constructed at a certain time and place [meaning that] both the message it embodies and the medium through which that embodiment occurs are themselves historically contingent” (Mayhew, 2007, p. 24). Textual analysis, therefore, involved “deconstructing the political assumptions they (manuscripts, letters etc.) embodied” in order to provide a high-resolution study exposing the tensions surrounding the issue of onshore oil exploration during the early to mid-20th century (Mayhew, 2007, p. 24).

The scale of the petroleum industry and episodic nature of onshore oil exploration suggested there would be a rich array of possible archival sources. A project framework developed in 2009 highlighted a diverse array of protagonists, institutions, government departments, private companies and landowners, each one relating to at least one body of archival material.

In order to fulfil the aim and objectives identified in Chapter 1, nine archives were identified and subjected to in-depth textual interrogation. Five collections (Chatsworth Estate Archive; The British Petroleum Archives, University of Warwick; The National Archives, Kew; British Geological Survey Archive, Keyworth; and Dukes Wood Oil Museum) were used to investigate places, techniques and technologies, institutions and private companies. Four archive collections were examined in pursuance of the roles of key protagonists, including the Churchill Archives Centre, Churchill College (Frank Whittle); Keele University Special Collections and Archives (Philip Southwell); Hallward Library, University of Nottingham, Manuscripts and Special Collections (Peter Kent) and Parliamentary Archives (key politicians operating during World War One). By drawing on a range of empirical sources. an “intertextual mosaic has been compiled” (Dunnett, 2011, p. 60), which has resulted in an accurate historical study.

Archives represent containment centres of and for selected data, constructed based on a given prerogative, which may change over time to reflect social, cultural and economic values. As a researcher it was important to be aware of this so as not to merely regurgitate an unbalanced historical account, drawing only from the often biased opinions represented within each collection. Each archive contained material relating to a particular phase of onshore oil exploration, with the exception of the BGS and BP archives which covered multiple phases. This affected how the archives were used insofar as some were used to search for specific pieces of the jigsaw at a given moment in time, whilst others were examined more extensively to map out a particular phase of exploration.

Overall, engaging with multiple archival bodies gave an "in depth insight into the material circumstances, states of minds, motivations, decisions, assumptions and values" of petroleum geoscientists operating within the British East Midlands from World War Two to the mid-1960s (Drake and Finnegan, 1994, p. 16). Qualitative archival research "[gives] form to the identities and capacities of past communities, spaces and landscapes, while simultaneously erasing that which cannot be so easily captured" (Dwyer and Davies, 2010, p. 89). The consultation of archives enables the analysis, interrogation and synthesis of the "traces left by former lives" and gives deceased subjects a voice in 21st century historical debate (Ashmore, *et al.*, 2012, p. 81).

The archive can be defined as a repository where materials of social and historical importance are stored, presented and ordered (Harvey Brown and Davis Brown, 1998). For cultural and historical geographers, "the archive is akin to the natural laboratory of the natural scientists– a place or space in which discoveries are made" (Osborne, 1999, p. 52). Like the natural environment, however, archives are subjected to deposition and erosion, often resulting in a partial historical record. As I became more familiar with the operation and function of archives I came to realise that gaps in the historical record are often linked to the desire to promote an archive in the best possible light to those accessing it.

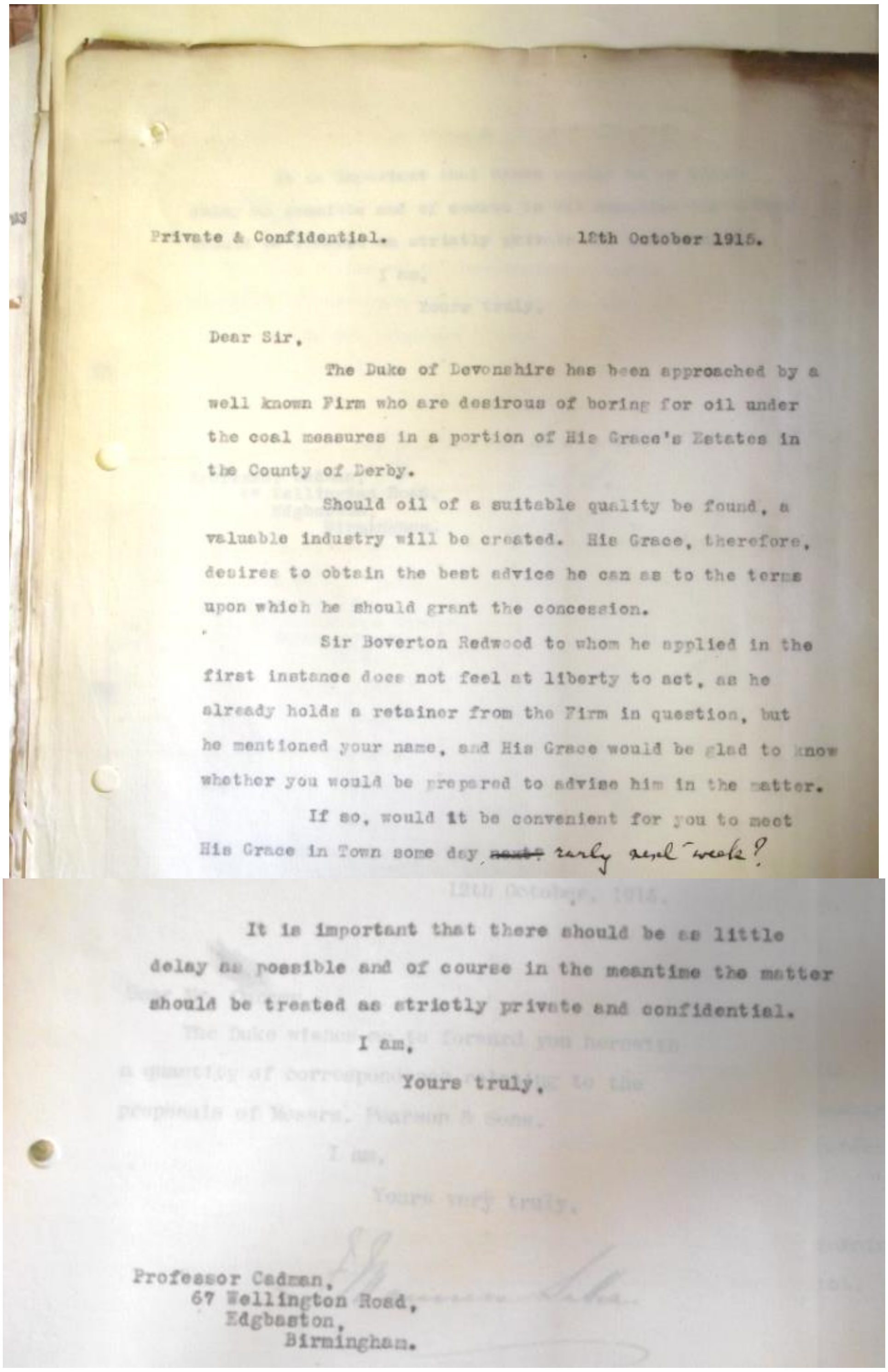
The archives of private companies or institutions are "sites of and for authority" with gatekeepers (archivists) managing what would and would not enter the collection (Johnston and Withers, 2008, p. 5). Therefore, the current state of each repository was a reflection of the judgments and actions of creators and stewards past and present. Material now contained within the archives would not originally have been seen by outsiders due to corporate confidentiality and or personal sensitivity. In addition to revealing the secrets of the dead community, there can be moral and ethical implications for their ancestors. The unavailability of sources resulted in periodic assessments of the overall thesis structure. When gaps were found to exist, alternative archives were employed where possible to provide the required continuity.

The Duke of Devonshire's private archive was "discovered" almost by accident when a conversation with a local historian pointed to a small body of material located at Chatsworth House. I subsequently contacted Archivist Mr Stuart Band of the Chatsworth Estate who confirmed several boxes of material labelled "Oil" had been spared from being thrown into a skip in October 2009. Having written a letter to the "archive team" outlining my intent and research credentials I was invited to view the uncatalogued material, not knowing that I would be the first person to do so in almost a century. This material was kept in the current Duke of Devonshire's private library, instantly giving the archive an intimate, personal and private sensibility.

Removing the lids from the various archive boxes was an exciting moment, given that the contents were completely unknown to anyone, and the implications were potentially ground breaking. Inside three of the boxes, I was presented with a series of clearly labelled orange folders – each marked with dates. In other boxes I was presented with an amalgamation of pamphlets, drilling logs, legal agreements, photographs and personal correspondence between the Duke of Devonshire, his land agents, fellow landowners, solicitors and members of the Cavendish family. The contents of each orange folder were meticulously arranged in chronological order, making it relatively straightforward to tease out the main strands of the narrative.

A discussion with archivist Mr Stuart Band suggested that the material had been compiled by the Duke's land/mineral agents and solicitors, who were employed to ensure the Duke's estates were appropriately managed. Moreover, as the episode became increasingly political it was important for the Duke and his staff to carefully track and monitor past and present changes as they had the propensity to affect his estates. As I, and indeed anyone else, was totally unaware of the contents of the Chatsworth Estate Archive there was no means to target specific lines of enquiry (broad date ranges on folders covered several years). Therefore, I had to assign a great deal of time to familiarising myself with the contents and ordering of the numerous folders. In total, four full weeks were spent in the Chatsworth Estate Archive, more time than all other archives combined. Arguably the most significant document contained within the Chatsworth Estate Archive (in the context of this thesis) is a letter dated 12th October 1915 written to John Cadman from the 9th Duke of Devonshire (see figure 3.1). The letter, which enquired as to whether John Cadman would be willing to act as the Duke of Devonshire's personal oil advisor provided a starting point to trace John Cadman's role in the embryonic development of the British East Midlands oilfields.

Figure 3.1: Letter dated 12th October 1915 from the Duke of Devonshire to John Cadman.



Private & Confidential. 12th October 1915.

Dear Sir,

The Duke of Devonshire has been approached by a well known Firm who are desirous of boring for oil under the coal measures in a portion of His Grace's Estates in the County of Derby.

Should oil of a suitable quality be found, a valuable industry will be created. His Grace, therefore, desires to obtain the best advice he can as to the terms upon which he should grant the concession.

Sir Boverton Redwood to whom he applied in the first instance does not feel at liberty to act, as he already holds a retainer from the Firm in question, but he mentioned your name, and His Grace would be glad to know whether you would be prepared to advise him in the matter.

If so, would it be convenient for you to meet His Grace in Town some day ~~next~~ early next week?

It is important that there should be as little delay as possible and of course in the meantime the matter should be treated as strictly private and confidential.

I am,

Yours truly,

Professor Cadman,
67 Wellington Road,
Edgbaston,
Birmingham.

***Source:** Andrew Naylor, September 2011. From: CEA. Box: Hardstoft oil (1) driller's reports. Folder: Correspondence from July 1915 to Nov 1916. S. Pearson and Co. Ltd.*

The British Petroleum Archives, University of Warwick was an important archive collection given the pre-eminence of BP, and its precursors and subsidiaries, in the onshore industry (Ferrier 1982; Bamberg 1994). A preliminary investigation suggested a rich collection of unpublished geological and commercial company reports on all phases of onshore exploration and exploitation, a full collection of company magazines and other illustrated publications on the activities at each UK oilfield, and a large photographic collection.

According to Barry, the emergence of so called "oil archives" began in the latter part of the 20th century but "acquired salience in the early 2000s" (Barry, 2015, p. 96). Barry argues that oil archives have arisen in response to three movements. Firstly, in opposition to numerous sources, including watchdogs, consumers, investors, NGOs and affected populations. Oil archives help to promulgate alternative perspectives from those offered by oil critics, "demonstrating their commitment to the ethical values of corporate responsibility" (Barry, 2015, p. 96). Secondly, and in relation to the former, in response to environmental and social responsibility, which has, and continues to add to the materials deposited within oil archives. Finally, to promote transparency. Oil archives such as the British Petroleum Archive, University of Warwick are managed and governed by the company, who controls what will and will not be made available for consultation. Onshore oil exploration has become an extremely emotive 21st century subject. Making once sensitive company data available to the public runs the risk of fuelling the geopolitical fire. Barry argues that "the emergence of the oil archives is both the product of conflict between corporations, international organisations and their civil society critics and an attempt on the part of corporations and international institutions to govern such relations" (Barry, 2015, p. 98).

A review of the archive's online catalogue revealed a rich body of empirical material relating to D'Arcy's systematic search for oil during the interwar period and throughout World War Two. Summary reports by key protagonists, personal correspondence, annual accounts, drilling programmes and in depth geological reports provided a means to track the regional development of field sites as D'Arcy's interwar exploration campaign advanced. Perhaps most significantly, the archive revealed the role of geologists and politicians in the formulation, passing and practical implementation of the Petroleum (Production) Act 1934 (recently confirmed and extended by the 1998 Petroleum Act).

The archive also revealed the details of subsurface controversies with local landowners during World War Two, the physical extent of the Nottinghamshire oilfields and the geographic distribution of licence areas under the terms of the 1934 Act. Such politics are mirrored within the oil archive itself. As stated by Barry, an archive is an historical actor governed by archive politics and forms of power. Their contents are constantly shifting and are constrained by the limits of what is deemed suitable for public consumption. Significantly, "oil archives are marked by systematic absences" (Barry, 2015, p. 107). They have a degree of temporality insofar as the materials they contain are released for consultation only after an event and following a review by company archivists. There is little one can do to remedy this; however, it is important to consider the implications of such archive politics on the accuracy and completeness of research. The BP Archive is not democratized and reflects the ongoing conflicts of interest between the oil companies and their numerous critics and activists.

In addition to BP Archive material, the micro-scale administration and financial arrangements governing the Nottinghamshire oilfields was rendered with intricate detailing following a visit to the Dukes Wood Oil Museum. Peering into one of the many glass display cabinets (sadly in varying states of decay) I spotted a rather tatty looking, red, bound book entitled "Original conveyance dated 5th June 1940". This fascinating manuscript, which I later borrowed, represented the often ad hoc arrangement of archive collection and the "oddities" which often find their way into a collection. Moreover, it made me realise that while no two sources of empirical research are the same, they all have an equal level of importance when attempting to piece together a fragmented, hidden history.

Although oil archives are deemed open and available to the public, "in practice they are likely to be read by metropolitan professionals, investors, bankers, officials, and activists" (Barry, 2015, p. 99). During my time in the BP Archive I encountered only researchers, indicating that the demographic is skewed and not representative of the general public. Discussions with such individuals revealed that all of the material they had requested had been carefully scrutinised, sometimes on the day of consultation. This again reiterates the sensitive nature of the research, and the propensity for incomplete representation.

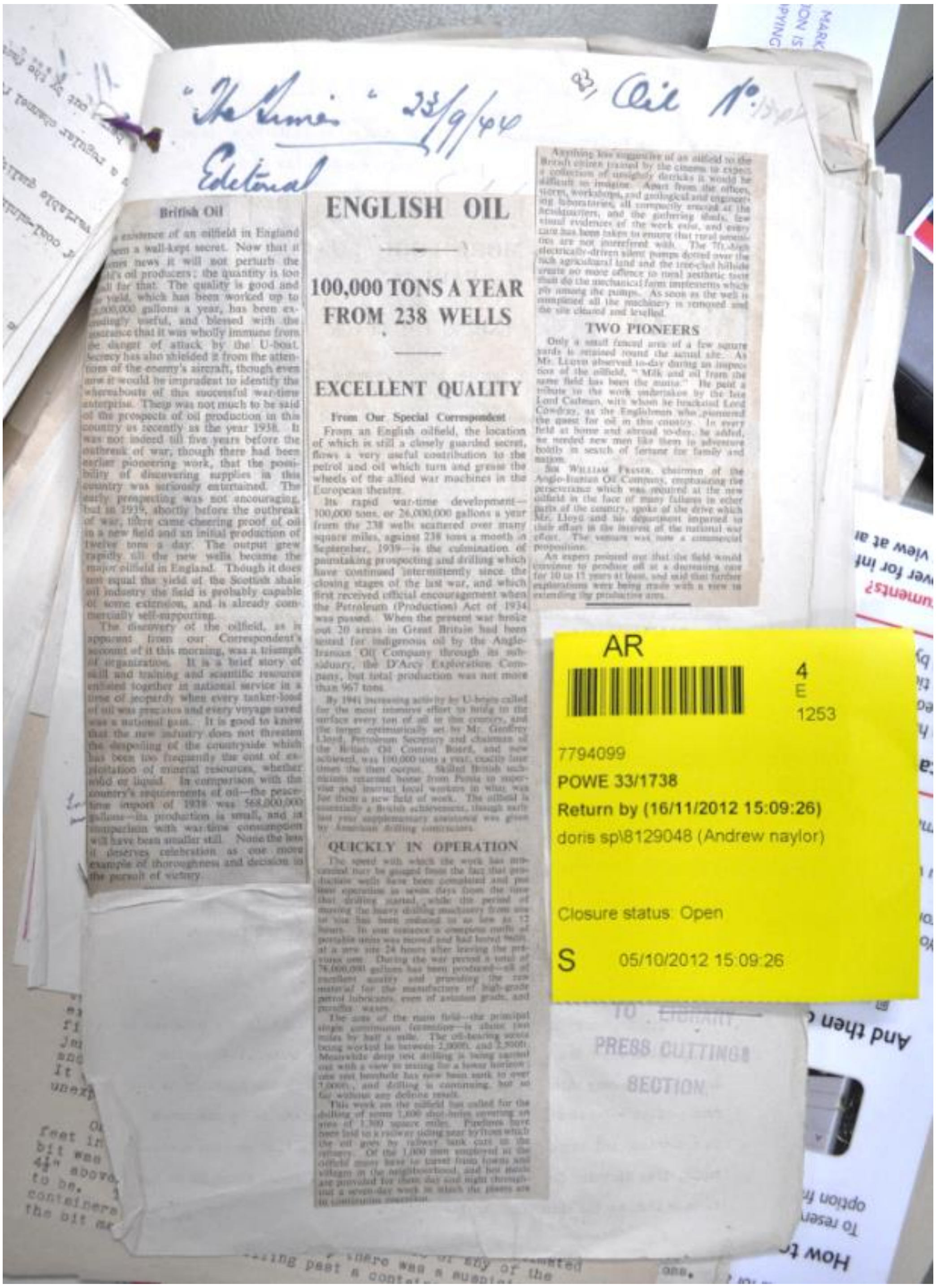
The BGS Archive contains administrative and scientific records covering UK and overseas operations, as well as personal staff papers, physical artefacts, photographs and rare maps. A discussion with BGS Archivist Mr Andrew Morrison, in particular, revealed a rich body of material relating to the BGS's role in onshore oil exploration during the interwar period. Specifically, the material chronicled how the institution had helped stimulate advancements in geophysical methods (including interpretation and mapping) during the 1930s, aiding in subterranean mineralogical discovery via the successful collaboration between government departments and industry. The material also postulates the role of geologists in influencing energy policy, as well as reflecting on how scientists disseminated geophysical techniques and technologies into a somewhat hesitant British higher education system. To a lesser extent the material also presents the BGS's advisory role during the various phases of commercial onshore oil exploration.

Finally, the collection reveals a fascinating array of well-preserved newspaper cuttings which illustrate, quite literally, explosive media responses, largely pro-oil, towards the prospect of a domestic oil economy. In some respects the material corroborates the claim that "National Geological Surveys were established…to provide consistent strategic information concerning geology and resources that would aid in economic development to their governments, and thus to their societies" (Turner and Rosenbaum, 2003, p. 383).

However, the archive focusses heavily on only a few years during the interwar period. Consequently, it does very little to shed light on the intimate relationships between the BGS and the various companies operating during the period examined, suggesting a breakdown in communication, particularly during World War Two. Furthermore, the coverage, or lack thereof suggests that the BGS has, historically, reacted only when stimulated to do so by industry experts or following the passing of key legislation.

Relevant archival material at The National Archives, Kew was identified prior to my visit using an online search engine. Only two files were found to be relevant. The titles of the records were tantalising, referring simply to mining licences under the terms of the Petroleum (Production) Act 1934. In fact, the empirical material covered a vital missing link in Chapter 6. Up until visiting The National Archives, Kew I had drawn blanks as to how the Nottinghamshire oilfields were governed, administered and operated during World War Two. The material from Kew (see figure 3.2), though limited, provided exactly these answers, as well as elucidating subsurface controversies with local landowners, government planning agencies and local authorities during the course of World War Two.

Figure 3.2: Example of newspaper clipping found within The National Archives, Kew.



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ENGLISH OIL

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QUICKLY IN OPERATION

TWO PIONEERS

AR

4
E
1253

7794099

POWE 33/1738

Return by (16/11/2012 15:09:26)

doris sp\8129048 (Andrew naylor)

Closure status: Open

S 05/10/2012 15:09:26

PRESS CUTTINGS SECTION

__Source:__ Andrew Naylor, November 2012. From: WNAK. POWE 33/1738.

This thesis unites the biographical accounts of the living with the biographical accounts derived from the heavily fragmented archival sources of the dead. An obvious limitation in relation to the former is the small number of subjects still alive today. However, more challenging and complex issues arise when consulting archives, as one is presented either with not enough information, or too much.

McGeachan, *et al*., (2012) expose some of the issues associated with absence and abundance through their geobiographical account of eminent zoologist Dr. Hugh Cott (1900-1987), who turned his attention to military camouflage in World War Two. McGeachen, *et al*., (2012, p. 172) state that “in approaching the cultures and geographies of military conflict a scientific biography focusing on the interconnecting sites and spacings between Cott, his science and camouflage was charted, in order to write a multi-faceted biography of camouflage's life-path”.

While the archives provided important information on the places and spaces in which the science of camouflage was produced and negotiated, Cott’s personal experiences were lost. The challenge, McGeachen, *et al*., argue was to “get under the clipped (military) language, to consider the experiences as well as the strategic impacts and effects… the issue of the "military archive", especially how to utilise it as a means of getting at the embodied aspects of military experience in order to write of lively military lives - human and nonhuman - became a methodological and archival challenge, an exercise in working with, and through, absence and abundance” (McGeachen, *et al*., 2012, pp. 172-173). Their biography was, therefore, an exercise which involved combining “memory, history, geography and storytelling” (McGeachen, *et al*., 2012, p 173).

By organising a plethora of archival remnants, arranged sequentially this thesis recalls the memories of the dead in a form which describes and investigates the cultural ideologies and political agenda of the 20th century. As the process of archival research unfolded it became apparent that the lives of the human actors examined were multi-layered and interwoven, involving a variety of field sites, institutions and political arenas. The historical representations of the chosen subjects, therefore, showed a level of plurality and plasticity, with different archival sources portraying a subject’s life in different ways.

A traditional biographical account tends to examine only a single strand of an individual’s life, whereas I attempt to bring together the various aspects of each subject’s life in order to meet the three objectives of the study. The catalogue of the papers and correspondence of Sir Peter Kent (1913-1986) is rich in varied sources, enabling a biographer to focus on various aspects on Kent’s life, for example Kent the East African archaeological team member, Kent the deep sea oil explorer, Kent and his role within institutions such as the Natural Environment Research Council and so forth. Choosing what would, and would not be presented within the thesis meant disentangling the life of the subjects examined and looking holistically through and across the archives.

When reviewing archival documents it became important to consider the time at which the original documents were written as well as their intended audience. Thomas, for example, found that Lady Curzon had used her correspondence circles in different ways, censoring certain information while privileging other material (Thomas, 2004). This meant that the subject exerted her own agency, shaping representations and influencing the flow of knowledge across the spaces of empire. A biogeographical approach "[reveals] the subtle nuances…which challenge the basic dialectic of public/private" (Thomas, 2004, p. 515). A biogeographical approach can never be free from encumbrances such as subjectivity, politics and power, as "within a generation…each cause writes its version of contemporary history and brings the past to bear on it. The questions we ask come from contemporaneous anxieties and interest" (Rupke, 2006, np). However, one can, having read and understood the pitfalls of traditional biographical research, endeavour to ameliorate issues such as spotlighting and the linear-jigsaw effect. As McGeachen, *et al*., explain;

"A geographical sensibility to the archive and to biographical subjects understands that just as lives have their geographies, so fragments have dispersed geographies of their own. By thinking more creatively about the complex interplay between what the archive holds and what is missing in the writing of lives, historical geographers have the opportunity to explore these fragments and their geographies in more depth, and create a diverse set of stories that centre upon their uncertain subjects" (McGeachen, *et al*., 2012, p. 172).

By tracing the lives of several leading geological experts of the 20th century through archive collections, the project explores the engagement and many connections between government officials, consulting geologists, landowners, solicitors, academics and venture capitalists. This approach adds to the work of Paul Lucier, who, in introducing a new type of professional, the "consulting scientist", traced the movements of individuals in their wide-ranging commercial engagements from Nova Scotia to the coast of California, to critically assess how their work fuels the rapid growth of the American coal and oil industries (Lucier, 2008).

The unpublished papers and autobiographies of key protagonists were fully investigated using four archive collections: 1). Weetman Dickinson Pearson (1856-1927) and Sir John Cadman (1977-1941) – Parliamentary Archive; 2). Phillip Southwell (1894-1981) - Keele University Special Collections and Archives; 3). Sir Peter Kent (1913-1986) - Hallward Library, University of Nottingham, Manuscripts and Special Collections; 4). Frank Whittle (1907-1996) - Churchill Archives Centre, Churchill College. These collections provided the thesis with its geobiographical spine.

John Cadman, Weetman Dickinson Pearson, Phillip Southwell and Sir Peter Kent, and their many geological and company associates, championed, to varying degrees, the cause of British onshore oil exploration in the East Midlands. Frank Whittle, in attempting to develop a novel concept in oilfield drilling, opened up the potentialities of subsurface mineralogical exploration, adding to our understanding of how and why subsurface geographies can be accessed, interrogated and ultimately, exploited. The personal correspondence, technical papers and summary reports of the aforementioned individuals reveal how their numerous international experiences shaped their attitudes towards British onshore oil exploration and stimulated research and development into experimental oilfield technologies.

Of the three personal collections, material relating to Sir Peter Kent most readily lent itself to the formulation of a geobiography, as the contents covered all aspects of Kent's life both in the UK and overseas. Many of the 94 boxes of material were bequeathed to the university in February and August 1990 by Lady (Lorna) Kent. The collections catalogue, compiled by Timothy E. Powell and Peter Harper of the National Cataloguing Unit for the Archives of Contemporary Scientists is unique and does not conform to standard referencing systems, which presented challenges early on when attempting to communicate my requests to view material. The system is extremely comprehensive, perhaps too much so. Whilst researching in other archives I had grown accustomed to being presented with burgeoning folders, having only generalised item descriptors. Antithetically, folders within the Nottingham collection often contained only a few sheets of paper, with record titles explicitly stating their contents. While this made research more straightforward, it took away the feeling of anticipation one gets when first receiving a body of material. In essence, the feeling of discovery was nullified in knowing the material had been meticulously worked through by someone else. Of the 94 boxes, my focus was limited to a section entitled "biographical and bibliographical" which, explicitly, chronicles Kent's career from early childhood (including his decision to become a geologist) to his role in the discovery of the four Nottinghamshire oilfields.

The Frank Whittle collection, located at the Churchill Archives Centre, Cambridge contained over 96 boxes and ten rolls of material, covering Whittle's numerous, often experimental engineering projects, lectures/broadcasts and involvement with various societies and organisations. Of the eight broad categories (arranged alphabetically from A – H), my interests focused on section B, "research and development", which contained subsection, B.272-574 detailing a novel research project in oilfield drilling. It would appear, following discussion with the archive team that no other scholars have requested to view material relating to Whittle's role within the oil industry. The material served to stimulate wider discussion on the notion of subsurface geographies and, in particular, how earth scientists are today unlocking the potentialities of formerly uneconomic stratigraphic zones locked many thousands of meters below the ground surface.

The Parliamentary Archive and Keele University Special Collections and Archives housed only a minimal amount of relevant empirical data. However, in both cases they provided answers to longstanding questions. A keyword search of "Cadman" and "Cowdray" on the parliamentary electronic catalogue, "portcullis" revealed a number of potentially interesting documents, which provide evidence on the broader national debates surrounding national security and oil dependency during World War One, and, the role of key politicians in bolstering British onshore oil exploration during the first, early 20th century phase of exploration.

Finally, the Keele University Special Collections and Archives contained a 14 page autobiography of Phillip Southwell. This only came to light following a discussion with geologist and historian Hugh Torrens, who personally compiled the archive over many years, and several overseas visits, and who kindly loaned photocopies. The unpublished autobiography is incomplete, tantalisingly finishing just prior to Southwell's engagement in the World War Two phase of onshore oil production. Nonetheless, it provided a fascinating insight into Southwell's international experiences and intimate relationship with John Cadman, both of which would have a significant impact on the development of the Nottinghamshire oilfields.

From a practical research perspective, I found archives where material was searchable online, allowed photography and had clearly labelled boxes and or folders, by far the easiest to work on. In stark contrast, I was often daunted and, certainly from the outset, intimidated by archives whose collections were disorganised and uncatalogued. Having said this, nothing beats the excitement of discovering a new and uncatalogued body of material, unseen by anyone in over a century. Perhaps the greatest challenge inherent to archival research was physically gaining access to the numerous collections themselves. During the period of research the BP archive was closed for many months due to major refurbishment, while the Chatsworth Estate Archive opens only from April to October each year. Some archives, for example The National Archives, Kew, required little or no booking, while smaller, equally popular archives, such as the Cambridge Archives Centre required I book several days in advance.

I attempted to access archive collections in a manner which conformed to the overall chronology of the thesis. The challenge, given closures, booking and accessing procedures was therefore choreographing visits to best maximise their impact on informing research in a progressive manner. On occasions where access was not feasible, I often had to work on an alternate phase of exploration, which affected the flow of ideas and the overall structuring of arguments, as a later discovery could impact on an earlier line of enquiry or set of explicit assumptions.

3.3 Interview research methods

Over the last two decades there has been increasing emphasis placed on the use of biographical accounts to reconstruct historical geographies, particularly those of ordinary lives. Oral testimonies provide a living history of a person's unique life experiences, giving those who have been "hidden from history" an opportunity to have their voice heard (Oral History Society, 2009, np). These fleeting opportunities offer the chance to record history face-to-face, providing "information about…social groups whose written history is either missing or distorted" (Portelli, 2006, p. 34).

Historical interviews provide valuable insights beyond the archive, and help the historical geographer situate knowledge production in its historical and individual context. They enable complex questions to be discussed and clarified, and often highlight areas of interest, which would otherwise have gone unnoticed, had only archival sources been used. Oral testimonies were used to gain valuable perspectives and observations from eyewitnesses, which, on occasion, resulted in "small but telling details that previously escaped notice and were overlooked in the historical narrative" (Ritchie, 2014, p. 12).

Historical interviews can provide a deeper understanding of scale and time. Robertson argues oral testimonies provide a "picture of the past in people's own words" (Robertson, 2006, p. 2). George and Stratford add that they provide "a means to step back to the mix of past times and places as they are mediated through the words and memories of another person in the present" (George and Stratford, 2010, p. 141). The overriding rationale for the inclusion of oral testimonies was to reveal the complex cause and effects of oilfield developments within the British East Midlands from 1939 to 1964, "show[ing] the connections, casual and otherwise between particular historical events and larger social, economic, and political trends and developments [as well as] understand the meaning, implication, and impact of historical events" (Ritchie, 2014, p. 460).

Autobiographies are an effective means of supplementing conventional archival research methods and can add clarity and resolution to manuscripts and collections. Moreover, should oral testimonies be found to be contradictory, they can lead a researcher to re-examine archival sources. From a geographical perspective, historical interviews become a "powerful source of situated learning…it can facilitate enhanced understandings of space, place, region, landscape, and environment" (George and Statford, 2010, p. 140).

The resurgence of biographical methods is partly attributable to the need to recover the "fragmentary record" of field practice which can evade the historical radar of archives (Lorimer, 2003a, p. 199). Portelli argues that oral testimony "tells us less about events and more about their meaning. Interviews often reveal unknown events or unknown aspects of known events; they always cast new light on unexplored areas of the daily life" (Portelli, 2006, p. 36).

However, as interviews are distant from an event there exists the propensity for distortion of faulty memory, subjectivness and perception. Ritchie argues that:

"Although oral historians recognise the fallibility of memory, they do not put more weight on a source just because it is written down. They have found that memos have been written to obscure rather than illuminate what happened; that memories can be notoriously self-serving; and that newspapers sometimes get things wrong" (Ritchie, 2014, p. 12).

Interview methods were only practicable in relation to Chapter 6. Throughout the thesis reference is made to "high profile" characters that already hold an elevated position in the history of petroleum geosciences. Although critical to the overall structure of the thesis and indeed the narrative, it "is equally important to tell the life stories of the apparently more conventional and indeed low-profile men and women who contributed" (Driver and Baigent, 2007, p. 102).

The process of undertaking interviews involves identifying subjects, learning the subject area and the biography of the interviewee, undertaking the interview itself, transcribing the recording, editing and publishing the material (Ritchie, 2014). Interviews were conducted only in the second year of the project, allowing me to become fully conversant in the broader literatures in order to provide an accurate context, before setting a series of logically ordered questions. Interviews can be unpredictable, with interviewees deviating from the questions set. Having an understanding of the events being investigated allowed me, the researcher, to steer the direction of the interview, reducing the number of pauses and avoiding embarrassment on the part of the interviewee and myself.

Sadly, there are very few people who worked on the four Nottinghamshire oilfields alive today, with all interviewees are now in their late 80s. Through use of the museum's informative website[1] I contacted Mr Kevin Topham, Curator of Dukes Wood Oil Museum, Britain's only onshore oil museum. It emerged that Mr Topham had worked in the Nottinghamshire oilfields (and elsewhere in the UK) and was happy to meet for an informal chat. Mr Topham also stated he would invite two former colleagues, Mr Doug Wallace, from Eakring, and Mr Ivan Brentnall, from Mansfield to offer their perspectives.

I met the three men at the museum in the summer of 2010, which is sited on land now belonging to the Nottinghamshire Wildlife Trust. The museum is built from two former "geolabs", which were used to house geotechnical equipment during oilfield operations. It contains a vast array of oilfield artefacts, photographs, secondary texts, memorabilia and some original manuscripts, including original borehole logs. During the meeting the three men showed me a short video produced by the British Broadcasting Commission (BBC) on the Nottinghamshire oilfields. This was followed by an in depth discussion on their respective roles

[1] www.dukeswoodoilmuseum.co.uk

in the development of the Nottinghamshire oilfields. I also learnt that Mr Wallace's wife, Sivyl, had worked as a secretary for senior petroleum geoscientists at Eakring from the 1940s to the 1960s. I enquired whether or not it would be possible to interview her, in order to gain an understanding of the institutional collaborations and global discoveries made by scientists based at Eakring. Mrs Wallace agreed to be interviewed and located historical photographs and other personal material chronicling her working career within the industry.

Following preliminary discussions I was given a tour of the museum, during which the significance of noteworthy artefacts and articles were explained. This preliminary meeting gave me the opportunity to conduct local background research, familiarise myself with the geographies of the Nottinghamshire oilfields, build a rapport and candidness with the subjects and identify key themes, which were latterly used to refine questions for interview and potentially extend research. My discussions with the two men went unrecorded; however, I gained both men's consent to record subsequent, "formal" interviews. Preliminary discussions revealed a rich potential source of data, which would complement archival research. Consequently, I provisionally allocated one hour for each interview, to which both men formally consented. Furthermore, I discussed ownership and copyright formalities, reassuring the two men that they would have the right to specify how the material would be subsequently utilised and disseminated.

This thesis used open-ended, semi-structured interview techniques as they offer the potential to address overall themes, as well as the subject-specific minutiae, tailored to individual participants (Karen and Stratford, 2010, p. 145). As discussed by Ritchie, as an interviewer, one becomes "a partner in the process, helping interviewees become as forthcoming as possible. Interviewers need to guide without leading, providing names, dates, and other information to keep the dialogue moving" (Ritchie, 2015, p. 75). Semi-structured interviews enable respondents to fully develop their memories "…paving the way towards a rich source of data: knowledgeable, first-hand insights into the interrelated everyday pasts of people and places" (Andrews *et al*., 2006, 172). However, in order to generate responses which had a spatial element it was necessary to prepare a rudimentary interview guide, outlining themes and detailed lines of questioning.

Each interview represented an "audio-snapshot" framed around a specific event, or period of history in which the interviewee participated. I arrived to each interview early, at a convenient place for the interviewee and engaged in polite conversation prior to commencing recordings, so as to put each interviewee at ease. To this end I ensured the portable recording device was placed out of site so as not to distract the interviewee. Questions were arranged in a logical and structured manner, designed in such a way as to avoid single-sentence answers. Rather, I aimed to seek "broader, longer, and more interpretive answers" (Ritchie, 2015, p. 76).

As discussed by Ritchie, "there are a number of basic questions that can be asked. There are basic descriptive or "help-me-understand" questions; structural or "walk-me-through-a-typical-day" questions; follow-up or clarifying questions; experience or example questions; comparison or contrasting questions, and closing questions" (Ritchie, 2015, pp. 80-81). Each interview began with open-ended questions, leaving specific questions until later in the interview. This allowed the interviewees to present his/her feelings, speculate on events and pursue lines of enquiry before narrowing the focus of the questioning. Earlier on in the interviews I asked neutral, topical questions. Although they did little to add to the known written narrative, they helped to relax the interviewee, demonstrate my understanding of past events (thus gaining trust) and provide an historical, chronological and spatial framework. From here it was easier to ask in-depth, potentially confrontational questions.

Interviews opened with a general discussion on an interviewee's life, recording key details, including when and where they were born, their education and their careers before (if applicable) entering the onshore oil industry. Next came questions specific to the oil industry. What was your job role on entering the industry? How did your role change over time, and where did your career take you, geographically? Asking an interviewee to describe a typical working day, would trigger a barrage of memories, including details of who they worked with, what technical difficulties they faced in the field, and details of celebrated scientists, such as Frank Whittle. Next, questions relating to the social impacts on the surrounding towns and villages, following the arrival of D'Arcy. What effects did the industry have on the rural fabric of the area, and where did the workforce come from? How did the arrival of the industry accelerate rural development? And how did the industry go about establishing its base within the British East Midlands? Natural wrap-up questions centred on each interviewee reflecting on their life (over the period/event examined) and allowed them to draw their own conclusions. Prior to ending the recording I asked each interviewee whether they had anything to add, which could have been considered relevant to the narrative. I also stated how the recording would be processed and utilised, where it would be deposited (Nottingham University) and when they should expect to receive a copy of the transcript for their approval.

I interviewed Mr and Mrs Wallace together at their home at Eakring on 6th February 2011. The couple were able to give explanations to material in a manner which "[forged] new connections [and took] research in new directions" (Ashmore, *et al.*, 2012, p. 88). During the interview, which lasted approximately two hours, the couple recounted the arrival of D'Arcy in the village of Eakring and traced oilfield development before, during and after World War Two. As the interview progressed they began to dig out photographs, field books and even aeroplane tickets dating back to the 1940s, which chronicled their careers with D'Arcy. Towards the end of the interview Mr Wallace suggested we drive around the village of Eakring and the neighbouring vicinity. With memories now fresh in the mind, Mr Wallace gave a running commentary of oilfield activities in the area as we drove, including installations and the location of individual wells.

My interview with Mr Ivan Mitchell was carried out at his home in Mansfield on 14th February 2011. His house contains several artefacts and photographs relating to his days spent with the D'Arcy Exploration Company Ltd, which were again used as focal points for in depth discussion. During the one hour interview Mr Mitchell explained how the oilfield workers had been given the name "the Mansfield mafia" by members of the local community, offering an insight into the social impacts of onshore oil exploration within the British East Midlands.

I interviewed Mr Kevin Topham inside Dukes Wood Oil Museum on the 20th February 2011. Conducting the interview inside the museum meant Mr Topham could present physical objects and draw from selected texts and manuscripts to reinforce his arguments and act as prompts. These prompts enabled me to pick up on areas that may have gone unrecorded, as well as offering the chance to probe certain areas more deeply. After a very short period of time, I came to appreciate the wonderfully diverse and fulfilled life Mr Topham has lived. One memory would trigger another, as the pace of the interview intensified. While this was highly productive, it became necessary to rein in the interview, in order to ensure focus and clarity.

The accuracy of oral testimonies is only ever as good as an individual's memory. When undertaking historical research, it is important to be objective and remain neutral. By 'reclaiming history', an interviewee might privilege information significant to their personal life. This knowledge may not, however, be significant to an interviewer's research. By using semi-structured interviews I, the researcher, was in control of the conversation and responsible for minimising research bias. Asking the interviewees the same questions in the same order made it easier to steer the interviews and provided a natural level of organisation ahead of qualitative analysis (Kitchin and Tate, 2000). This approach could have restricted the level of individuality provided by respondents, however, I allowed interviewees to expand on salient points and encourage discussions beyond the scope of the questions when an important point was being made.

Dey (1993), cited in Kitchin and Tate (2000, p. 213), argues that qualitative analysis involves three stages: description, classification and interconnection of data. Description, according to Kitchin and Tate (2000, p. 213) "lays the foundation for deeper analysis" and is central to any study. However, it is only by grouping data and looking for patterns and relationships that I was able to interpret meanings and understand respondents' answers, filling in the gaps that archive methods "were unable to bridge efficaciously" (Hay, 2010, p. 100) and providing the data with meaning. The questions I asked were designed to examine the situational and contextual positions of former oilfield workers. Gaining a detailed account of the social settings, social contexts and spatial arena, as well as time frames in which an action or phenomenon occurred was central to tying interviewees' responses in to the historical narrative.

Having generated the data I began transcribing each interview (typically within two or three days of collecting the data so that it was fresh in the mind), into a coherent, self-generated text, which took approximately four to six hours per one hour of recording. The transcription process is the first of Dey's (1993) three phase process. During transcription I began making notes that related to specific ideas and began connecting specific lines of enquiry with archival material and secondary texts. Following transcription I began annotating the transcripts, looking for "recurring patterns in the data to make connections" (Kitchin and Tate, 2000, p. 235). Interviewees shared commonalities such as their place of work, relationships to key members of staff at Kirklington Hall Research Centre and training they'd received. Being an iterative process, with each new transcription and annotation undertaken came a greater level of resolution and the emergence of new themes, which were grouped into categories.

Categories were given suffixes or 'codes', which are the interpretive tags to text based on the main themes relevant to the research (Cope, 2010, p. 440). Interviews were rich in detail and provided additional, first hand lived experiences of life in the Nottinghamshire oilfields. However, without some form of organisation before and after the interviews it would have been difficult to identify trends, themes and connections to broader literature (Cope, 2010). The coding process generated key themes, which linked to the project's theoretical framework and broader literatures, in particular its geobiographical spine. Post field analysis revealed a number of trends, categories and common elements (Cope, 2010, p. 448) relating to an interviewee's life world. For example, data relating to career history was coded with the letters 'ch'. Spatial aspects were coded 's', while questions relating to 'East Midlands oilfields' where coded with the letters 'EMO'. A second system using colours was also employed. Generalised themes were coloured green, while interviewee specific data – specific life events - were coloured blue. This coding system enabled me to compare and contrast data. This gave rise to a deeper understanding of the intricate relationships and associations between each interviewee, allowing me to embed their geobiography in the appropriate place within the thesis, in line with the geobiographies of their peers at specific points in time and at known places. A final phase involved cross referencing interviewee data as well as corroborating responses against archival material, contemporary sources and modern texts. The triangulation of data was particularly important given the limited cohort and served to ensure the objectivity and validity of interview data, which could be viewed merely as the views and opinions of a discrete group of respondents.

3.4 Characteristics of study area

The thesis narrative is constructed around two field sites – Hardstoft in Derbyshire and Eakring in Nottinghamshire (for the purpose of the thesis Eakring incorporates Dukes Wood, Kelham Hills and Caunton see figure 3.3 and 3.4). Plate tectonics are responsible for the processes of anoxic burial and the migration of organic material, which predominantly occurred in newly developing ocean basins, such as the Gulf of California, where oil and gas is being made in real time (Anderson, 2006, np). Over millions of years, continental drift redistributed these organic remains on the back of plates, from once mild climates, to the often hostile climates of the poles (Oil has been produced from the North Slope basin in Alaska since 1968) and deserts (Saudi Arabia, Iran, Iraq, Kuwait) as well as continental shelves (North Sea and Russia,) and tropical rainforests (For example in the Americas and Africa, as well as Ecuador, Columbia, Burma, Peru) (Anderson, 2006, np). According to Vactor:

"If the surface of the globe morphed to resemble the distribution of conventional oil production or reserves it would barely be recognisable. The Middle East would dominate the globe. North America would be the next largest block, followed by Africa, East Asia, South America, and Europe. The Arctic would probably look much larger, but might shrink once explored" (Vactor, 2010, p. 23).

The localities of current oilfields are, therefore, coincidental and widespread. Over millions of years the landscape in which the field sites examined are situated was subjected to intense geological processes including compression, uplift, thrusting, faulting and deep burial. This created the necessary high geothermal gradients needed for hydrocarbon formation, and the four prerequisites of a petroleum system: 1. a source rock, which is often black shales exhibiting good organic carbon content and which have been buried to sufficient depths or in a high geothermal gradient to generate hydrocarbons; 2. a route of migration for hydrocarbons, facilitated by faults and dip of strata; 3. early development of structures into which hydrocarbons can migrate containing reservoirs of at least reasonable porosity and permeability; 4. a seal by an impermeable cover, preferably salt but often shales (Schlumberger, 2015, np).

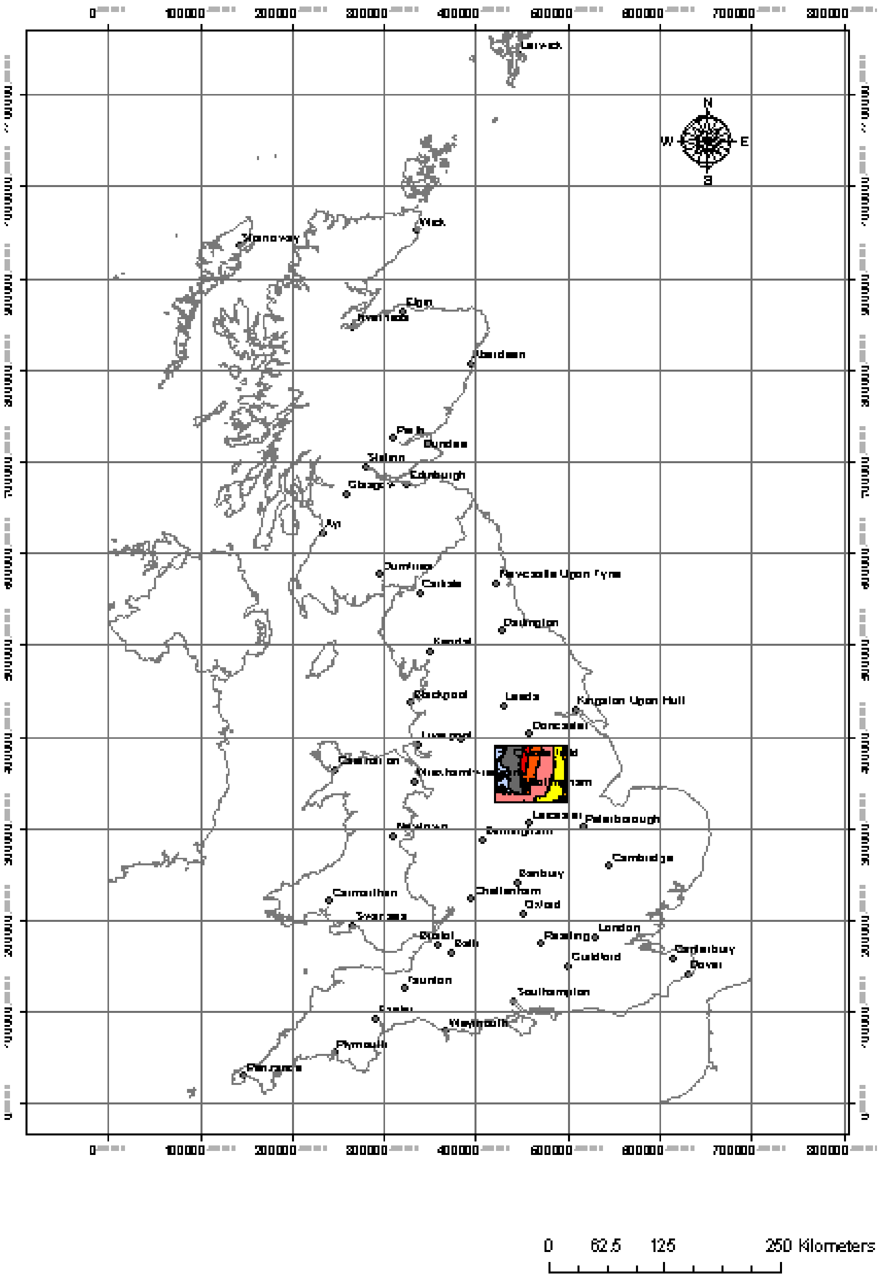
Oil is a fossil fuel that "occurs concentrated in nature as economic accumulations trapped in structures and reservoir rocks beneath the earth's surface" (Evans, *et al.*, 2011, p. 1). Oil occurrences are common throughout the United Kingdom owing to a varied geological past. For example, Selley has reviewed 173 hydrocarbon discoveries in Britain spread across seven geographic areas – the Orcadian basin of North East Scotland, the Midland Valley of Scotland, the flanks of the Pennines, the Welsh Borderlands, Cornwall, the Dorset coast of the Wessex basin and the south-eastern Weald (Selley, 1992). In Derbyshire, John Farey catalogued a number of seepages found in outcrops during the 18th and early 19th centuries, particularly at Ashover, Castleton, Cromford, Eyam, Stoney Middleton and Matlock (Farey, 1811). In the

1840s, an accidental discovery of oil in a coal mine at Riddings, Derbyshire, led to arguably one of the earliest oil refineries in the world, located at Alfreton Iron Works where James Young discovered the process of cracking hydrocarbons to produce distillates, as well as paraffin wax, which replaced sperm and tallow oil as a form of domestic lighting and led to his name James "Paraffin" Young. Young later began experimenting with a new type of coal emerging on the market in Bathgate, Scotland named Cannel coal, kick-starting the Scottish Oil shale industry. Expanding rapidly into the first two decades of the 20th century, at the height of the industry in 1912 over 12,000 people were employed in the Scottish oil shale industry, providing 2% of global oil output (MSSOI, 2012, np). According to Harvie, production peaked in 1913 at 3.5 million tons (27,125,000 barrels) (Harvie, 2010). However, with the British government acquiring a majority shareholding in the APOC in 1914 the economic viability of the industry was undermined (Bamberg, 1994) and it ultimately collapsed.

Within the study area identified, seepages are located in the Carboniferous Limestones; with non-marine shales being the source of some oil (Kent, 1954). The Limestones overlie Upper Carboniferous shales and sandstones of the Millstone Grit, which occur along a major trend line along the east side of the East Midlands dome. Deposited during the Carboniferous period, the oil is now trapped in asymmetrical anticlines (Harvey and Gray, 2013, p. 51). According to Selley, the geology of the area "was once an oil-bearing structure of Middle East proportions, with petroleum reservoired in the Millstone Grit which once extended across the crest" (Selley, 1992, p. 229).

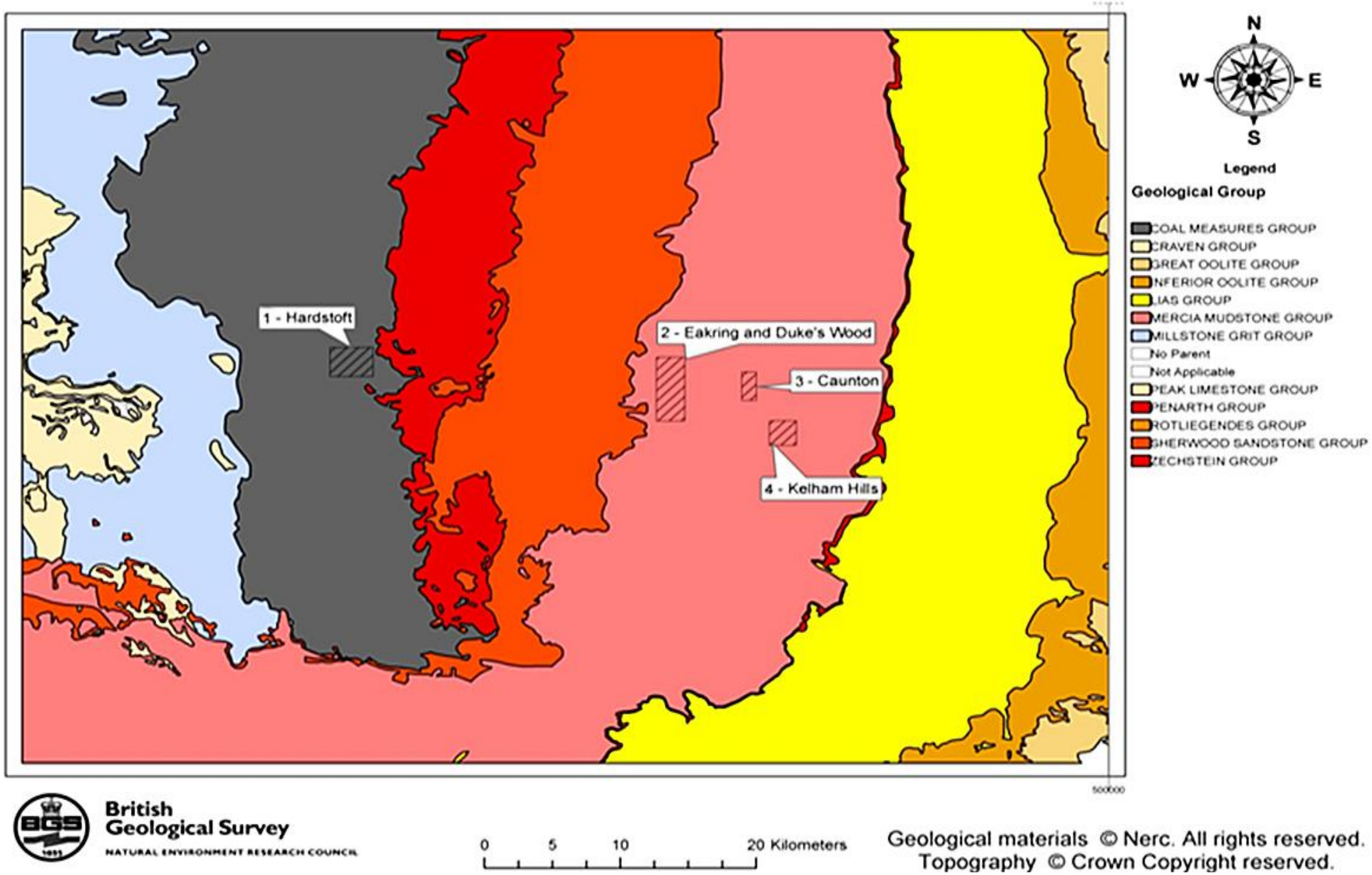
Harvey and Gray define the study area as the East Midlands Hydrocarbon Province, "comprising several concealed Carboniferous sub-basins...[existing] in a swathe extending 110 km (70 miles) from near Loughborough (Leicestershire) to Saltfleetby on the Lincolnshire North Sea coast" (Harvey and Gray, 2013, p. 49). Hardstoft in Derbyshire is located in the Coal Measures Group, while Eakring is sited in the Mercia Mudstone Group (see figure 3.3 and 3.4) which span the Denarth and Rotliegendes Groups.

Figure 3.3: 1:50,000 map of UK showing study area.



Source: *Andrew Naylor (2015) using ARC GIS 9.*

Figure 3.4: Large scale map of study area showing main lithologies.



Source: *Andrew Naylor (2015) using ARC GIS 9.*

3.5 Conclusion

This chapter has served several purposes. Firstly, it illustrates the significance and scope of archival research. Secondly, it outlines the use of oral testimonies to inform the research through real-world, first hand experiences of life in the Nottinghamshire oilfields and at Kirklington Hall Research Centre and to support inter-textual analysis. Finally, it places the thesis in the British East Midlands and discusses the typical geological prerequisites required for a petroleum system to exist. The interdigitation of multi-sourced, inter-textual analysis with oral testimonies has allowed this research to reveal the myriad connections linking people, places, technologies and institutions within the onshore oil industry in the British East Midlands from 1908 to 1964.

The adopted approach has resulted in an empirically rich narrative, uncovering links which would otherwise have remained hidden from view within the numerous archives. The examination of multiple collections has reduced the number of gaps in the historical record. In addition, the propensity to introduce research bias (which could occur if using one collection) has been negated, thus allowing the project to convey an empirically accurate representation of 20th century cultures of onshore oil exploration in the British East Midlands. The following three Chapters (4, 5 and 6) are written in chronological order. Most of the archival collections are confined to individual sections or chapters, however, some collections overlap, i.e. the British Petroleum Archive, University of Warwick which contains materials relating to all three empirical chapters.

Chapter 4 – Land, oil and power: Hardstoft, Derbyshire - Britain's first commercial oilfield

4.1 Introduction

This chapter examines the first serious attempt to locate oil in commercial quantities in Britain. It covers a period of 18 years spanning from 1908 to 1927 and is split into six sections, plus a conclusion. The second section provides a political and scientific rationale for domestic onshore oil exploration during the second decade of the 20th century. The third section identifies the three central protagonists during the period identified, including entrepreneur and venture capitalist Weetman Dickinson Pearson, later Lord Cowdray, hereafter referred to as Cowdray, the 9th Duke of Devonshire, Victor Cavendish, and, crucially, Birmingham University academic and consulting petroleum geologist John Cadman. The fourth section investigates Britain's first oil strike at Kelham, Nottinghamshire in 1908 using conventional drilling technologies. It then moves on to chronicle the progression of preliminary investigations in Derbyshire, as well as the formulation of draft leases, which were intended to offer landowners equitable terms for any oil that might be found under their territories.

The fifth section begins by briefly discussing unsuccessful attempts to revive the Scottish oil industry during World War One, at a time when oil dependency was growing by the hour. It then moves on to examine an attempt to push through Parliament a Bill to facilitate widespread oil exploration in Britain. The Bill would ultimately fall through. However, with the support of Liberal politicians, notably British Prime Minister Lloyd George and Winston Churchill, the Petroleum (Production) Act 1918 would be quickly brought in, alongside a wartime Act to allow the government to gain entry to land for the purpose of onshore oilfield development. With this, Cowdray would offer the services of his company to the British government for free. This forms the basis of section six. The final section chronicles the discovery of Britain's first oilfield, located on the Duke of Devonshire's Derbyshire estate in May 1919. Abandoning the well, the British government would later hand ownership to the Duke, who would find himself questioning whether he had finally secured black gold, or had been presented with a white elephant.

The chapter unwraps a convoluted and highly politically charged episode in British history, which centres on a single field site – Hardstoft in Derbyshire. It will examine how, during the second decade of the 20th century, Britain attempted to negotiate a path towards domestic onshore oil security. Spurred on initially by human inquisitiveness, entrepreneurialism and patriotic ideologies, the challenge of locating a secure source of oil in

Britain quickly shifted to become an issue of national security in the wake of World War One, which massively increased oil usage.

Britain had a long established solid mineral exploration/exploitation regime. However, these minerals share one important quality – they are all immobile (static) in the environment making them relatively easy to locate, quantify and consequently govern. Once one knows the vertical and lateral extent of the deposit (its physical volume) it is a relatively simple task to calculate the yield and estimate its value. Oil, on the other hand, is highly mobile within the earth's crust, presenting challenges ranging from how to ascertain the subsurface extent of an oil pool, to how to achieve equitable fiscal terms. Such questions will be explored in greater depth over the course of the chapter.

4.2 Domestic oil security: political and scientific rationality

In 1914, petroleum technologists of the American firm S. Pearson & Son Ltd presented to their British employer, Lord Cowdray, Managing Director of the Mexican Eagle Oil Company, results of preliminary investigations "to see just what the numerous indications of petroleum in Great Britain really meant" (Veatch, 1921, p. 6). Utilising data from the BGS, in particular survey work undertaken on Britain's extensive coal seams, they argued "the Midlands of England were a most amazing and striking character" being worthy of speculative exploration (Veatch, 1921, p. 6). This view was not shared by many British geological experts, who thought that only minute quantities might be found (Giffard, 1923). Smith argues some geologists during World War One announced they would drink any domestic oil which might be found (Smith, 2002a).

Over the next few years a heated political battle unfolded over two "Petroleum Bills". These centred on whether it would be in the public interest to pursue British oil exploration, and whether legislation would help or hinder oil production, which grew in importance as the war progressed (Spender, 1930). Conventional oil exploration was a novel concept in Britain in the first decade of the 20th century, and few had industry experience. With the onset of World War One, America had declared all oil related equipment strategic material not purchasable by foreigners. Consequently, drilling expertise would have to come from overseas.

Following only a brief period Cowdray announced to his business partner Lord Alexander Murray, Director in charge of the Company's Petroleum Research Department that he would be willing to spend £100,000 (rising to £500,000 if preliminary results proved successful) to fund a new project in England.[1] Cowdray planned to drill speculative exploratory

[1] Notes on the draft lease for consideration at the conference to be held at Messrs. Currey's Offices. 2nd November 1916. CEA: Box AS/2524 (i). Folder "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.

test wells to validate the hypothesis that Britain's subsurface geographies contained crude oil. If proven correct, a new industry might be started, creating jobs and securing a vital domestic fuel source.

Cowdray's leading petroleum technologist, A. C. Veatch stated the company's plan "[involved] the greater part of England and the south of Scotland, and since the project is so comprehensive, we desire to have associated with us men of outstanding business ability and importance in each locality. It would be our intention to form separate companies for operating in different localities, each of which would have the benefit of our special knowledge of oil prospecting, and the technical direction of our expert scientific and technical staff".[2] Cowdray's motivations were both patriotic and commercial. He believed the development of a new business was "of very great importance to [the] country – particularly in the days following the war".[3] The outcome of World War One rested on the ability to control, distribute and extract copious quantities of crude oil.

In 1916, with no proven domestic reserves, the United Kingdom imported 90% of its oil (McBeth, 1985). As early as 1904, British policy stipulated that oil concessions in the Empire would only be granted to British owned companies, highlighting the desire to stand independent of foreign controlled oil interests (Ferrier and Bamberg, 1982). In early 20th century Britain, mineral ownership was a complex and protracted process, even when original draft proposals were adequate and legitimate (Marcosson, 1924). Introducing a new energy regime could impact on the administration and governance of subsurface spaces, creating a potentially controversial topic. Landowner Charles Markham believed Cowdray wanted to monopolise territory and pointed out they "would never play that kind of game in this part of the world; there were far too many freeholders and it was quite possible for anybody to put a borehole in their own cottage plot".[4]

Domestic oil security was entangled with proposals for late 19th and early 20th century land nationalisation, which became a central policy in English radical reform from the 1880s onwards. The movement was largely inspired by Henry George's (1839-1897) single tax on land, which sought to give back private land to the masses, igniting a swirl of land ownership controversies and the notion of "Georgism" throughout Europe. In Britain, radical contemporary Thomas Spence had argued in the late 18th century that the control of land meant the control of men, devising a "plan" to remove landlords who possessed the power to control the population and indeed the government (Parssinen, 1973). Land reform gained momentum

[2] Letter dated 16th March 1917 from A. C. Veatch to W. D. Wadsworth. CEA: Box: Hardstoft oil (1) driller's reports. Correspondence from July 1915 to Nov 1916. S. Pearson & Co. Ltd.
[3] Letter dated 29th November 1915from A. C. Veatch to J. Cadman. CEA: Box AS/2524 (i). Folder "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.
[4] Letter dated 16th April 1917 from C. Markham to W. D Wardsworth. CEA: Box: Hardstoft oil (1) drillers reports. Correspondence from July 1915 to Nov 1916. S. Pearson & Co. Ltd.

following the initiation of the Royal Commission on Agricultural Depression, placing it at the centre of political debate (Roberts, 1993).

Agrarian radical Jesse Collings (1831-1920) pushed for the “three acres and a cow” model to transform the British land system in order to elevate the welfare of the British population (Readman, 2008). Colling’s classic “land reform” scheme was intended “to extend the largely ignored Ruralist perspective and assert the duality of meaning in the phrase 'back to the land', placing increased emphasis on the desire to return private, enclosed acres back to rural labourers in a drive to recreate the old farming classes of yeoman and peasant farmers (Roberts, 1993, p. 231). Collings felt it unjust that “territorial aristocrats” had dispossessed the poor through the enclosure acts. Using land for leisure and gaming was seen as “the most abhorrent manifestation of the evils of land ownership” (Roberts, 1993, p. 241). Collings’ plan to recreate “productive areas that conformed to a landscape aesthetic based upon utility” was based on the desire to make country dwellers independent of landlords by offering “peasant” or “yeoman” proprietorship loans of up to 100% (Roberts, 1993, p. 231). He introduced the Purchase of Land Bill in 1895 and campaigned for land reform up to 1914, repeatedly attempting to replace landlordism with mass land occupying ownership.

In 1908 Chancellor and Liberal politician Lloyd George introduced plans for a super tax of the rich. Land taxation was seen as a way of improving Britain’s social condition and reducing the deficit in unequal ownership of land. On 30th April 1909 the Board of Inland Revenue gathered data on land values across Britain by making landowners submit information on their hereditaments or “unit of occupation” - in order to calculate “Duties on Land Values” (Short and Reed, 1986). The Finance Act (1909-1910) reduced the deficit in unequal ownership of land by taxing the capital appreciation of a property or Estate based on improvements made to it. This Incremental Value Duty meant British landowners would have to surrender a proportion of their annual revenue to the government on account of improvements and expenditure through infrastructure and large scale development projects. As stated by HM Revenue & Customs (HMRC), the Bill was rejected by the House of Lords. However, in 1911 a Parliament Act removed the Lords’ power of veto. HMRC state that at the beginning of World War One, the standard rate of income tax stood at 6%, yielding an income to the Exchequer of £44 million, with a further £3 million in super-tax. By the end of the war this rate had increased to 30%, generating £257 million with an additional £36 million in super-tax (HMRC, 2012, np).

The new tax structure had a huge impact on British landowners. Prior to World War One the Duke of Devonshire had paid a combined income tax and super-tax of £15,000, but by 1918 this had risen to over £80,000.[5] The increase prompted the Duke to sell off parts of his

[5] Letter dated 16th August 1918 from Lord Hartington. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners Petroleum Committee 1917-1924.

Derbyshire estate, for example Chiswick was sold to the Chiswick Council. Oil wealth was a means to defray the new tax structure, making it an attractive proposition for Britain's landowners. However, should a district be found to contain oil, it could become uninhabitable, removing land tenancy as a form of income.[6] If oil were found on the Duke of Devonshire's estates, the land value would increase thus making landowners liable for increased payments.

4.3 The triangulation of British oil interests: landowners, private enterprise and the state

During 1915 to 1917 Cowdray concluded arrangements with over 40 prominent landowners in Mid and East Lothian, North Staffordshire and Derbyshire.[7] The 9th Duke of Devonshire (1868 – 1938) was one of the largest landowners contacted. His Derbyshire estates had been worked by numerous collieries for centuries, resulting in a heavily bisected subsurface. In America, coal winning operated in symbiosis with oil exploitation at this time. However, transposing the American paradigm would be far from straightforward in Britain. Three figures would form the backbone of this early 20th century phase in Britain's move to locate commercial oil deposits – the Duke of Devonshire, Lord Cowdray and Birmingham University Lecturer John Cadman.

Cowdray (1856-1927) left school at 16 to become an apprentice at his family's construction company, S. Pearson & Son Ltd, which had been founded by his grandfather Samuel Pearson (Jones, 2004, np). In 1875 he toured America, becoming interested in the dynamism of American trading. In 1879 he became joint partner of the firm with his father and in 1894 he became sole partner. Under his direction, the company became one of the largest contractors in the world. In April 1901, having missed a train connection in Mexico, he spent the night at Laredo on the Mexico-United States border, close to the Texas oilfield discovery. That evening he pondered a new business proposition, and went on to negotiate oil concessions with the Mexican dictator. He established The Mexican Eagle Oil Company, which, by 1907 was granted rights over 600,000 acres of land in Mexico. Cowdray was created baronet in 1894 and raised to the peerage in 1910 as Baron Cowdray of Midhurst, Sussex. In 1910, "Pearson luck" shone on Cowdray's drillers, as they tapped a gigantic oilfield. By 1914 Mexico had become the third largest oil-producing country after the United States and Russia, controlling approximately 60% of production. Cowdray created a vertically integrated business strategy, from upstream exploration and extraction to downstream refining, distribution and selling.

[6] Letter dated 16th August 1918 from Lord Hartington. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners Petroleum Committee 1917-1924.

[7] They included The Earl of Dalhousie, Sir Charles Seely, The Duke of Norfolk, The Duke of Rutland, Earl of Shrewsbury, Lord Rothermere, Lord Petre, Lord Stair, The Duke of Buccleuch, John Dalkeith, Marquis of Linlithgow, W. M. Arkwright of Sutton Scarsdale, the Trustees of St Thomas' Hospital, Lord Belper, the Hon Strutt and R.S.W. Sitwell Esq and The Duke of Devonshire amongst others.

Torrens elucidates that John Cadman (1877-1941) was born at the Villas in the North Staffordshire mining village of Silverdale, where he became affectionately known as "our Jack" (Torrens, 2004a, np). He came from a long line of mining professionals. His Grandfather John Furnival Cadman was manager of the Northwood colliery in Hanley, Staffordshire; his father, James Cope Cadman was a leading figure in mining engineering and surveying in the West Midlands. At the age of 17 Cadman became an apprentice at his father's colliery at Silverdale. In 1896 he was awarded Staffordshire County Council's first mining scholarship, going on to study Mining and Geology at Armstrong College, Newcastle on Tyne. He graduated with a first class honours degree in 1899 and was elected fellow of the Geological Society in 1900. He continued his studies to become DSc in 1908.

Cadman moved to Scotland in 1902, accepting the post of HM Inspector of Mines for East Fife and East Lothian, returning to Staffordshire as Inspector of Mines in 1903. His love of oil ignited when he saw small seepages at Longton Colliery, Staffordshire and again in the Bathgate oil shale region. In September 1904 Cadman was seconded as Chief Inspector of Mines in Trinidad, where he was asked to regulate the digging of asphalt which was at this time causing multiple litigation cases. According to Smith he "succeeded in settling many knotty problems… and did much to stimulate the development of the colony's oil industry". Cadman's posting lasted four years, during which he successfully established the Mines and Petroleum Department (Smith, 1941, p. 917).

On his return to Britain, Cadman became Professor of Mining at Birmingham University, replacing Professor Richard Redmayne who left to become Chief of the Mining Department of the Home Office. His main role was to lecture on the principles and practice of coal and metal ore mining. However, his passion lay in petroleum mining, and so he put before the University authorities a scheme to create a special branch of mining and gain the powers to award degrees in Petroleum Technology (Torrens, 2004a, np). Britain's first course of lectures on the geology of petroleum was given in the 1911-1912 session by Dr Arthur Wade in the Department of Geology, Imperial College, London (Hobson, 1991). Wade observed that petroleum science had been undertaken independently by chemists, oil well drillers and prospectors and desired to amalgamate theories from chemistry, mining and geology to better understand the natural history of petroleum (Wade, 1912).

Cadman hoped to build on this revolutionary idea. However, during its first year (1912), his course was widely criticised. For example, during his Presidential address, British geologist and educational administrator T. H. Holland announced "I really cannot find one commendable feature in the latest and most flagrantly advertised of our now bewildering variety of university degrees, the 'B.Sc. (Petroleum Mining)', at Birmingham … It is unfair to entice young men into a blind alley, and saddle them with a freak title that will handicap every attempt that they make in after life to specialise in a recognised branch of technology" (Holland, 1914, pp. 351-352). Despite criticism, in 1918 "*Oil News*" stated Cadman's course was "perhaps his most important public work…which has already been instrumental in providing men for [the world's] great oilfields" (*Oil News*, 22nd June 1918, p. 291). In 1913 Cadman ordered the installation of three fully functioning Persian drilling rigs on the Birmingham campus. He then argued for the need to train "Bore Masters" (oil rig drillers) so that the international oil market could utilise British subjects, rather than rely on those trained in America. Birmingham graduates were highly regarded and could immediately take up responsible positions in the oil industry (Biddlestone, 1991). The Birmingham course elevated Cadman's reputation in the oil industry, so that by 1913 he was recognised as one of the foremost British petroleum technologists.

At this time, Britain's industrial, foreign and domestic policies were being materially influenced by the need to secure supplies of oil, which "became a decisive factor in determining oil policy" (Brown, 2003, p. 2). This was exacerbated during the first decade of the 20th century by German expansionism, which put Britain on high alert for war. This in part, underpinned Winston Churchill's rationale to investigate the potential of converting the Royal Navy fleet from coal to oil. Coal had been Britain's preferred maritime fuel source and was considered essential for British commerce, its navy and empire (Gray, 2014). It was abundant in supply, supported local communities, and, unlike oil, would not spontaneously combust on contact with enemy fire. The United Kingdom's coal reserves supported a huge export industry, with coal from Cardiff being shipped throughout the world. Furthermore, Britain had an established global coaling network (Dahl, 2001). This included a number of foreign coaling sites, connected across spatial networks, which gave rise to a robust infrastructure that ensured "quality naval coal was available globally on a huge geographical scale" (Gray, 2014, p. 9). Moving away from its established global energy network meant the British navy was no longer able to control its fuel supplies in isolation, becoming a pawn controlled and affected by the nature of the supplying industry and the politics of producing countries (Brown, 2003).

Churchill saw numerous advantages with oil burning, however. Oil had twice the thermal energy of coal, which gave vessels a greater range and increased power. It was easier to store and could be pumped onto a ship rather than be loaded by the crew, which freed men for other duties. Refuelling could be undertaken at sea, which lessened the need for round trips. The increased level of flexibility also offered naval engineers the opportunity to redesign the vessels themselves. Churchill stated "The ordeal of coaling a ship exhausted the whole ship's company. In wartime it robbed them of their brief period of rest; it subjected everyone to extreme discomfort" (Churchill, 1923, p. 134). The Italian Navy had indicated the efficacy of oil burning, in conjunction with the requirement for modernisation during the 1880s, with Britain seeking to use oil in its high speed destroyers by 1900 (Evans and Peattie, 1997). By 1904 the United States had recommended using oil as a standalone fuel, commissioning their first oil burning destroyer, USS Paulding, in 1910 (Weissenbacher, 2009). Recognising the potential of oil for the Navy, Churchill pressed hard for a revision to Britain's energy regime upon becoming First Lord of the Admiralty in 1911.

Replacing Britain's strategic network of global coaling stations with oil fuelling nodes meant Britain had to secure the cooperation of at least one oil giant. Churchill secured aid from the Anglo Persian Oil Company (APOC), established in 1909 to exploit the vast oilfields of south-west Persia. Here, refined oil would be supplied to the Navy by a large oil refinery at Abadan. As a radical alternative to coal, the British government required an expert opinion on the quantity and quality of oil from the Persian fields. Cadman's ever growing reputation resulted in him being appointed on an Admiralty Royal Commission to investigate secure sources of oil (Farmanfarmaian, 2008, p. 221). Samples of the Persian oil were sent to Birmingham University, where they were analysed by Sir Oliver Lodge, who undertook experiments in his own research laboratory (Rowland and Cadman, 1960, pp. 57-60). These experiments furnished the British government with the precise scientific data needed to make an objective decision on the Persian oil situation. A contract to supply the Royal Navy with fuel oil was signed in May 1914, securing the supply of 40 million barrels of oil over 20 years (Richie, 1995). The agreement was followed by an Act of Parliament, justifying the decision on the basis of the Royal Commission's scientific findings, publicised six days before the outbreak of war.

4.4 The beginnings of commercial 'conventional' oil exploration in Britain

The first conventional oil strike in Britain was made whilst boring for coal at Kelham, near Newark, Nottinghamshire on 21st August 1909. The bore had been started on September 14th 1908, under the supervision of Mr J. Ford, Mining Engineer of The Coal and Iron Development Syndicate. Ford stated that the well progressed to 480 feet using percussive chisel-drills, before switching to rotary methods employing a diamond bit to secure accurate core samples. Oil was struck at a depth of 2,439 feet in porous sandstone 13 feet deep, giving a yield of five to six gallons per day which lasted for eleven months (Ford, 1909).

Mr Charles E. Best, Managing Director of The Coal & Iron Development Syndicate, commissioned British Petroleum Consultant Boverton Redwood[8], W. H. Dalton of the BGS and geologist Mr A. W. Eastlake to report on the discovery. They intimated the oil was a true petroleum of paraffin base, dark reddish-brown in colour of moderately high viscosity, having

[8] Redwood gained international acclaim following the publication of his "A practical Treatise on Mineral Oils and their By-Products" in 1897.

a specific gravity of 0.915 at 60^{0}C and flash point of 146^{0}F.[9] Ford believed the discovery was a "true normal deposit of petroliferous strata, likely to yield a very valuable supply of rich petroleum oil…which in view of the ever increasing demand for crude petroleum, and the very favourable conditions and advantageous position in which it has been found here, should lead to the establishment of a profitable oil industry in this country".[10]

Ford desired to sink several boreholes in order to produce oil on a commercial scale, which, he argued would be safe, easy and expeditious, owing to the accurate borehole data the company had gathered. He believed oil would flow regularly and in large quantities, and emphasised the geographical advantages of the bore. The navigable river Trent flowed through the estate on which the borehole had been sunk, providing cheap, direct and rapid transport to the Humber, where the Admiralty was due to establish oil depots. The oil could also be taken on river barges to depots in Grimsby or Hull for export, minimising costly handling. In addition, The Great Northern Railway ran through the estate providing a second means of bulk transport. Ford optimistically stated "I regard [this discovery] as a most promising oil proposition, which should quickly develop into a lucrative and prosperous undertaking".[11]

In 1914 Best submitted proposals to the Ministry of Munitions to drill in the vicinity of Kelham. The Ministry requested technical justification including the nature of the oil reservoir and the geological structure of the underlying Palaeozoic rocks. Ford's inexperience in oilfield development showed as he stated "I have no theory as to the source of origin of the oil" but, he argued, the finding of oil alone was sufficient to begin drilling operations.[12] Despite being willing to cover the expense of drilling themselves, the company was told it must gain a licence to bore for oil, which would only be issued once the financial stability of the company had been vetted. Moreover, credible geological data would have to be submitted and plant be shown to be available and fit for purpose.

Following a period of consultation, Best was issued a licence on 15th May 1914. He went on to form the "Oilfields of England" on 18th July 1914 with a floating capital of £250,000. On the advice of Redwood and Eastlake, the company proposed to drill three wells, marked "A", "B" and "C" on a preliminary report.[13] This created a surface triangle of 16.5 acres.[14] The first would be 160 feet N, 32^{0} E of the original coal borehole, driving an 8" diameter bore to

[9] Report of Sir Boverton Redwood and supplemental report attached. Entitled "Report on occurrence of petroleum at Kelham, near Newark, NOTTS" dated 15th November 1911. BGSA: GSM/XG/0/1-IGS2/862.
[10] Report by J. Ford dated 10th June 1914. BGSA: GSM/XG/0/1-IGS2/862.
[11] Report by J. Ford dated 10th June 1914. BGSA: GSM/XG/0/1-IGS2/862.
[12] Material taken from incomplete report giving details of discussion between Dr Gibson, Mr Ford, Dr Strahan and unknown Chairman. BGSA: GSM/XG/0/1-IGS2/862.
[13] Abstract of report by Sir Boverton Redwood and A. W. Eastlake dated 4th February 1916. BGSA: GSM/XG/0/1-IGS2/862.
[14] Letter (undated) from A. E. Sander (for the Oilfields of England Ltd) to the Controller of Munitions, Mineral Oil Production, Ministry of Munitions for War. BGSA: GSM/XG/0/1-IGS2/862.

2,500 feet. Redwood and Eastlake were "of opinion that there is absolute proof of the occurrence of crude petroleum at an easily accessible depth in the property under consideration…in quantity capable of remunerative extraction [via] the exploitation [of] suitably-placed wells".[15] The Oilfields of England had considerable difficulties in obtaining drilling equipment from America and drilled only two wells (A and B). Despite BGS guidance, neither located oil and the project was abandoned before well "C" was drilled.

Meanwhile, in Derbyshire, S. Pearson & Son Ltd evaluated geological data from the BGS in London, deducing that if oil were to be found in the UK, it would be located in the Carboniferous system. In other areas of the world, sandstones were typically productive. In the UK, however, these systems were poorly formed with many of the sandstone crests removed. Furthermore, indications of oil were common in the Carboniferous Limestone throughout the Coal Measures and lower part of the Yordale shales. Cowdray's team selected potential areas on the basis that:

1. the Lower Carboniferous was subject to impregnations;
2. the geological structure favoured the accumulation of oil at commercial drilling depths;
3. the geological structure possessed suitable porous beds to hold the oil, and impervious beds to prevent its escape.[16]

Three districts were ultimately pinpointed for exploration; the Lothians of Scotland, the Chesterfield District in Derbyshire and the pottery district in Staffordshire. By combining maps and plans produced by the BGS with mineral leases held by the Chatsworth Estate, Veatch and his assistant Mr Eugene Ickes (a geology graduate from California) and Mr Roderick Crandall (of Stanford University, responsible for technical administration) drew Britain's first "conventional" oil cartographies. The maps focused on land contours and anticlinal features forming the basis for detailed structural analysis. The Derbyshire and Staffordshire Districts were located due to their close proximity to the uplifts (anticlines) of the Carboniferous Pennine ridge system. Exploration in Derbyshire would test the eastern flank of the Pennine ridge, while that in Staffordshire would test the western flank (Wade, 1928, p. 357).

The Tibshelf area near Chesterfield was thought to be conducive to oil accumulation as (a) it had the closest anticlines, still retaining their impervious shale cappings to the Pennine ridge, and (b) "oil would be found overlying the limestone at the point where they joined the

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[15] Abstract of report by Sir Boverton Redwood and A. W. Eastlake dated 4th February 1916. BGSA: GSM/XG/0/1-IGS2/862.

[16] In-depth "Pamphlet" on the known occurrences of petroleum in the Carboniferous system of England. Large black folder contained within: CEA: Hardstoft Oil (2) correspondence.

shales".[17] Moreover, five large faults were thought to have created oil conservation structures around Hardstoft (see figure 4.1). In total, 11 sites were suggested across the three districts, seven in Derbyshire – Hardstoft, Heath, Brimington, Ironville No. 1, Ironville No. 2, Renishaw and Ridgeway and two in Staffordshire – Apedale and Warrington and two in Scotland.

[17] In-depth "Pamphlet" on the known occurrences of petroleum in the Carboniferous system of England. Large black folder contained within: CEA: Hardstoft Oil (2) correspondence.

Figure 4.1: Geological contour map developed by Veatch and Ickes showing outcrops and topographic information.

Source: *Andrew Naylor, August 2011. From: In-depth "Pamphlet" on the known occurrences of petroleum in the Carboniferous system of England. Large black folder contained within: CEA: Hardstoft Oil (2) correspondence.*

On 12th May 1915 S. Pearson & Son Ltd presented the Duke of Devonshire with a private memorandum in which they asked to acquire a mineral rights lease covering 3,000 acres (including some adjacent landowners) in Derbyshire.[18] The company proposed they form an exploration company with 60% capital subscribed by Cowdray, and the remaining 40% by landowners, calculated proportionately to total acreage. From this, Cowdray would receive repayment covering actual expenditure and a fee for administration. The company would pay a royalty of 5% on all oil won and sold, to be divided amongst landowners - again proportionate to acreage. A further 5% royalty would act as remuneration for the idea, initial risk of capital and technical expertise. Cowdray offered to pay landowners a subsoil rent of 2/- per acre merging into the royalty, which was to "commence at the expiration of three years from the commencement of the lease or from the organisation of the new company, whichever was earlier".[19]

Guided by his land agents, the Duke sought professional advice from Boverton Redwood, a British geologist who specialised in international oil exploration. However, at this time he "already [held] a retainer with the firm in question" so he suggested John Cadman for the role.[20] Land agent F. M. Sutton, acting on behalf of the Duke, wrote to Cadman on 12th October 1915 enquiring whether he would be prepared to advise the Duke on the grounds he "[desired] to obtain the best advice he can as to the terms upon which he should grant the concession".[21] Cadman replied "I shall be pleased to advise [the Duke] on the matter referred to in your letter".[22] An initial meeting was arranged at the Duke's solicitors at 14 Great George Street, Westminster, at 12 noon on Thursday 21st October 1915. Cadman and the Duke discussed Cowdray's proposals alongside Cadman's expected role. Following the meeting Cadman outlined the terms upon which he was prepared to act as Petroleum Advisor:

a) "a fee of one hundred guineas for work in connection with drafting licence and lease.
b) a retaining fee of one hundred and fifty guineas, together with out-of-pocket expenses, - to include periodic inspection of the drilling, and to advise His Grace generally upon the work being done under the lease. (£157.10.0d per annum)".[23]

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[18] Memorandum on Tibshelf dated 12th May 1915: CEA: Box AS/2524 (i). Folder: "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.
[19] Memorandum on Tibshelf dated 12th May 1915: CEA: Box AS/2524 (i). Folder: "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.
[20] Letter dated 12th October 1915 from Chatsworth Estate to J. Cadman. CEA: Box AS/2524 (i). Folder: "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.
[21] Letter dated 12th October 1915 from Chatsworth Estate to J. Cadman. CEA: Box AS/2524 (i). Folder: "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.
[22] Letter dated 13th October 1915 from J. Cadman to F. Manners Sutton, Esq. CEA: Box AS/2524 (i). Folder: "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.
[23] Letter dated 15th October 1915 from J. Cadman to Messrs. Currey & Co. CEA: Box AS/2524 (i). Folder: "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.

The Duke agreed to his terms, and Cadman began to examine Cowdray's empirical evidence with R. D. Wadsworth, another of the Duke's land agents. Cadman intimated that, while oil prospecting was highly speculative, the structural evidence presented by Cowdray's Petroleum Technologists was "sufficient to warrant a thorough test being made of the area in question…in these circumstances Messrs Pearson (Cowdray's staff) are considering a problem which is certainly worthy of attention".[24] However, he believed the terms were not equitable. His first point of objection was that the lease should not be required to deal explicitly with adjoining land. Given the scale of the Duke's estates relative to the adjoining areas, the Duke's property should be regarded as a separate entity. Secondly, he felt the terms had been dictated. In his opinion, the landowner was the only individual in a position to frame the terms of any lease. Cadman felt a 10% royalty was a more realistic figure and suggested setting a definite figure of 2/6d or 3/- per ton on the value of the oil raised. Alternatively, a figure might be calculated by integrating the net value of all necessary machinery. He stressed that a covenant be introduced into any formal lease, in order to indemnify the Duke against the likely protracted nature of the venture.

Before he submitted a lease for approval, Cadman wished to consult Cowdray's lead Petroleum Technologist, Dr. A. C. Veatch "to discuss with him generally the area within which Messrs Pearson are anxious to include in the lease".[25] In tandem, the Duke's mineral agents consulted literature on oil found within Carboniferous Limestone, including John Mawes (1802) *Mineralogy of Derbyshire*, John Farey's (1811) *A General View of the Agriculture and Minerals of Derbyshire* and White Watson's (1811) *A delineation of the Strata of Derbyshire from Bolsover to Buxton*. The results of their research were forwarded to Cadman, who stated "The information is all very interesting, and all adds to the chain of evidence which makes it worthwhile to put down prospecting holes to prove whether or not the limestone below the coal measure is oil-bearing".[26]

Cadman's initial proposals were immediately criticised. Alan Macpherson, land agent to the Duke, expressed his disappointment at Cadman's suggestion of a 10% royalty, arguing a higher starting value should be used as a point of negotiation.[27] In light of this, he argued the Duke should consider a price of 3/- per ton, rising to 4/- per ton, according to the specific gravity before terms were submitted to Cowdray.[28] The Duke took time to ponder his position,

[24] Letter dated 9th November 1915 from J. Cadman to the Estate Office, Chatsworth: CEA: Box AS/2524 (i). Folder: "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.
[25] Letter dated 9th November 1915 from J. Cadman to the Estate Office, Chatsworth: CEA: Box AS/2524 (i). Folder: "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.
[26] Letter dated 9th November 1915 from J. Cadman to the Estate Office, Chatsworth: CEA: Box AS/2524 (i). Folder: "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.
[27] Letter dated 12th November to A. Macpherson. CEA: Box AS/2524 (i). Folder: "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.
[28] Letter dated 25th April 1916 from W. D. Wadworth to J. P. Cockerell. CEA: Box AS/2524 (i). Folder: "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.

informing Cowdray it had been “necessary to obtain professional advice which has occupied a considerable time”.[29] Following Cadman’s suggestion he believed it “essential that [his] property should be the subject of negotiation investigation and development as an area by itself and quite distinct from any other property”.[30]

Lord Murray, Director in charge of Cowdray’s Petroleum Research Department agreed to pay all expenses, regardless of whether oil was found, and moved discussion to the nature of the details put to Cadman. Without going so far as to imply industrial espionage, Lord Murray elucidated “a competent geologist [might be] able to draw deductions with respect to other parts of England”.[31] The Duke responded, stating Cadman was fully aware of all developments, which he would treat with the strictest of confidence. He defended Cadman’s appointment, arguing “The possibility of establishing oil wells in England is so important and also opens up such a new field that I think you will agree that it is impossible for me to act in the manner without consulting the best expert advice obtainable”.[32]

When A. C. Veatch contacted Cadman he stated “Lord Murray tells me that His Grace the Duke of Devonshire has consulted you with respect to our English Project, and I would be very glad to meet you at any time and place convienient to you and discuss the subject”.[33] He pointed out the project might “[develop] a new industry at home [which] would be of very great importance to this country, particularly in the days following the war”.[34] He suggested he and Cadman meet either at Cowdray’s Head Office or Birmingham Univeristy to discuss the company’s proposals, stressing that no other landowner but the Duke of Devonshire had been approached at this time. However, following further consultation, the matter would be taken up with other landowners, a process which, it was hoped, would have the co-operation of the Duke and his advisors.

After several meetings with Veatch from November 1915 to February 1916, Cadman drew up his draft lease, which he submitted to the Duke on 21st March 1916.[35] The main problem had been the extent of the oil pool, which could underly adjacent landowners’ properties. The challenge was to represent landowners fairly, whilst acting on behalf of the Duke. He proposed

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29 Letter dated 16th November 1915 from the Duke of Devonshire to A. W. C. O. Murray: CEA: AS/2524. CEA: Box AS/2524 (i). Folder: “Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.
30 Letter dated 16th November 1915 from the Duke of Devonshire to A. W. C. O. Murray: CEA: AS/2524. CEA: Box AS/2524 (i). Folder: “Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.
31 Letter dated 18th November 1915 from A. W. C. O. Murray to the Duke of Devonshire: CEA: AS/2524. CEA: Box AS/2524 (i). Folder: “Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.
32 Letter dated 25th November 1915 from the Duke of Devonshire to A. W. C. O. Murray. CEA: Box AS/2524 (i). Folder: “Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.
33 Letter dated 25th November 1915 from the Duke of Devonshire to A. W. C. O. Murray. CEA: Box AS/2524 (i). Folder: “Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.
34 Letter dated 29th November 1915 from A. C. Veatch to John Cadman. CEA: Box AS/2524 (i). Folder: “Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.
35 Draft lease dated 21st March 1916 from J. Cadman to Messrs Currey & Co. CEA: Box AS/2524 (i). Folder: “Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.

a simple mathematical equation, giving the Duke discretion as to which proximal areas would be included in the lease, and the total royalty payable to each, being:

$$\frac{a}{a+b}$$

"a" represented the area owned by the Duke of Devonshire, while "b" represented adjacent landowners' property, to be included at the Duke's discretion. Cadman argued "a decision upon this point will have a material influence upon the terms which Lord Cowdray is prepared to pay, [thus] I should like to meet His Grace with a view to explaining more fully the proposals before submitting the general terms of the proposed lease".[36] Cadman's draft proposals suggested a lease period of five years for the initial exploration phase, during which test wells would be drilled to reveal whether the technical evidence was vindicated.[37] Oil royalties could be calculated in two ways - the first by a percentage value of the crude oil at the well's mouth, the second as a flat rate. Cadman favoured the latter, with revisions every 20 years up to 60 years.

While a well's mouth price would appear more equitable, "giving the lessees a proportional addition or reduction in the amount of the royalty payable" it would have to be constantly adjusted to reflect changing transport and field management costs.[38] He arrived at a fixed rate price by comparing the value of oil against coal in Britain, as well as the price paid for oil in the British colonies and Russia. Coal was achieving 6d to 8d per ton, and, as the thermal value of oil was three to four times greater than that of coals, a "value of 1/6d per ton appeared to be equitable".[39] Oil in Britain's colonies stood at 2/- per ton, with Russian imports standing at 1/4d per ton. In both instances, a reduction in royalty per ton was made on larger imports. Cadman arrived at a royalty of 2/- per ton without any reduction, providing adjustment periods were maintained. On minimum royalties and dead rent, he quoted typical figures from £1 to 10/- per acre for small areas, and 2/6d per acre for larger areas. For the Duke's territories he suggested a sliding royalty rising from £1,000 for up to 2,500 acres to £6000 for between 40,000-50,000 acres per annum.

Cowdray's petroleum geologists lacked non-invasive geophysical exploration tools; therefore the extent of oil reservoirs was poorly understood. Colliery data provided a relatively

[36] Letter dated 7th February 1916 from J. Cadman to Messrs Currey & Co. CEA: Box AS/2524 (i). Folder: "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.
[37] Draft lease dated 21st March 1916 from J. Cadman to Messrs Currey & Co. CEA: Box AS/2524 (i). Folder: "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.
[38] Draft lease dated 21st March 1916 from J. Cadman to Messrs Currey & Co. CEA: Box AS/2524 (i). Folder: "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.
[39] Letter dated 7th February 1916 from J. Cadman to Messrs Currey & Co. CEA: Box AS/2524 (i). Folder: "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.

detailed account of the subsurface, though it was limited to discrete areas, focused only on solids and lacked the necessary resolution to draw concrete conclusions. Anecdotal evidence and field reconnaissance offered only limited scope. The position of an oil lens raised a highly contentious issue. If oil were found to exist beneath a neighbouring landowner's property, the landowner may, unknowingly, be having his land sucked dry of its oil wealth. In an attempt to create equitable terms for all landowners, Cadman offered an alternate equation, providing special provisions for working adjoining vertical pools:

$$\frac{a}{a+b} \times c$$

Where "a", represented land owned by the Duke, "b" was land belonging to others, and "c" "the total royalty payment due in the whole "pooled" area in question".[40] Realising the potential problems associated with subsurface "oil pools" the Duke entrusted R. D. Wadsworth to establish "the areas under which the minerals do not belong to His Grace the Duke of Devonshire".[41] The cross hatching shown in figure 4.4 referred to areas where only the surface belonged to the Duke. Despite his Dukedom, his subsurface rights were embroiled in the particulars of complex surface and subsurface land leases, signed years before the notion of the domestic oil had come to fruition.

The Chatsworth Estate had a long established vertical exploitation regime, resulting in a complex interwoven subsurface geography. In the Hardstoft area, coal was leased by the Pilsley Company, Staveley Company, Hardwick Company and Babbington Coal Company (see figure 4.2). This subsurface ownership hologram did not share synchronicity with the surface, as shown in figure 4.3. Each company worked a specific seam at different depths. Sinking oil wells meant coal might have to be left in situ to act as support of the well. This had financial implications, as potentially economic seams could not be worked. A lease made between the Duke and the Pilsley Company, dated 16th February 1874, reserved the right to "all manner of mines and minerals whatsoever".[42] In order for the English Project to proceed, it became reliant upon a covenant submitted by Cowdray, indemnifying the Duke against injurious claims expected in due course by the colliery owners.

Cadman's revised equation was reviewed by the Duke's agents, who felt the five year exploratory lease period was too long. They argued they should discuss the total number of

[40] Draft lease dated 21st March 1916 from J. Cadman to Messrs Currey & Co: CEA: Box AS/2524 (i). Folder: "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.
[41] Letter dated 31st August 1916 from W. D. Wadsworth to A. Macpherson. CEA: Box AS/2524 (i). Folder: "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.
[42] Letter entitled "Tibshelf Minerals" dated 3rd July 1916. CEA: Box AS/2524 (i). Folder: "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.

wells to be sunk, as fewer wells may require a shorter lease and vice versa. Crucially, there was no mention of the overall area in question, which was vital to facilitate discussions with coal lessees. If only the Tibshelf area was to be included, this, by acreage, would fall within the small area; £1 and 10/- per acre. If the area was less than 2,500 acres, the Duke would not achieve the minimum £1,000 dead rent.[43] The group felt the 60 year lease was feasible, but argued if two shillings per ton royalty was achieved from the British Colonies and Russia, domestic oil should surely be worth more, as transport costs were less. A prospective company, they argued, should pay a royalty for the "privilege" of sinking exploratory wells. Costs, they intimated, should cover drilling and compensation to tenants for restoration of land damage, which was customary in usual colliery leases.[44] The group were also concerned that any changes to the land over 60 years would affect its future use and remove its utility value. Further discussions ensued, resulting in the suggestion that three wells should be sunk on the Duke's Derbyshire Estate in the initial five year exploration lease period, with a 2/- per ton royalty placed on all oil found.[45]

Figure 4.2 indicates the extent of mineral extraction in the vicinity of the first suggested borehole at Hardstoft. Babbington's solicitors argued the Hardstoft borehole would significantly hamper the development of the black shale seam of coal (which existed at a depth of 450 feet) and required assurances that no water, gas or oil could enter the seam. M. Deacon of H. M. Petroleum Executive was appointed to oversee discussions on the matter, stating "I am of opinion that, in order to preserve the perpendicularity of the borehole and to avoid the possibility of the coal workings being interfered with by water, oil or gas, it will be necessary…to leave a supporting pillar in the Blackshale Seam".[46] The dimensions of the exclusion zone are shown in figure 4.4 and equate to a column occupying a surface area of two acres. M. Deacon estimated the volume of commercially saleable coal within the exclusion pillar would be 10,570 tons. Based on a profit of 2s 0d per ton, plus a royalty of £90 per acre, discounted to a value of 8% per annum, the final figure to be paid to Babbington stood at £1,016.[47]

[43] Notes upon Professor Cadman's letter to Messrs Currey and Co. dated 21st March 1916. CEA: Box AS/2524 (i). Folder: "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.

[44] Notes upon Professor Cadman's letter to Messrs Currey and Co. dated 21st March 1916. CEA: Box AS/2524 (i). Folder: "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.

[45] Letter dated 17th April 1916 entitled "Tibshelf minerals" giving details of meeting held at 14 Great George Street Westminster. CEA: Box AS/2524 (i). Folder: "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.

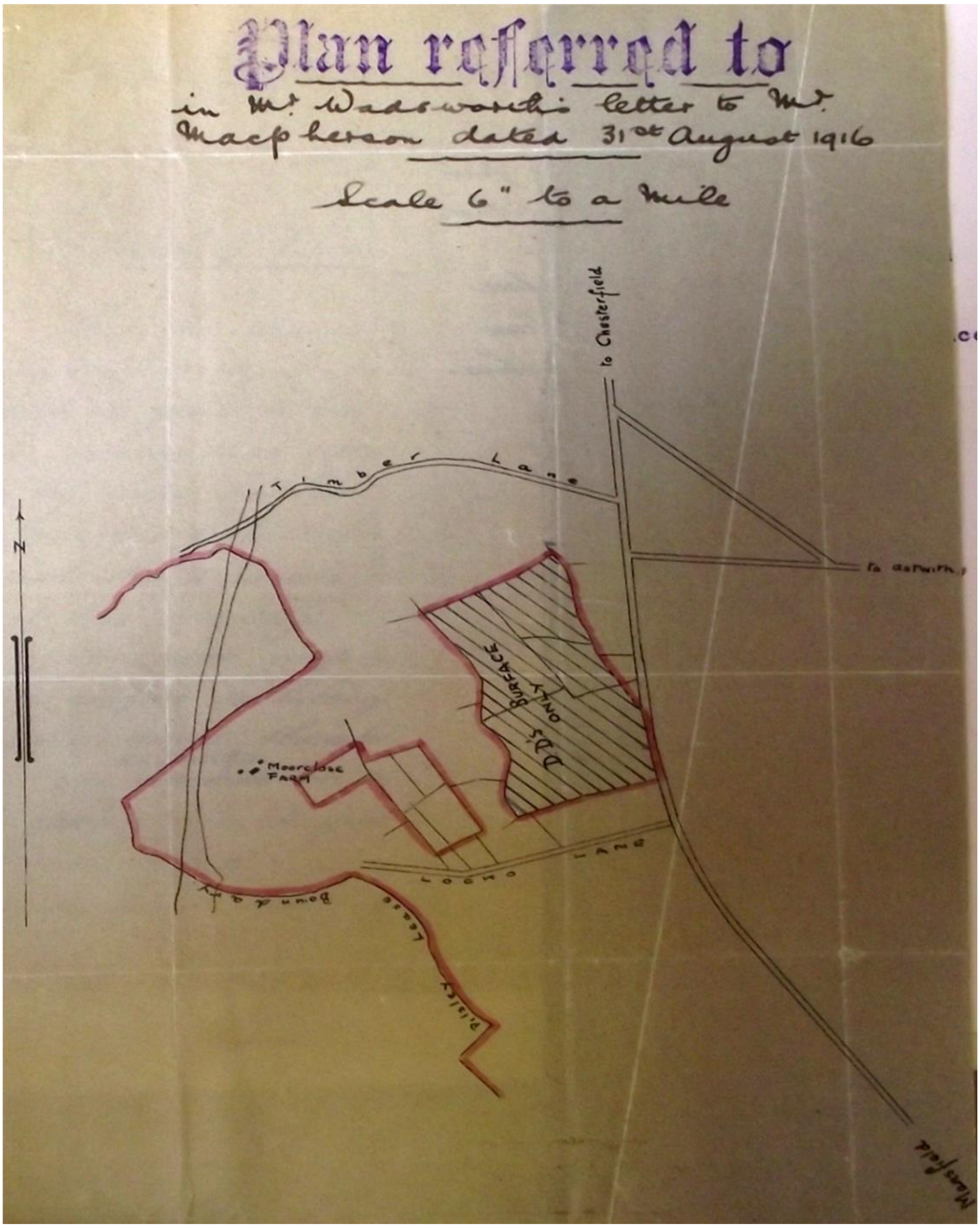
[46] Letter entitled "MINISTER OF MUNITIONS, MESSRS. S. PEARSON & SON LTD. And the BABBINGTON COAL COMPANY" dated 17th August 1920 from M. Deacon to The Director H. M. Petroleum Executive. CEA: Folder: 97. Petroleum. (Hardstoft).

[47] Letter dated 17th August 1920 from M. Deacon to The Director H. M. Petroleum Executive. CEA: Folder: 97. Petroleum. (Hardstoft).

Figure 4.2: Position of Hardstoft No. 1 borehole showing subterranean land leases held by the Hardwick Colliery Co. Ltd (yellow), Babbington Co. (green) and Pilsley Co. (red).

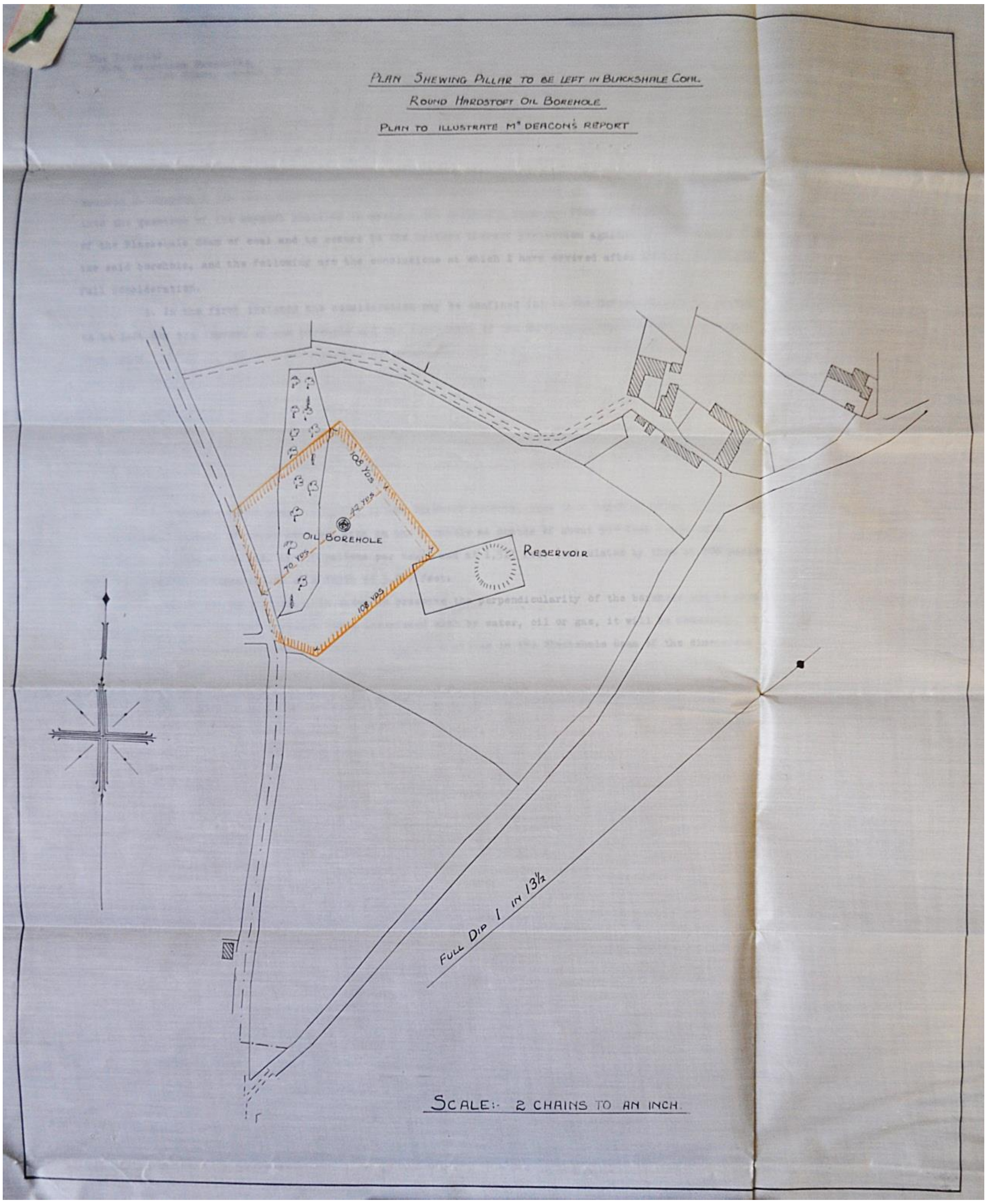
Source: *Andrew Naylor, August 2011. From: "Pamphlet" on the known occurrences of petroleum in the Carboniferous system of England. Large black folder contained within: CEA: Hardstoft Oil (2) correspondence.*

Figure 4.3: Land ownership rights reserved to the Duke of Devonshire in the vicinity of Hardstoft as of 1916.



Source: *Andrew Naylor, August 2011. From: W. D. Wadsworth (31ST August 1916). CEA: Box AS/2524 (i). Folder: "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.*

Figure 4.4: Position of Hardstoft No. 1 exclusion zone with associated dimensions.



Source: *Andrew Naylor, August 2011. From: Plan attached to letter dated 17th August 1920 from M. Deacon to The Director H. M. Petroleum Executive. CEA: Folder: 97. Petroleum. (Hardstoft).*

4.5 The Pearson (Cowdray) Agreement

In 1916, Cadman was appointed Chairman of the Inter-Allied Petroleum Council, before becoming Director of His Majesty's Petroleum Executive in August 1917.[48] Cadman's government oil duties had come via a recommendation by Sir George Fiddes to Walter Long, who in turn put the suggestion before Liberal politician Lloyd George (Long, 1923). Like others, Lloyd George was sceptical of the collier-turned-academic taking this vital role in British defences. In time, however, Lloyd George came to respect the "brisk, alert, and energetic man of medium height, whose smooth face had almost a boyish look" (Marcosson, 1924, p. 15).

Prior to his appointment, Britain's oil administration had been handled by numerous disparate departments who were not communicating effectively. As stated in *The Times*, "various government departments required petroleum products in huge and ever increasing quantities – the Admiralty for the Fleet, the War Office for motor traction, and the Air Service for aeroplanes to mention three – and made their purchases without much care for the requirements of each other or thought about the future" (*The Times*, 1918, p. 140).

Cadman consolidated Britain's oil usage and found stocks to be drastically underestimated. He presented his findings to Walter Long on May 28th 1917 and submitted proposals for the formation of a specialist Interdepartmental Committee on 15th June 1917.[49] Cadman reconfigured the Petroleum Supply Branch of the Ministry of Munitions of War into the Munitions Mineral Oil Production Division (MMOP) in July, which was charged with overseeing the domestic production and distribution of mineral oils.[50] As controller of domestic oil he deliberated on technical details with Boverton Redwood, reporting to the Ministry through Sir L. W. Evans, who ensured government departments were kept up to date with oil developments and formed sub-committees on storage capacity, shipping and the submarine menace.[51] Having been appointed state oil controller, Cadman requested he be released from his retainer to the Duke. This, the Duke's solicitors articulated, was unavoidable and reluctantly agreeable. A. Macpherson purported:

"[Cadman's] appointment cuts both ways, for while it gives us a friend in court it deprives us of Professor Cadman's services. I am sure our representations will receive

[48] The Petroleum Executive was later absorbed into the Petroleum Department placed under the Secretary for Overseas Trade. In 1922 it was again absorbed into the Board of Trade. In 1928 its status was downgraded as it became a branch of the Mines Department of the Board of Trade. Cadman remained as Director until 1921.
[49] Report entitled "Formation of the M. M. O. P." date unknown. BPA: ArcRef 68964.
[50] Report by the Ministry of Munitions of War entitled "Mineral oil production" date unknown. BPA: ArcRef 68964.
[51] Report by the Ministry of Munitions of War entitled "Mineral oil production" date unknown. BPA: ArcRef 68964.

sympathetic attention but whether they will prevail against the avowed policy of the socialist elements in the government is another matter".[52]

At this juncture, the English Project had been ongoing for three years without any drilling having been undertaken, largely due to the protracted behaviour of the landowners. This prompted investigations into alternate means of securing domestic oil. In February 1917, efforts were made to reignite the potentialities of the rapidly declining Scottish oil shale industry. Workers' and landowners' committees were formed, with Cadman and Mr J. C. Clarke acting as mediators. In order to stimulate production, the eight hours working act was suspended, men were recalled from colours and transferred between mines and managers, and workman committees were formed to tackle absenteeism.[53] Workers agreed to a subsurface war bonus of 6d. per day, however, labour shortages and military service led to the possibility of strike action.[54]

Cadman pointed out that since the invention of the incandescent burner, gas works had ceased to use cannel coal, which was left underground as an unsalable product.[55] A number of collieries had supplied him with the results of investigations alluding to potential yields of 20/80 gallons of crude oil per ton of cannel coal.[56] By removing part of the elaborate refining process (known as scheme G), an additional 20% could be secured from Scottish shale.[57] Ultimately, however, a shortage of labour and the resource intensive refining process precluded the resurrection of the Scottish oil shale industry during World War One.[58]

Aware of the pressing need for fuel oil, Cowdray attempted to accelerate his English Project by submitting a draft Petroleum Bill to the House of Commons on 15th August 1917, having placed an order in America for all necessary machinery to begin drilling during the summer of 1918. In tandem, as a way of tackling the longstanding land ownership question, he suggested the government requisition land under the Defence of The Realm Act (DORA) as one branch dealt with land ownership. The 1916 Acquisition of Land Act had allowed the military rights to land without the landowners' consent, if it were deemed necessary to the war effort. By inserting a simple amendment Cowdray hoped to temporarily remedy the longstanding ownership problem. DORA gave the government the right of occupancy, and not

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52 Letter dated 15th October 1917 from A. Macphereson to W. D. Wadsworth. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners Petroleum Committee 1917-1924.
53 Report entitled "Scottish shale industry (P. E. 5). Date unknown. BPA: ArcRef 68964.
54 Report entitled "Scottish shale industry (P. E. 5). Date unknown. BPA: ArcRef 68964.
55 Report by J. Cadman dated 20th May 1917 entitled "Oil production from cannel coal". BPA: ArcRef 68964.
56 Report by J. Cadman dated 20th May 1917 entitled "Oil production from cannel coal". BPA: ArcRef 68964.
57 Report from J. Cadman to Sir L. Worthington Evans, Bart. M. P. dated 13th August 1917. BPA: ArcRef 68964.
58 Post war the APOC purchased the remaining six Scottish shale oil producers under a subsidiary named Scottish Shale Oils Ltd.

ownership, thus it was a temporal fix exercised under hostile circumstances. Amendment 2a.a.a was inserted on 15th January 1918 "With a view to developing as economically and expeditiously as possible any supply of petroleum which may exist in strata in the United Kingdom".[59] Amendment 2.a.a.a of DORA temporarily silenced the landowners, giving the government access to all areas deemed to have petroliferous potential. Coupled with the passing of the Petroleum (Production) Act 1918, Lord Cowdray was finally able to enact the English Project.

Cowdray's first shipment of equipment reached Britain on 7th July 1918, with the remainder arriving as and when shipping would allow.[60] At this time, fifteen speculative areas in the UK had been submitted to the Secretary of State to the colonies. The new legislation would ultimately result in the nationalisation of British oil. It included provisions to make a nine pence royalty payment to landlords, and a principle of compensation should coal mines ever be nationalised.

In a letter to A. Macpherson, Lord Hartington, the 9th Duke of Devonshire's eldest son expressed his concerns surrounding the Bill. He felt the royalty was grossly inadequate, though he acknowledged that a smaller royalty payment was less likely to be attacked by the Labour party than a larger royalty, which would undoubtedly receive their attention. Ninepence was certainly better than nothing, he remarked.[61] Lord Murray had told Lord Hartington that Cowdray's staff believed "the oil [would] be of a remarkably high quality, rather than excessively plentiful" thus demanding a higher price.[62] Consequently, Lord Hartington felt a royalty should be a percentage of the oil's overall value. The Bill was met by hostility from the Labour party, who had for decades opposed the payment of royalties to landlords for coal. At a meeting held in September 1917, Lord Hartington studied the terms of the proposed Bill with Cadman, who, despite asking to be released from his contract with the Duke, was still acting as his advisor.[63] The Petroleum Production Bill had two primary features:

1. the exclusive right of searching and boring for and getting petroleum within the United Kingdom should be vested in the Crown or License;

[59] Regulations attached to letter dated 13th April 1918 entitled "Petroleum" CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners Petroleum Committee 1917-1924.
[60] HC Deb 31 October 1918 vol 110 cc1593-7.
[61] Letter dated 4th September 1917 from Lord Hartington to A. Macpherson. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners Petroleum Committee 1917-1924.
[62] Letter dated 4th September 1917 from Lord Hartington to A. Macpherson. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners Petroleum Committee 1917-1924.
[63] Letter dated 15th October 1917 from A. Macpherson to J. P. Cockerell. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners Petroleum Committee 1917-1924.

2. a sum of 9d per ton on all petroleum should be paid into a special fund to be distributed among the landowners interested in the area from which the petroleum had been won.[64]

The ninepence royalty created uproar amongst Britain's landed gentry who believed it to be far too low. Nonetheless, the Labour party desired to confiscate all undeveloped mineral resources so that any profits from hydrocarbon exploration would be vested in the nation. The Duke's agents arranged a meeting with Walter Long to negotiate a fair royalty payment of no less than 2/- per ton.[65] A. Macpherson prepared a short memorandum, which Lord Hartington submitted to Long's secretary.

Meanwhile, A. Macpherson contacted the Land Union, which had been successful in obtaining amendments to the 1916 Acquisition of Land Act. At 12.45 on Thursday 25th October 1917, Lord Hartington and A. Macpherson met with Walter Long at Westminster.[66] No other landowners were present as it was felt a clearer discussion could be had on a one to one basis. The following details are taken from a letter sent from J. P. Cockerell to A. Macpherson.[67] Lord Hartington and A. Macpherson hoped Walter Long would press for the Bill to be dropped, so that landowners could enter negotiations with the Admiralty directly. Long opened by arguing there was little hope of increasing royalty payments. In fact, "he had to face an amendment for the deletion of the royalty altogether". In his opinion, if the royalty clause were to be thrown out completely he wished to see the Bill dropped. However, he was unsure if this view was shared by fellow cabinet ministers. Long suggested royalties be calculated on a sliding scale, relative to total tonnage. The pair asked whether the measure would cover only the period of the war, to which Long intimated it was "impossible as the initial cost of prospecting was too great". If, however, the Bill were to be passed, landowners might be able to claim expenses back through the Losses Commission.

Lord Hartington argued that while they had no desire to revolt in principal, they would join other landowners in approaching the Land Union to attempt to secure fairer terms through The House of Lords. Following the meeting, the results were put to Crofton Black of the Land Union, a member of the Land Agents' Society, Sir F. Walker, the Duke of Northumberland's agent, and his solicitors Mr Ray and Mr A. H. Kerr, who had assembled nearby. They decided at once to draw up draft amendments, focusing on three elements:

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[64] Copy of Petroleum Production Bill contained within CEA: Box AS/2524 (i).
[65] Letter dated 15th October 1917 from A. Macphereson to W. D. Wadsworth. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners Petroleum Committee 1917-1924.
[66] Letter dated 22nd October 1917 to Lord Richard Cavendish. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners Petroleum Committee 1917-1924.
[67] Letter dated 26th October 1917 from J. P. Cockerell to A. Macpherson. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners Petroleum Committee 1917-1924.

1. royalty payments to be substituted for a royalty of one eighth of the value of any oil found, to be paid in cash or kind (as was the custom in America);
2. the elimination of a clause relating to the Railway Canal Commission leaving the entire control in the hands of The Board of Trade;
3. the right of the property owner to full compensation for damages incurred.[68]

The Petroleum Production Bill was ultimately rejected following its third reading, with cabinet members pointing out that under a previous session contentious legislation could not be resubmitted during war time (Veatch, 1921). It was subsequently decided that a Bill ought to be passed to ensure no one could sink a test well for oil or gas in Great Britain without a licence from the government. Furthermore, royalty payments and land ownership issues would be dealt with after the war. The government also retained powers to reserve certain areas and issue licences so long as drilling operations were properly carried out.

By March 1918 the Land Agents' Society had formed a small sub-committee to offer advice to landowners on land ownership and mineral rights in the UK.[69] The Marquis of Crewe was appointed Chairman, with C. R. Knollys, the Duke of Buccleuch's agent, communicating with landowners as well as formulating a defensive strategy.[70] The Land Union had successfully defended landowners' rights against the Finance Act (1909-1910), while The Surveyors' Institution, Land Agents' Society and other agencies had opposed state legislation relating to surface territory. However, none of them had experience in oil and petroleum.

A meeting of landowners and their agents was held at 16 Bedford Square, London at 1400 on Friday 5th April 1918.[71] It resulted in the formation of an Association of Rural Landowners, closing the door on urban landowners who were not eligible to apply.[72] On 10th April 1918 *The London Telegraph* reported a (landowner) committee had been appointed "to consider…the production of fuel oil from home sources…and to consider the steps which have been taken by the Ministry of Munitions in this connection".[73] English and Scottish proprietors would communicate either through the Scottish Land and Property Federation or through a

[68] Letter dated 28th October 1917. CEA: Box AS/2524 (i). Folder "Oil Tibshelf Minerals 12 May 1915 to 30 November 1916.
[69] Letter dated 25th March 1918 entitled "Meeting of land Owners and Land Agents". CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners' Petroleum Committee 1917-1924.
[70] Letter dated 25th March 1918 entitled "Meeting of land Owners and Land Agents". CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners' Petroleum Committee 1917-1924.
[71] Letter dated 13th April 1918 entitled "Petroleum". CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners Petroleum Committee 1917-1924.
[72] Agenda for Landowners Association. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners Petroleum Committee 1917-1924.
[73] Letter dated 11th April 1918 from W. D. Wadsworth to A. Macpherson. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners Petroleum Committee 1917-1924.

smaller sub-committee of the Association of Rural Landowners appointed on 12th April 1918.[74] Only landowners who had been approached by, or were involved in negotiations with the government would be eligible for the Association of Rural Landowners' services. The Association was granted separate funds to defray expenses and actively monitor the petroleum policy regime using industry experts where necessary.[75] Land agents would have periodic meetings to communicate current and ongoing issues. Mr Yate Lee was charged with developing a draft lease,[76] which was subsequently passed to Cunningham-Craig, a world renowned British Petroleum geologist,[77] who, for a fee of £105, added technical detailing before submission to the government.[78]

The development of "undeveloped minerals" required expertise in oil matters and a source of funding. The Association of Rural Landowners was managed by a central council, elected from various county organisations, with leading landowners in each county tasked with forming central bodies to draw up rules and regulations. For the first time in British history, landowners joined forces in opposition of government control of subsurface territories. In order to access the services of the Association of Rural Landowners, each landowner would pay a small annual subscription proportional to the size of his/her estates, as shown in table 4.1.

Table 4.1: Annual subscription payable to Association of Rural Landowners.

Size of estate	Annual subscription
Under 2,000 acres	10s 6d
Over 2,000 and under 30,000	£1.15s 0d
Over 30,000 acres	£2: 2 0d

Source: *Tabulated from pamphlet entitled "The development and exploitation of unproved minerals in Great Britain: Proposed Association of landowners. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners Petroleum Committee 1917-1924.*

[74] Letter dated 12th April 1918 entitled "Petroleum Rights. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners Petroleum Committee 1917-1924.
[75] Agenda for Landowners Association. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners Petroleum Committee 1917-1924.
[76] Letter dated 17th May 1918 from A. H. Kerr to A. Macpherson. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners Petroleum Committee 1917-1924.
[77] See Torrens (2004b).
[78] Agenda for meeting to be held on 20th June 1918. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners Petroleum Committee 1917-1924.

On 16th May 1918, Cunningham-Craig had received crucial information on the exploration campaign, elucidating the government had come to an agreement with Cowdray to match a £500,000 investment to test for free petroleum.[79] This, he argued, "[would] probably mean a monopoly for the drilling for the group, [with] a good deal of "wild catting" [likely] in various Estates. [In light of] inefficient government officials [a monopoly might be] disastrous for landowners".[80]

The thought of a Cowdray monopoly prompted the Association of Rural Landowners to "elicit competition from other oil companies".[81] Drilling locations would be chosen by Cunningham-Craig, who "[did] not think it advisable that the Cowdray group should have a monopoly, even with government co-operation".[82] A. Macpherson was of the opinion that the Duke of Devonshire should engage in discussions with the D'Arcy Exploration Company Ltd, a subsidiary of the APOC formed in 1914. D'Arcy representatives attended a meeting organised by the Landowners' Committee on the 11th July 1918 to discuss their possible role in averting a Cowdray monopoly. D'Arcy representatives stated they were prepared to drill for petroleum but the introduction of the Petroleum Bill had made the proposition more precarious. British Conservative politician Worthington Evans intimated "the D'Arcy Exploration Company Ltd was in a very small way of business and could not obtain the necessary plant for drilling [therefore] he could not advise proprietors to enter into negotiations with the D'Arcy Company".[83] Regardless, D'Arcy was not prepared to drill experimental wells on the Devonshire estate until they had tried "some half dozen other places which they [thought] were more promising".[84]

The Duke's mineral agents remained hopeful that in time they might "eventually induce the D'Arcy Company to try [their] area also".[85] Writing to A. Macpherson on 21st August 1918, Lord Hartington stated "So long as we can ensure that the property is not locked up indefinitely, I do not suppose that it much matters if they do not investigate it at once".[86]

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[79] Letter dated 16th May 1918 from Cunningham-Craig to A. H. Kerr. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners Petroleum Committee 1917-1924.

[80] Letter from A. H Kerr to E. H. Cunningham Craig. Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners' Petroleum Committee 1917-1924.

[81] Letter dated 16th May 1918 from Cunningham-Craig to A. H. Kerr. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners' Petroleum Committee 1917-1924.

[82] Letter dated 16th May 1918 from Cunningham-Craig to A. H. Kerr. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners' Petroleum Committee 1917-1924.

[83] Letter dated 18th July 1918 from J. A. Greene to A. H. Kerr. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners' Petroleum Committee 1917-1924.

[84] Letter dated 16th August 1918 from Lord Hartington. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners' Petroleum Committee 1917-1924.

[85] Letter dated 16th August 1918 from Lord Hartington. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners' Petroleum Committee 1917-1924.

[86] Letter dated 21st August 1918 from Lord Hartington to A. Macpherson. Letter dated 16th August 1918 from Lord Hartington. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners' Petroleum Committee 1917-1924.

4.6 The oil imperative: expediting oil exploration in Derbyshire

By spring 1918, German submarines were having a disastrous effect on allied oil supplies. After consulting all government departments on the fuel shortages, Walter Long had argued a "minimum stock of oil products should be secured… If the stocks in this country are allowed to fall below this margin of safety disastrous consequences will ensue and I am to state that this minimum stock has not yet been secured".[87] So desperate was the need to secure oil that in August 1918, British Liberal politician Lloyd George finally announced the domestic oil situation "[is]…of the highest importance that any possible sources of free oil supply within the United Kingdom should be explored at once by the expert investigators".[88] Lord Cowdray subsequently agreed to offer the services of his firm at the disposal of the government free of charge (Cowdray was willing to offer 10 oil rigs) as well as agreeing to make his scientific investigations available to others.[89] Cowdray's only covenant was that the government would pass legislation to eradicate the damaging practices of indiscriminate drilling. In response, Lloyd George contacted Churchill, remarking:

"Lord Cowdray on behalf of his firm of Messrs. S. Pearson & Son [has] made a most generous, self-sacrificing offer to the government to place the whole of their highly promising investigations…as to the probable existence of free oil in Great Britain, and their services at their disposal of the nation… before they disclose the results of their scientific researches legislation should be passed which would prevent the waste of oil and ruin of oil pools resulting from indiscriminate drilling and safeguard an industry so vital to the nation".[90]

Lloyd George argued that the prorogation in the House of Commons was long, the Petroleum Bill having only recently received its first reading in the House of Lords. He stated "Messrs. S. Pearson & Son have made an agreement with your Ministry, whereby without fee or reward, direct or indirect, they will act as the government's agents in developing this oil. On the strength of this agreement they have imported men and material and are ready to go ahead".[91] In his opinion, it would be a national misfortune if the Act were delayed through the failure to pass the legislation through the present session. Lloyd George concluded by asking Winston Churchill to contact Lord Cowdray so as to "proceed forthwith with their drilling operations and in return to assure them that the government will take steps to carry the Bill through its remaining stages in the House of Lords in the earliest weeks of next session".[92]

[87] Letter dated 13th February 1918 from Sir J. Cadman to Secretary to the Restriction of Imports Committee (secret). PA: LG/F/32/5/6.
[88] Letter dated 14th August 1918 from D. Lloyd George to Winston Churchill. PA: BL/83/6/28.
[89] Letter dated 4th November 1917 from Lord Hartington to A. Macpherson. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners' Petroleum Committee 1917-1924.
[90] Letter dated 14th August 1918 from D. Lloyd George to Winston Churchill. PA: BL 83/6/28.
[91] Letter dated 14th August 1918 from D. Lloyd George to Winston Churchill. PA: BL 83/6/28.
[92] Letter dated 14th August 1918 from D. Lloyd George to Winston Churchill. PA: BL 83/6/28.

Before travelling to France, Churchill asked John Bernard Seely, Minister of Munitions, to communicate with Cowdray on his behalf. Seely wrote to Churchill, who expressed "his attention to take all possible steps to pass the Bill into law as soon as Parliament assemble[d]. I hope this will enable you to continue the operations which are of such vital importance to the state, especially under the present war conditions".[93] Lord Cowdray responded the following day stating "Have wired my firm to proceed forthwith with utmost expedition".[94]

Meanwhile, the Association of Rural Landowners attempted to stimulate D'Arcy to act before the Bill had its second reading in the House of Lords.[95] However, with the impetus of Lloyd George and Winston Churchill, the Petroleum (Production) Act 1918 passed through Parliament on 10th September 1918, becoming known as the "Pearson Agreement". As Director of the Petroleum Executive, John Cadman, acting alongside the Geological Advisory Committee (consisting of BGS Director Dr A. Strahan, Dr W. Gibson of the BGS, Professor Boulton of Birmingham University, Professor Watts of Imperial College, London and Cadman himself)[96] became responsible for approving 15 areas for oil exploration, which amounted to an aggregate of 100 acres.[97] The Petroleum (Production) Act 1918 was Britain's first piece of legislation relating to the searching and boring for oil – a landmark in British history.

The state agreed to allocate £1 million in public funds to the exploration campaign, with the Pearson (Cowdray's) Company acting as agents of the state, receiving no remuneration for any oil found and passing all geological results to the British government (McBeth, 1985; Jones, 1981). Should the Duke of Devonshire not cooperate with Cowdray his land would be commandeered under DORA. In the interest of national security he gave permission to allow Cowdray to make arrangements with tenants and pay compensation accordingly. Despite government pressure, the Duke defiantly stipulated that sites must be properly fenced and not less than 2,000 yds "Crow walk from Hardwick Hall".[98] Moreover, compensation would be paid to tenants and the Duke for loss of surface rents at agricultural value. Finally, he specified that no spoil bank would exceed ten feet in height, so as not to interfere with the view from Hardwick Hall.

In Derbyshire, the passing of the Act meant that Cowdray, having ordered equipment despite a delay in supporting legislation, could erect drilling machinery on the Duke of

93 Letter dated 16th August 1918 from J. B. Seely, Ministry of Munitions to Lord Cowdray. PA: BL83/6/28.
94 Letter dated 17th August 1918 from Lord Cowdray to John Bernard Seeley. BL 83/6/28.
95 Letter dated 21st August 1918 from Lord Hartington to A. Macpherson. Letter dated 16th August 1918 from Lord Hartington. CEA: Box AS/2524 (i). Folder: Petroleum (Production) Bill. Landowners' Petroleum Committee 1917-1924.
96 HL Deb 06 November 1918 vol 31 cc1049-102.
97 HC Deb 31 October 1918 vol 110 cc1593-7.
98 Letter dated 2nd September 1918 from J. P. Cockerell to A. Macpherson. CEA: Box No. AS/2524 (ii). Folder entitled "Oil boring at Hardstoft 2 September 1918 to 17 July 1919.

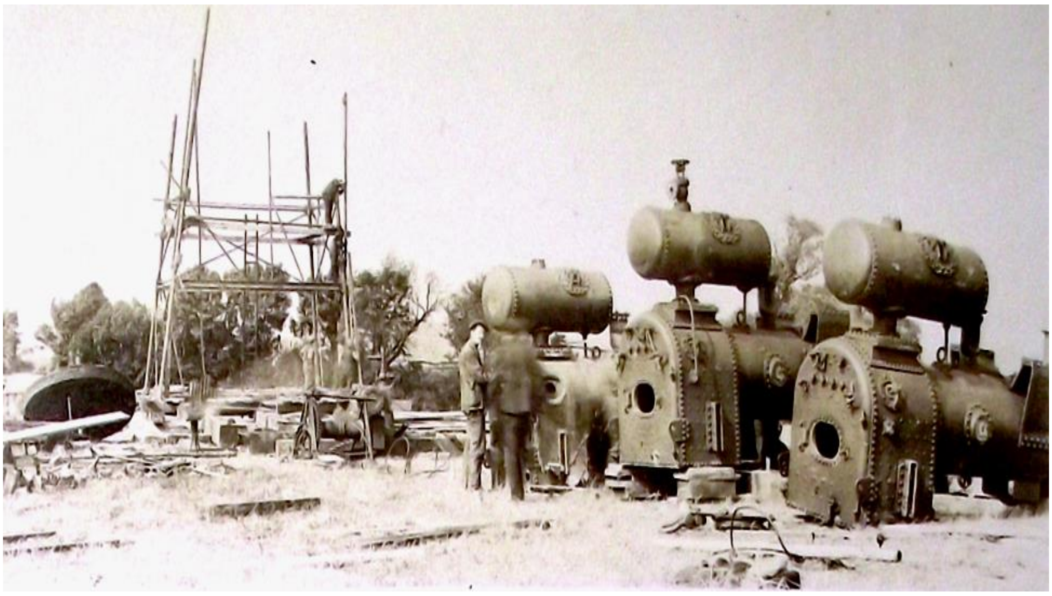
Devonshire's estate immediately. On 19th September 1918 the Duke of Devonshire's mineral agent, Cowdray, and Colonel Bathurst discussed preparations being made at Biggin Farm near Tibshelf (Hardstoft No. 1) and at Manor Farm near Stainsby (Heath).[99] A further two sites had been chosen on the property belonging to Sir George Sitwell, approximately 0.5 miles south west of Renishaw Hall, and on the recreation ground at Brimmington Common.[100] Although the Duke still disputed the validity of DORA, it did offer hope for post-war resettlement. It was argued that it would have been a "mere waste of time to submit an elaborate form of agreement with Messrs Pearson (Cowdray), if the government all along intended to take the oil for nothing".[101] With this agreed, arrangements were made for the commencement of drilling. This puzzled A. Macpherson, who questioned the intentions of the Duke by writing to his son, Lord Hartington:

"[The] newspapers state you propose to inaugurate [the] boring for oil near Hardwick next Thursday. Hope this not true as it would prejudice legal position of Duke and other Landowners".[102] Although the Duke and his representatives would do everything to facilitate the finding of oil, "His Grace could not admit the right claimed by the government to take the oil without payment nor must the fact of access having been granted be taken as an admission on His Grace's behalf to the validity of D.O.R.A Regulations under which the government purport to act".[103]

The first borehole, Hardstoft No. 1, was located on the crest of a subsidiary Pennine fold. Machinery was erected in the summer of 1918 by American drillers J. E. Jones and W. D. Groves and "Tool dressers" F. Neptune, E. S. Green, A. Whitfield, B. Henderson (assistant) and J. Simpson (see figures 4.5 and 4.7). They were housed in the two wooden shacks shown in figure 4.8. The inauguration took place on Tuesday 15th October 1918, 27 days before the Armistice was signed (see figure 4.6 for the completed derrick). A large crowd gathered around the borehole, eagerly awaiting Lord Hartington's inaugural address.

[99] Letter dated 19th September 1918 to Arthur H. Battock. CEA: Box No. AS/2524 (ii). Folder entitled "Oil boring at Hardstoft 2 September 1918 to 17 July 1919.
[100] Letter dated 19th September 1918 to Arthur H. Battock. CEA: Box No. AS/2524 (ii). Folder entitled "Oil boring at Hardstoft 2 September 1918 to 17 July 1919.
[101] Letter dated 3rd October 1918 from A. Macpherson to J. P. Cockerell. CEA. Box No. AS/2524 (ii). Folder entitled "Oil boring at Hardstoft" 2 September 1918 to 17 July 1919.
[102] Letter dated 9th October to Lord Hartington. CEA. Box No. AS/2524 (ii). Folder entitled "Oil boring at Hardstoft 2 September 1918 to 17 July 1919.
[103] Letter dated 9th October to Lord Hartington. CEA. Box No. AS/2524 (ii). Folder entitled "Oil boring at Hardstoft 2 September 1918 to 17 July 1919.

Figure 4.5: Construction of Hardstoft No. 1 showing boilers shipped in from America.



Source: *Andrew Naylor, August 2011. From: In-depth "Pamphlet" on the known occurrences of petroleum in the Carboniferous system of England. Large black folder contained within: CEA: Hardstoft Oil (2) correspondence.*

Hartington's speech gave poignant reminders as to the cause of the campaign:

"I need not emphasise the tremendous importance of the undertaking which we are inaugurating today. We all know that petroleum is a most vital necessity for the Air Service, for the Army and for the fleet. Many have suffered a certain amount of inconvenience from the shortage of it. If we can feel that Derbyshire is assisting, even a small degree, to assure a home oil supply to the Fleet, or to release tonnage, we shall be more than satisfied…I am sure that everyone here will agree with me that our best thanks are due to Messrs Pearson (Cowdray) for the patriotic way in which they have put their skill, their experience and their plant at the disposal of the government for this undertaking…I think the landowners of England have behaved no less patriotically. Messrs Pearson (Cowdray) had the plant and we had the oil".[104]

Hartington continued with cautionary warnings aimed at the British government:

"I have come down here this afternoon to make it clear that my father's attorneys, acting on his behalf, are prepared to do all that lies in their power to secure a supply of mineral oil to His Majesty's government. I wish to make it clear at the same time that we do not permanently give up our rights over the oil. The government are sinking this well with our consent. Had our

[104] Lord Hartington's inaugural address given on Tuesday 15th October 1918. CEA. Box No. AS/2524 (ii). Folder entitled "Oil boring at Hardstoft 2 September 1918 to 17 July 1919.

consent not have been given I understand that we should have been served with a notice under the Defence of The Realm Regulations, but we do not admit the legality of the regulations governing the production of oil…We are not prepared to see vast fortunes made out of oil and what remains to us of our fair countryside defaced without compensation to those interested in the soil. Moreover, we do not believe in a policy under which the management of what may be a very important industry should be entrusted to or vested in the state. Such a policy would be foreign to the tradition of our country, to the great principles which have given England the position she holds and, I believe, in the long run to the best interests of this budding industry".[105]

For the Duke, the oil below his land was his property. The state had exercised regulatory powers under extreme war conditions. However, the British landowner, drawing on long established subsurface traditions, was not going to submit long-term to the state's temporal powers. Shortly after the speech, Hartington stated that everything "went off satisfactorily…it was on the whole very well received. Lord Cowdray himself applauded very heartily all the way through, and told me afterwards that he thought it was exactly right…there were a good many of my supporters there".[106]

[105] Lord Hartington's inaugural address given on Tuesday 15th October 1918. CEA. Box No. AS/2524 (ii). Folder entitled "Oil boring at Hardstoft 2 September 1918 to 17 July 1919.

[106] Letter dated 15th October 1918 from Lord Hartington to A. Macpherson. Box No. AS/2524 (ii). CEA. Folder entitled "Oil boring at Hardstoft 2 September 1918 to 17 July 1919.

Figure 4.6: Hardstoft No. 1. Britain's first commercial oilwell.

Source: *Andrew Naylor, August 2011. From: CEA: Hardstoft oil (1) drillers' report.*

Away from the borehole, the Duke of Devonshire's solicitors continued to contest the government's actions under DORA. In October 1918 the Association of Rural Landowners attempted to insert amendments to the Petroleum (Production) Act 1918, having prepared a draft licence and lease as a basis for negotiations between landlords and prospective prospectors.[107] Based on the existing Petroleum (Production) Act 1918, which made no provision for "compensation for injury done to mine or mineral owners,"[108] it would serve to

[107] Letter dated 3rd October 1918 from A. Macpherson to J. P. Cockerell. CEA Box No. AS/2524 (ii). Folder entitled "Oil boring at Hardstoft" 2 September 1918 to 17 July 1919.
[108] Letter dated 29th October 1918 to Messrs Currey and Co. CEA: Box No. AS/2524 (ii). Folder entitled "Oil boring at Hardstoft" 2 September 1918 to 17 July 1919.

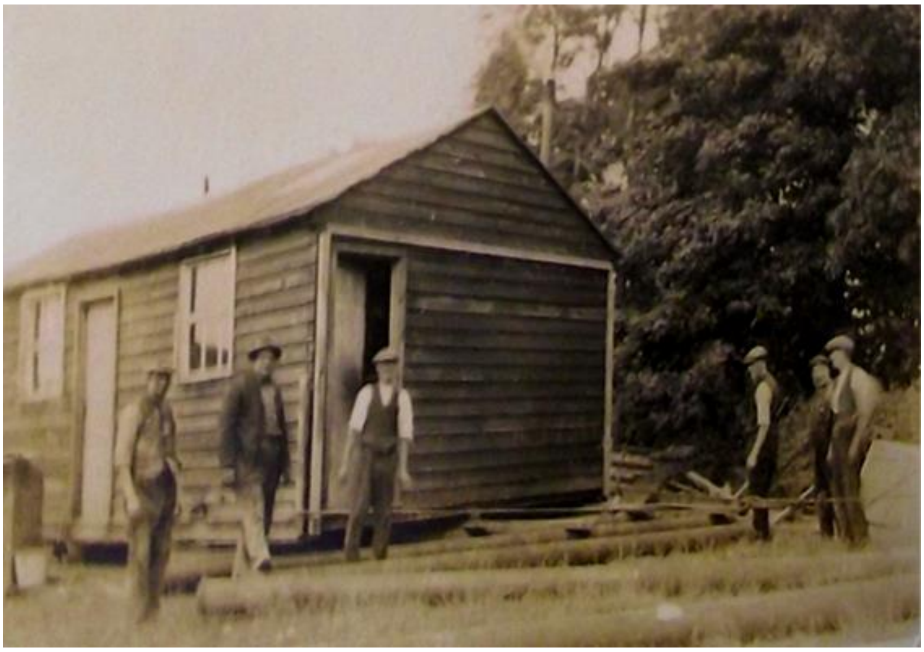
protect “the rights of mineral owners as well as surface owners”.[109] It was anticipated by the Association of Rural Landowners that the revised Petroleum (Production) Act 1918 would influence national policy and provide legal protection against “serious damage [that] was almost certain to result from drilling operations”.[110] Should damage be caused, the Ministry of Munitions or Cowdray (acting as its agent) would be liable under “common law, however, nothing within part 2a.a.a of DORA or the Petroleum Act exonerated either from ordinary common law liability for damage”.[111] The situation was compounded by the fact that the Ministry of Munitions and/or Cowdray’s company might cease to exist in years to come when subsidence might create cause for litigation.

Figure 4.7: Cowdray’s American drilling team pictured in front of Hardstoft No. 1.

Source: *Andrew Naylor, August 2011. From: In-depth “Pamphlet” on the known occurrences of petroleum in the Carboniferous system of England. Large black folder contained within: CEA: Hardstoft Oil (2) correspondence.*

[109] Letter dated 1st November 1918 to Messrs. Currey & Co. CEA: Box No. AS/2524 (ii). Folder entitled “Oil boring at Hardstoft” 2 September 1918 to 17 July 1919.
[110] Letter dated 3rd December 1918. CEA: Box No. AS/2524 (ii). Folder entitled “Oil boring at Hardstoft” 2 September 1918 to 17 July 1919.
[111] Letter dated 3rd December 1918. CEA: Box No. AS/2524 (ii). Folder entitled “Oil boring at Hardstoft” 2 September 1918 to 17 July 1919.

Figure 4.8: Cowdray's drilling team erect one of two wooden accommodation blocks.



Source: *Andrew Naylor, August 2011. From: In-depth "Pamphlet" on the known occurrences of petroleum in the Carboniferous system of England. Large black folder contained within: CEA: Hardstoft Oil (2) correspondence.*

The drilling rig used at Hardstoft consisted of an 85ft tubular steel derrick (a system which would be employed across all eleven drill sites) and a thirty horsepower drilling engine with a 12" bore powered by portable locomotive boilers.[112] Percussion drilling methods were employed, producing pulverised samples which were difficult to interpret, making accurate assessments of lithologies and facies difficult. A drill log was not started for Hardstoft No. 1 until 30th October 1918, at a depth of 25 feet; for the first 160 feet, no geological samples were taken. Cadman subsequently intimated drillers required the instruction and supervision of the BGS to record "the fullest particulars and stratification of the rocks".[113] He personally guaranteed he "would have no difficulty in providing funds through H. M. Petroleum Executive" (up to the full £1 million) to cover the appointment of temporary staff from the BGS to oversee exploration as it developed.[114] Dr Gibson of the BGS was appointed to inspect the Hardstoft boring, alongside geologist Mr Eastwood, who carried out systematic observations.[115]

[112] In-depth "Pamphlet" on the known occurrences of petroleum in the Carboniferous system of England. Large black folder contained within: CEA: Hardstoft Oil (2) correspondence.
[113] Letter dated 18th June 1919 from the Secretary, H. M. Treasury. BGSA: GSM/XG/0/1. IGS2/857.
[114] Letter dated 29th May 1919 by Major Ogilvie. BGSA: GSM/XG/0/1. IGS2/857.
[115] Letter dated 6th June 1919 from A. Straham (BGS Director) to the Director H. M. Petroleum Executive. BGSA: GSM/XG/0/1. IGS2/857.

The BGS agreed to furnish the Duke of Devonshire, with records of the strata being passed through at 500 feet intervals[116], with the BGS itself retaining 0.25 lbs of material every five feet.[117] Drilling footage at Hardstoft No. 1 averaged 50 feet per day, though this was higher in the softer shales and sandstone. The "spudding in" of Hardstoft No. 1 was followed by Renishaw, Heath (also located on the Duke of Devonshire's Derbyshire Estate), Ironville 1 and 2, Ridgeway and Brimington, from January to April 1919.

With the drilling campaign underway, all parties waited for the first signs of oil. On 23rd February 1919 an American Peace Commissioner presented Lord Hartington with a telegram stating oil had been struck in Derbyshire "TO KNOCK PENSYLVANIA SILLY!"[118] Lord Hartington contacted A. Macpherson in order to validate the claim, and added that the fate of a royalty claim rested on the forthcoming enquiry into coal mining conditions. The 'Sankey enquiry' placed the nationalisation of the coal industry at the forefront of the public's mind. Established on moral grounds, it sought to investigate miner's wages, working hours and, significantly, inequalities stemming from private ownership of coal mines (Milward and Singleton, 2002). On the 24th February 1919 Lord Hartington declared "If it is decided that a royalty on coal is justified, I suppose that our chances are better than they were".[119] Hartington had discussed the matter with Arthur James Balfour, 1st Earl of Balfour and British Prime Minister from July 1902 to December 1905, on the evening of 23rd February 1919. Balfour pronounced Lloyd George was strongly in favour of a royalty, though he felt it should be a small one. Lloyd George was not prepared to agree to a sliding scale royalty, but as Balfour pointed out, the miners had a stronger objection to this than to a fixed royalty.[120]

Meanwhile, J. P. Cockerell of the Chatsworth estate responded to the Paris telegram stating "there is no truth in the Paris story".[121] He had been:

"over at Hardstoft on Monday last and they [had] stopped work for over a month owing to difficulties they [had] met with, but started the drill again whilst I was there. Their depth [was] somewhere under 1,100 ft.…the story that oil had been found rose from the fact that at Brimington borehole they did strike something of an oily nature which the Americans call "Cart Oil"; and which I believe is merely a mixture of oil, water, and sand, so I should not say that

[116] Letter dated 23rd December 1918 to A. Macpherson. CEA. Box No. AS/2524 (ii). Folder entitled "Oil boring at Hardstoft" 2 September 1918 to 17 July 1919.
[117] Letter dated 20th June 1919 from A. Straham (BGS Director) to J. Cadman. BGSA: GSM/XG/0/1. IGS2/857.
[118] Letter dated 24th February 1919 from Lord Hartington to Macpherson. CEA. Box No. AS/2524 (ii). Folder entitled "Oil boring at Hardstoft 2 September 1918 to 17 July 1919.
[119] Letter dated 24th February 1919 from Lord Hartington to Macpherson. CEA. Box No. AS/2524 (ii). Folder entitled "Oil boring at Hardstoft 2 September 1918 to 17 July 1919.
[120] Letter dated 24th February 1919 from Lord Hartington to Macpherson. CEA. Box No. AS/2524 (ii). Folder entitled "Oil boring at Hardstoft 2 September 1918 to 17 July 1919.
[121] Telegram from J. P. Cockerell to the Chatsworth Estate dated 24th February 1919. CEA. Box No. AS/2524 (ii). Folder entitled: Oil boring at Hardstoft 2 September 1918 to 17 July 1919.

this looks like "knocking Pennsylvania silly". I might add that the American Foreman to whom I was talking at Hardstoft told me confidently that he was personally very sanguine about striking oil, but this statement you must take for what it is worth".[122]

4.7 Domestic success: black gold or white elephant?

At 450 feet Cowdray's drillers encountered the black shale coal seam and struck springs of water at 900 feet, issuing out at 600 gallons per hour and again at 1,513 feet at 700 gallons per hour.[123] On the night of 27th May 1919, more than six months after the signing of the Armistice, Hardstoft No. 1 struck oil at a depth of 3,077 feet at the top of a faulted Carboniferous Limestone feature, providing concrete evidence that Britain's geological structures contained oil. The drilling log showed that oil had entered the well at 3,070 feet, and at 3,085 feet the "sand" in the well had changed to "sandy lime" indicating the presence of 15 feet of porous sand from which the oil was percolating.[124] The company went on to extend the well to 3,130 feet with a terminal diameter of 6 5/8".

Lord Cowdray wrote to Sir John Cadman, rejoicing "The searches at Hardstoft are most pleasing and gratifying and I remain with my reputation intact". He thanked Cadman for his efforts over the episode, remarking "it was only by your unfailing and wise support that we have enabled to so rapidly put our recommendations to the test". He pointed out that only those familiar with the "art and science of the oil industry" could have foreseen Britain's hydrocarbon potential, concluding "I can only hope that our gift will be wisely handled and benefit the nation…if that shall be done I shall be content and you (Cadman) will have achieved an veritable national service."[125]

The oil flowed from the well head under pressure against a column of water on Saturday June 7th 1919. As stated by Wade (1928), the oil, which averaged six barrels per day, compared favourably with US producing wells of the time. Wade elucidated "the oil is of very good quality and resembles Pennsylvanian crude. It is of light gravity and has a paraffin base…The oil is dark brown in colour with green fluorescence" (Wade, 1928, p. 358). According to the *Derby Daily Telegraph*, 7th June, 1919, p. 3 drilling operations were temporarily suspended at Hardstoft while arrangements were concluded "to impound the expected enormous yield".

[122] Telegram from J. P. Cockerell to the Chatsworth Estate dated 24th February 1919. CEA. Box No. AS/2524 (ii). Folder entitled: Oil boring at Hardstoft 2 September 1918 to 17 July 1919.
[123] Letter entitled "MINISTER OF MUNITIONS, MESSRS. S. PEARSON & SON LTD. And the BABBINGTON COAL COMPANY" dated 17th August 1920 from M. Deacon to The Director H. M. Petroleum Executive. CEA Folder: 97. Petroleum. (Hardstoft).
[124] Report upon the Hardstoft Wells by Mr A. Frank Dabell dated 18th October 1922. CEA Folder: 97. Petroleum. (Hardstoft).
[125] Letter dated 3rd June 1919 from Lord Cowdray to J. Cadman. ArcRef: 62595 Oil sites. 27th August 1918 to 3rd June 1919.

Despite its national significance, the discovery was attacked by the Archdeacon of Chesterfield who lamented that:

"The air (around Hardstoft) is full of the smell of petroleum, the windows of houses are smeared with it, and even the food tastes of it, while trees and hedges have begun to show the effects of its poison" (*Derby Daily Telegraph*, 16th June, 1919, p. 3). A *Derby Daily Telegraph* reporter, who was subsequently sent to investigate the debacle, found no truth in the Archdeacon's claims, with "vegetation all appearing healthy and no smell, except when in close proximity to the well" (*Derby Daily Telegraph*, 16th June, 1919, p. 3). In reality, the volume of oil encountered at Hardstoft was inversely proportional to its political, economic, scientific, social and historic implications. Following World War One, severed oil tanker routes were reinstated rendering the British government's onshore oil interests obsolete. Oil from Hardstoft No. 1 was stored in one large primary tank (which could hold 150,000 gallons; 552.3 tons of oil) and several smaller surrounding battery tanks. A. Macpherson stated the Duke of Devonshire had "...a little gold mine" and referred to the December addition of *Oil News*, which claimed Scottish mineral oils were selling at £10.5.0 - £11.15.0 per ton. American Cylinder Lubricating oil was achieving as much as £29.15.0 per ton once refined.[126] The value of the oil increased markedly upon refining, prompting A. Macpherson to send samples to various refiners in England to receive quotations.[127] Cowdray was clearly very optimistic, stating that a further eight drillers had arrived in Liverpool on Thursday 2nd October 1919 aboard the White Star Line's "Cedric" (*Derby Daily Telegraph*, 7th October, 1919, p. 2).

Captain J. D. Penrose, who was charged with overseeing drilling operations on the Duke's estates, produced a memoir chronicling drilling operations.[128] Penrose highlighted a number of technical problems, which affected drilling progress. These included encountering unrecorded coal workings, boreholes collapsing, and the loss of tools down the wells. Only Renishaw produced hydrocarbons (maximum flow rate 250,000 cubic feet per day), in the form of methane gas similar to that found in local coal workings. In addition, the British government was not forthright in the collection and removal of oil stored at Hardstoft. On 21st July 1920 Captain J. D. Penrose of the Chatsworth Estate Office wrote to the Petroleum Department advising that the oil be disposed of, in order to obviate the needless provisions of additional tanks on site.[129] Above ground the Hardstoft oil deteriorated rapidly, with a proportion lost to evaporation. Penrose argued that: "Pending the settlement of permanent regulations in regard to the petroleum industry in this country, and other outstanding questions, it is proposed that

[126] Letter dated 5th December 1919 entitled "Hardstoft oil well". CEA Folder: 97. Petroleum. (Hardstoft).
[127] Letter dated 5th December 1919 entitled "Hardstoft oil well". CEA Folder: 97. Petroleum. (Hardstoft).
[128] In-depth "Pamphlet" on the known occurrences of petroleum in the Carboniferous system of England. Large black folder contained within: CEA – Hardstoft Oil (2) correspondence.
[129] Letter dated 21st July 1920 from J. D. Penrose to Petroleum Department. CEA. Box No. AS/2524 (ii). D.D. v. Cadman and others 21 July to 29 Dec 1922.

the oil be sold and the proceeds thereof placed on deposit at the London Joint City and Midland Bank in the name of [the] department until a decision has been reached".[130] The Duke would hold the Ministry responsible for any poor decisions made (deterioration, evaporation and market fluctuations) and reserved the full rights to claim the proceeds of any oil sold. In October 1920, 500 tons of oil were sold to the Anglo-American Oil Company (AAOC) for £3011.315.14.10.[131] However, the monies remained in limbo until the Duke and the Petroleum Department had come to an amicable agreement on settlement terms. By December 1921 a further 450 tons of oil had collected in the tank, giving a cumulative total of 900-1000 tons of oil, worth approximately £19,000-£20,000 based on £21 per ton.[132]

By 1921, following successive failures, the government had closed nine of the original 11 drilling sites, leaving only Hardstoft and D'Arcy (West Calder) operational. A. Macpherson received final confirmation of Cowdray's intention to abandon the English Project on 18th July 1922, when he humorously stated Messrs Pearson (Cowdray) "thank [the Duke and his agents] for…giving them the opportunity and wish us all good luck in the venture!"[133] By this time the British Government had invested £564,000 in the programme, which had failed to produce oil in commercial quantities. The Duke of Devonshire, having invested his time and money, was left with a white elephant. The political debates leading up to the sinking of the first well had had a huge gestation, whereas the abandonment took place over only a few months. The Duke now had three options available to him: 1. abandon the two wells; 2. offer rights to a third party or 3. take over ownership completely. The first option would have closed the door on a possible long term income. Furthermore, with Hardstoft and Heath being the only two wells on the Duke's estate, the oil question had still not been fully ratified. The third option was considered as a last resort only if a third party could not be found.

A syndicate, consisting of industrialists (ship builders) and consulting petroleum engineer and geologist Dr J. A. L Henderson, proposed an ambitious plan to establish an autonomous British oil company. Dr Henderson was "tremendously keen on the whole question of oil production in the British Isles" submitting proposals to the Duke on 13th July 1922.[134] The group proposed to form a limited company with a capital of £60,000 and cash working sum of

[130] Letter dated 21st July 1920 from J. D. Penrose to Petroleum Department. CEA. Box No. AS/2524 (ii). D.D. v. Cadman and others 21 July to 29 Dec 1922.
[131] Letter contained within CEA. Box No. AS/2524 (ii). D.D. v. Cadman and others 21 July to 29 Dec 1922.
[132] Letter contained within CEA. Box No. AS/2524 (ii). D.D. v. Cadman and others 21 July to 29 Dec 1922.
[133] Letter dated 18th July 1922 from A. Macpherson to U. Roland Burke. CEA Folder: 97. Petroleum. (Hardstoft).
[134] Details of meeting held at 1400 at 21 Buckingham Gate, London on 17th January 1921. CEA: Box No. AS/2524 (ii). D. D. v. Cadman & Others 21 July 1920 to 29 Dec 1922.

£40,000.[135] This would cover the initial expense of negotiating terms through solicitors, the purchasing of material and the formation of a company to become lessees. The lease area would embrace the current two wells, alongside a separate estate lying to the south of Blackwell and the areas in D'Arcy, Scotland.

The group planned to sink one well in the Blackwell area and a single well at Hardstoft, suggesting a lease period of 37 years. The first five years would be a trial period during which they could surrender the lease, giving six months' notice, after which it would increase to three year intervals. They would drill to 3,100 feet unless commercial oil or gas was encountered at shallower depths, or if drilling technicalities rendered it impractical to proceed. Dr Henderson planned to sell the oil within the UK, believing Scottish Oils would pay "an average price of £4 per ton on "our" crude".[136]

Before leaving Britain to visit America, the group met at the offices of their solicitors - McNeil and Sime, where they formed the 'United Kingdom Petroleum Syndicate' for the purpose inter alia of negotiating the proposed lease of the area at Hardstoft and Heath...and the [purchasing] of drilling plant and material on the ground".[137] The group acknowledged £100,000 would not be sufficient for the "development" of the Duke's estate in Derbyshire, in addition to the area around D'Arcy belonging to Earl Stair and others. However, if the preliminary investigations gave satisfactory results they intended to form a much a larger company.

For the initial testing phase, Dr Henderson felt no landlords should receive any shares, as exploration and prospecting was a not for profit exercise. However, if the testing company were to locate oil in paying quantities, it might pump and sell the oil in order to finance the cost of sinking further test wells, though it was never intended to be a dividend paying company. The group offered three possible royalty terms: 1). 2/- per ton with 10% participation; 2). 4/- per ton without participation; 3). a sliding scale based on average production per day alongside 10% participation (see table 4.2).

[135] Letter dated 22nd September 1922. CEA: Box No. AS/2524 (ii). D. D. v. Cadman & Others 21 July 1920 to 29 Dec 1922.
[136] Letter dated 22nd September 1922. CEA: Box No. AS/2524 (ii). D. D. v. Cadman & Others 21 July 1920 to 29 Dec 1922.
[137] Letter dated 22nd September 1922. CEA: Box No. AS/2524 (ii). D. D. v. Cadman & Others 21 July 1920 to 29 Dec 1922.

Table 4.2: Sliding scale for oil royalties proposed by Duke of Devonshire's Technical Advisor.

Average daily production per well - tons	Royalty payment
1-10	1/
10-20	2/
20-40	2/6d
40-60	3/
60-80	3/6d
80 and over	4/

Source: *Tabulated from letter dated 22nd September 1922. CEA: Box No. AS/2524 (ii). D. D. v. Cadman & Others 21 July 1920 to 29 Dec 1922.*

Unsure of Henderson's proposals, the Duke re-engaged John Cadman to ascertain his views and opinions. Cadman gave his opinion in a letter to A. Macpherson that a capital of £60,000 and working capital of £40,000 would be insufficient to develop both regions, arguing that at least two wells should be sunk in the Hardstoft area and one in the Blackwell area.[138] A single additional well at Hardstoft would be insufficient to test the petroliferous prospects of the vicinity. The royalty, he argued "is quite out of the question, [being] one which I could not advise his grace to accept…Dr Henderson [should] be advised that His Grace is unable to accept less than 3/- or 4/- per ton royalty, plus 10% participation in the company to be formed".[139] Following an initial review the syndicate offered a revised proposal, with a working capital of £50,000 per region, providing the Duke was given a 10% participation in the syndicate and any subsidiaries formed thereafter.[140] They agreed to purchase all of the existing plant and machinery, provided the Duke purchase some equipment from the government. Furthermore, they agreed to indemnify the Duke against claims made by the Babbington colliery company.[141] Following the adjustment of draft leases, the syndicate had until January 1st 1924 to form and

[138] Letter from J. Cadman to A. Macpherson entitled "The Duke of Devonshire. Petroleum Boring at Hardstoft and Heath". Date unknown. CEA: Box No. AS/2524 (ii). D. D. v. Cadman & Others 21 July 1920 to 29 Dec 1922.
[139] Letter from J. Cadman to A. Macpherson entitled "The Duke of Devonshire. Petroleum Boring at Hardstoft and Heath". Date unknown. CEA: Box No. AS/2524 (ii). D. D. v. Cadman & Others 21 July 1920 to 29 Dec 1922.
[140] Letter dated 9th November 1922 from J. Cadman to A. Macpherson entitled "The Duke of Devonshire. Petroleum Boring at Hardstoft and Heath". Date unknown. CEA: Box No. AS/2524 (ii). D. D. v. Cadman & Others 21 July 1920 to 29 Dec 1922.
[141] Letter dated 9th November 1922 from J. Cadman to A. Macpherson entitled "The Duke of Devonshire. Petroleum Boring at Hardstoft and Heath". Date unknown. CEA: Box No. AS/2524 (ii). D. D. v. Cadman & Others 21 July 1920 to 29 Dec 1922.

register a testing company. No formalised licences would be issued until a concrete schedule was implemented.

As stated, the Duke's third option was to take over control of the two wells. By 2nd August 1921 the government was prepared to withdraw DORA regulations and hand back the borehole to the Duke (largely on account of escalating running costs) subject to it having the power to grant licences to any person they desired, under the terms of the Petroleum Act, 1918.[142] Following a meeting held at the Hotel Windsor on 26th October 1921 (between the Duke of Devonshire and William Clive Bridgeman, Secretary for Mines), T. J. Barnes, solicitor to the Board of Trade wrote to the Duke's mineral agents stating the Board would "be in a position to give…a definite reply in the near future".[143] Significantly, the letter was entitled "The Duke of Devonshire against Cadman and others". Over the course of the episode, John Cadman's role had morphed from advisor to the British landowner to advisor of the state; however, he was still acting on behalf of the British landowner in an advisory capacity.

In March 1922 the British Cabinet consented to formally negotiate with the Duke. In order for him to gain full control of the Hardstoft No. 1, he would have to agree to stop legal proceedings, renounce his claim to any oil won up to the date of the agreement, take over plant and pay a sum to the Secretary for Mines relating to the cost of boring and value of plant. Cadman would value Hardstoft No. 1 based on its anticipated future prospects, as well as place a value on oil to be retained by the Secretary for Mines. In return, the government would evacuate the Duke's property, transfer plant, renounce its claim to any oil after the date of the agreement and, importantly, grant the Duke a licence under the Petroleum (Production) Act 1918 without any restriction on the Duke's right to charge royalties.[144] Cadman now acted as government arbitrator, responsible for:

"[deciding] what sum the Duke might fairly be asked to pay for taking over the bore-hole and plant with a view to its future development…being conditional on the terms of the license to be granted to His Grace for future working, as the government fully appreciate that His Grace will not incur the expense of taking over unless he has power to sub-let and take a royalty".[145] So confident was the Board of Trade in Cadman's valuation that they were initially prepared to accept "whatever price he put upon it".[146]

[142] Letter dated 2nd August 1921 from A. Macpherson to U. Roland Burke. CEA: 97. Petroleum (Hardstoft).
[143] Letter dated 16th December from Messrs Currey to T. J Barnes. CEA: Box No. AS/2524 (ii). D. D. v. Cadman & Others 21 July 1920 to 29 Dec 1922.
[144] Letter dated 19th March 1922 from Rt. Hon. W. C. Bridgeman, Minister of Mines, to the Duke of Devonshire. CEA: Box No. AS/2524 (ii). D. D. v. Cadman & Others 21 July 1920 to 29 Dec 1922.
[145] Letter dated 19th March 1922 from Rt. Hon. W. C. Bridgeman, Minister of Mines, to the Duke of Devonshire. CEA: Box No. AS/2524 (ii). D. D. v. Cadman & Others 21 July 1920 to 29 Dec 1922.
[146] Letter dated 19th June 1922 from A. Macpherson to U. Roland Burke. CEA Folder: 97. Petroleum. (Hardstoft).

According to the solicitors of the Board of Trade, the cost of the plant up to 31st March 1922 amounted to £32,124.18.6, of which drilling and development costs equated to £26,779,15 and production costs £5,345,18.6.[147] The cost of the plant and machinery, including the casing in the well, amounted to £9,957.[148] In addition to plant, the Ministry of Munitions had paid £3 per acre per year to surface owners.[149] The value of the oil was difficult to estimate given market fluctuations. As a bench mark, 503 tons of oil had realised £3011,315.14.10 in October 1920.[150] As of 15th April 1922, 470 tons of oil were in stock. The Board of Trade allocated a value of £6 per ton, giving a total value of £2,820.[151]

By 1st May 1921 a draft form of a license was in preparation. It made provisions for adjoining landowners, both above and below ground, meaning a contingent liability would have to be implemented. This would indemnify the Duke against actions taken by the Babbington Colliery Company, as soon as their coal workings contacted the exclusion zone surrounding the Hardstoft borehole. A licence would only be issued once all outstanding matters had been settled. The Duke felt he should only be expected to purchase equipment essential to future exploration. While he was happy to have John Cadman as government arbitrator, he staunchly refused to repay the government the cost of the boring operations. According to the Duke, he:

"Had no say whatsoever in the conduct of these operations and, if they proved more costly than was anticipated, [he could] take no responsibility. All [he was] prepared to pay [was] such a sum as may be determined as the present value to [him], as the owner of the oilfield, of the existing bore-hole (exclusive of the value of any oil still to be won there from) having regard to the probable length of time that it will still require to be used".[152]

He also further stipulated that surface rent and compensation for damage be paid by the government prior to their evacuation, and that all plant not purchased by him be removed and the land surface remediated to its former condition. In response, the government argued the Duke might require all of the plant on the site in order to maintain pumping operations, though agreed that the Duke should not be required to pay any more for the plant than it might fetch on

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[147] Letter dated 1st May 1922 entitled "The Duke of Devonshire V. Cadman". CEA: Box No. AS/2524 (ii). D. D. v. Cadman & Others 21 July 1920 to 29 Dec 1922.
[148] Letter dated 1st May 1922 entitled "The Duke of Devonshire V. Cadman". CEA: Box No. AS/2524 (ii). D. D. v. Cadman & Others 21 July 1920 to 29 Dec 1922.
[149] Letter dated 22nd June 1922 . CEA: No. AS/2524 (ii). D. D. v. Cadman & Others 21 July 1920 to 29 Dec 1922.
[150] Letter dated 1st May 1922 entitled "The Duke of Devonshire V. Cadman". CEA: Box No. AS/2524 (ii). D. D. v. Cadman & Others 21 July 1920 to 29 Dec 1922.
[151] Letter dated 1st May 1922 entitled "The Duke of Devonshire V. Cadman". CEA: Box No. AS/2524 (ii). D. D. v. Cadman & Others 21 July 1920 to 29 Dec 1922.
[152] Draft of proposed reply for consideration. Date unknown. CEA: Box No. AS/2524 (ii). D. D. v. Cadman & Others 21 July 1920 to 29 Dec 1922.

the open market. They would include the derrick as well as a lorry (modified to receive and carry oil to the Pilsley Station) but no tools.[153]

The Duke's mineral agents felt pricing depended on future, and not past production, having no correlation with capital expended in the sinking of the well. If no oil had been found, the well would have been valueless.[154] Antithetically, had a Pennsylvania gusher been encountered, its value would have been greatly increased. The true value of the well could only be based on its present state, with a speculative guesstimate made on potential yield. As of 16th May 1922 the average yield was one ton, or 60 barrels of oil per week, making it hardly worth pursuing. Based on a per ton value of £7, a flow rate of one ton per day gave an annual income of only £2,555. The cost of drilling was purposely inflated by the Duke's land agents to highlight his financial risks. The well could not be left unsupervised at any time, requiring two men's salaries. The cost of transporting the oil from the well head to the railway was stated to be 10/- per ton. Rates and taxes had to be paid, along with administrative work and incidental expenses. R. D. Wadsworth calculated annual maintenance costs at £699.10.0, annual expenditure at £1,391.13.0 for six years and the value of the coal left around the borehole at £1,261.0.0 (compensation to the Babbington Coal Company). The exclusion zone was now one of two required to allow the progression of the well. The second was in the Typton coal and had a similar value attached. The Duke also had to plan a contingency should he need to plug an out of control well.

Licensing was only practicable once all parties had agreed to the terms of the draft lease. The Duke, however, did not give an immediate response, thus increasing the pressure on the government, who desired to relinquish ownership on the grounds of the wells becoming too costly. Under these conditions, the Duke could manipulate the terms of the licence in his favour. The tactics paid off, for as of 4th January 1923 he had eroded the price to be paid to £1,500 for essential plant and machinery.[155] On January 7th 1923 Roland Burke announced "The time has come when I think it is essential for us to decide on a definate policy in regard to the development, or otherwise, of oil production on this Estate".[156] The situation, he remarked, was interwoven with the coal situation, which was likely to make the venture "a lengthy episode."

Meanwhile, the Board of Trade had met with Dr Henderson, arguing it was prepared to intervene with a view to expediting negotiations with the Duke of Devonshire. J. Barnes, solicitor to the Board of Trade warned that "they must ask the Duke of Devonshire to fix a date

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153 Letter dated 4th August 1922. CEA: D. D. v. Cadman & Others. CEA: Box AS/2524 (ii) D. D. v. Cadman & Others 21 July 1920 to 29 Dec 1922.
154 Letter dated 16th May 1922 by T. A. Wadsworth entitled "Hardstoft oil well". CEA: Box AS/2524 (ii) D. D. v. Cadman & Others 21 July 1920 to 29 Dec 1922.
155 Letter dated 4th January 1923. CEA: Box AS/2524 (ii) D. D. v. Cadman & Others 21 July 1920 to 29 Dec 1922.
156 Letter dated 7th January 1923. CEA: Box AS/2524 (ii) D. D. v. Cadman & Others 21 July 1920 to 29 Dec 1922.

upon which he will be prepared to take over the custody of the well, as the Crown [was] being put to a good deal of expense in maintaining the plant".[157] Dr Henderson was now anxious to discuss his plans with colliery owners connected to his proposals, which included the Staveley, Shirebrook, Sheepbridge, Stanton, Hardwick, Pilsley, Babbington and Blackwell colliery companies.[158] Dr Henderson believed that unless the various colliery owners waived their rights to coal, which would be left in situ in support of each borehole, the cost of exploration would be prohibitive and they would have no chance of being able to float an exploration company.[159]

By late January 1923 J. D. Penrose stated that "Henderson's are wobbling at the last moment [therefore] it would be better to settle with the government and get the Licence ourselves. With a bit of luck another tank full of oil would easily pay for the pillar [of coal] and go a long way in paying for the plant".[160] Ultimately, Dr Henderson and his associates, having formed the ambitious United Kingdom Petroleum Syndicate, decided that the compensation payable to coal owners was too great a risk, both legally and financially. In addition global oil prices had fallen significantly, resulting in imported oil from Persia costing 10s/- per ton, which, due to high rail prices, was less than it would cost to transport the domestic oil to a refinery. The group had desired to erect an oil refinery on the Duke's estate, however, in order to return a profit the wells needed to produce 100-200 tons per month, which looked unlikely. With the realisation that Dr Henderson would no longer be willing to float an exploration company the Duke's options became limited. Mr Charles Paxton Markham, a local colliery owner (alongside others) considered working the well on terms declined by Dr Henderson. However, they also declined the offer. As the situation intensified A. Macpherson remarked "surely Dr Henderson is not the only pebble on the beach".[161]

The Duke's advisors agreed it was impossible for coal mining and oil exploration to exist in symbiosis in Britain, unlike America where the two had coexisted for decades. If the Duke were to develop the oilfield, he must identify areas where coal extraction was not currently, or likely to be carried out in the future. Of his entire Derbyshire estate, only 160 acres west of the Hardstoft No. 1 were free from encumbrances. The coal seams in this area were leased to the Pilsley Company and due to expire in September 1926.[162] Under the wording of

[157] Letter dated 1st February 1923 from T. J. Barnes; solicitor of the Board of Trade to Messrs. Currey & Co. entitled "Duke of Devonshire –v- Cadman. CEA: Box AS/2524 (ii). Folder "D. D. v Cadman & Others etc. 2 Jan. 1923 to 7 July 1924.
[158] Letter dated 2nd January 1923 to U. Roland Burke. CEA: Box AS/2524 (ii). Folder "D. D. v Cadman & Others etc. 2 Jan. 1923 to 7 July 1924.
[159] Letter dated 23rd January 1923 to U. Roland Burke. CEA: Box AS/2524 (ii). Folder "D. D. v Cadman & Others etc. 2 Jan. 1923 to 7 July 1924.
[160] Letter dated 24th January 1923 from J. D. Penrose to A. Macpherson. CEA Folder: 97. Petroleum. (Hardstoft).
[161] Letter dated 26th January 1923 from J. D. Penrose to A. Macpherson entitled "Petroleum". CEA: Box AS/2524 (ii). Folder "D. D. v Cadman & Others etc 2 Jan. 1923 to 7 July 1924.
[162] Letter dated 26th January 1923 from J. D. Penrose to A. Macpherson entitled "Petroleum". CEA: Box AS/2524 (ii). Folder "D. D. v Cadman & Others etc 2 Jan. 1923 to 7 July 1924.

the then current lease, the Duke was not liable for compensation and was at liberty to bore for oil. An area of nine acres to the south eastern corner (being on the company's most southerly border) of their leasehold was inaccessible due to geological faulting.

On 9th February 1923 J. Barnes wrote to the Duke stating the department was prepared to hand over ownership at a convenient time using the Transfers of Powers Act 1921.[163] Three final points of contention remained. Firstly, they asked the Duke to pay for 75 tons of oil that had accumulated in the oil storage tank, which they valued at a conservative £3.10, 0 per ton (oil arriving at Pilsley Station was being sold at £4.6.0 per ton). Secondly, the Duke was to formally relieve the department of all liability under the Agreement between the Minister of Munitions and the Babbington Colliery Company. Finally, the Duke would withdraw any claim against the government for the restoration of the ground surface. The Duke accepted the latter two covenants, however, he argued that the 75 tons of oil in storage should only be charged at £2.12.6. If the Board of Trade were not to agree to this, they should make provisions to clear the oil from the storage tanks before handing over ownership of the well. The Board agreed, so long as a government official took the measurements. On 24th March 1923 A. Macpherson elucidated "I have agreed with the Board of Trade that you should take over on Monday next".[164]

After more than eight years of heated political debates involving numerous state figures, mineral agents, solicitors, clerical staff and geological experts, the Duke finally gained control of his oil, under his land. Under the new licence, the government would become trespassers should they not vacate his property. Despite the Duke's success in winning rights to his oil, Hardstoft No. 1 produced only minimal quantities. It was prone to waxing due to its heavy paraffin base, meaning that over time output diminished significantly.

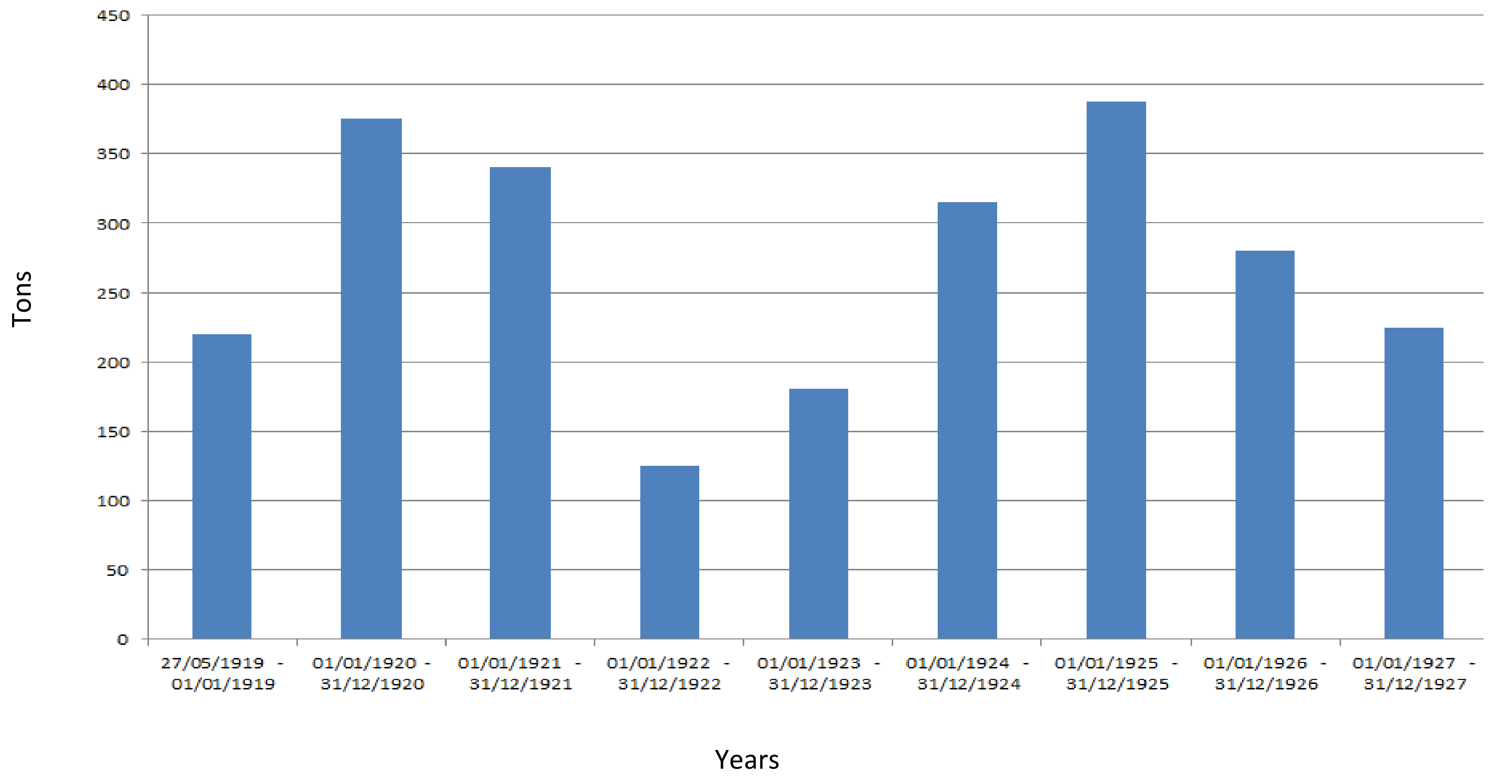
From 1st January 1920 to 31st December 1927 oil production stood at only 278.4 tons or 2087.8 barrels per annum, giving a daily average of 5.72 US barrels (see figure 4.9). Maximum annual oil production occurred in 1925 at 387 tons or 2902.5 US barrels.[165] Monthly oil production only passed 45 tons in March and September 1926 (46 and 47.5 tons respectively), and only from February 1925 to April 1926 was oil production consistently above 25 tons per month (see figure 4.10). Of the total fluid volume extracted from Hardstoft No. 1, over a quarter was water. From April 1927 water content rose sharply, and in November and December 1927 the fluid volume of water had surpassed oil (see figure 4.10).

[163] Letter dated 9th February 1923 from T. J Barnes, solicitor of the Board of Trade entitled "The Duke of Devonshire –v- Cadman. CEA: Box AS/2524 (ii). Folder "D. D. v Cadman & Others etc 2 Jan. 1923 to 7 July 1924.

[164] Letter dated 24th March 1923 from A. Macpherson to J. D. Penrose entitled "Petroleum". CEA: Folder "D. D. v Cadman & Others etc. 2 Jan. 1923 to 7 July 1924.

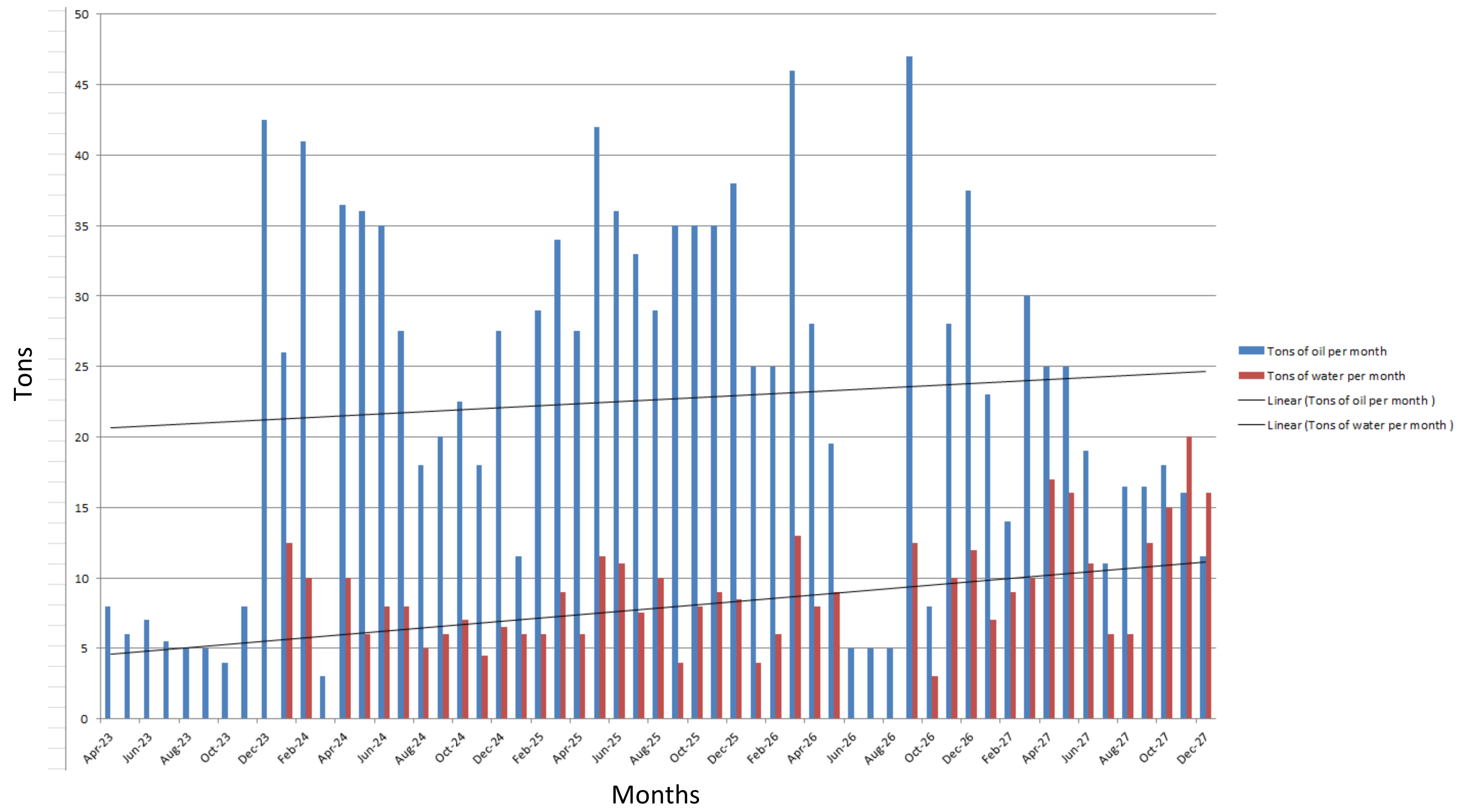
[165] In-depth "Pamphlet" on the known occurrences of petroleum in the Carboniferous system of England. Large black folder contained within: CEA – Hardstoft Oil (2) correspondence.

Figure 4.9: Total oil production (tons) from Hardstoft No. 1 from 27th May 1919 to 31st December 1927.



Source: *Data taken from in-depth "Pamphlet" on the known occurrences of petroleum in the Carboniferous system of England. Large black folder contained within: CEA: Hardstoft Oil (2) correspondence.*

Figure 4.10: Total oil and water (water extraction data only partial) extracted from Hardstoft No. 1 from April 1923 to 31st December 1927.



Source: *Data taken from in- depth "Pamphlet" on the known occurrences of petroleum in the Carboniferous system of England. Large black folder contained within: CEA: Hardstoft Oil (2) correspondence.*

Hardstoft No. 1 silenced the critics who believed Britain was devoid of commercially viable oil accumulations. Although small, producing a mere 26,000 barrels of oil (Harvey and Gray, 2013, p. 60), it signified a new era of British exploration and energy independence. During the episode, the government and the scientific community had gained valuable insights into Britain's subterranean territories. This knowledge would form the basis of all subsequent exploration campaigns, stimulating companies and private individuals to enter the complex domestic oil arena. With the British government's abandonment of domestic oil interests, the Association of Rural Landowners, which had been established to offer periodic advice on oil matters and keep track of developments in oil legislation within Britain, was dissolved in the early 1920s. Remaining money within the account was subsequently given back to the guarantors.

The Duke, however, remained convinced large quantities of oil existed beneath his estate, so ordered the drilling of two more wells (see figure 4.11 and 4.12), adhering to Cadman's earlier scheme and mirroring that proposed at Eakring, Nottinghamshire a decade later. The following details are taken from an untitled notebook in the possession of Chatsworth Estate Archive and gives a brief description of the latter two wells.[166] Hardstoft No. 2 (600 feet west of Hardstoft No. 1) was spudded in May 1924. It struck gas, pressurised to 370 lbs per square inch at 1,620, issuing at a rate of 20,000 cubic feet per day, which was used to fuel boilers and provide heating for the oilworkers' houses. It failed to encounter oil, was abandoned and subsequently plugged with cement in March 1925. Well No. 3, located 600 feet north east of Hardstoft No. 1 was drilled by the American Oil Company (which later became Esso). It penetrated the local hard rock known as "Porters rock" causing equipment damage. The well advanced through adandoned coal workings and experienced unexpected water ingress. A small oil show was encountered at 1,500 feet and drilling advanced to 3,825 feet. However, it was abandoned and plugged in June 1926. The APOC, which became the Anglo Iranian Oil Company (AIOC) in 1935, took over the Hardstoft No. 1 in August 1938, deepening it to increase oil output. The scheme worked for a short time, however, the well was closed down in 1945 and finally capped in 1952. Even today, if one travels to the site one will see and smell the oil which continues to rise to the surface under its own natural pressure.

The World War One exploration campaign ended with little commercial success. With words both of caution and optimism, one commentator summed up the episode stating, "the path of progress in geological thought is strewn with discarded theories, the working hypotheses of the individual in his search for truth. Primarily it was essentially a war measure, a forlorn attemp caused by a desperate need, and to view it in any other light is to rob it of its main excuse

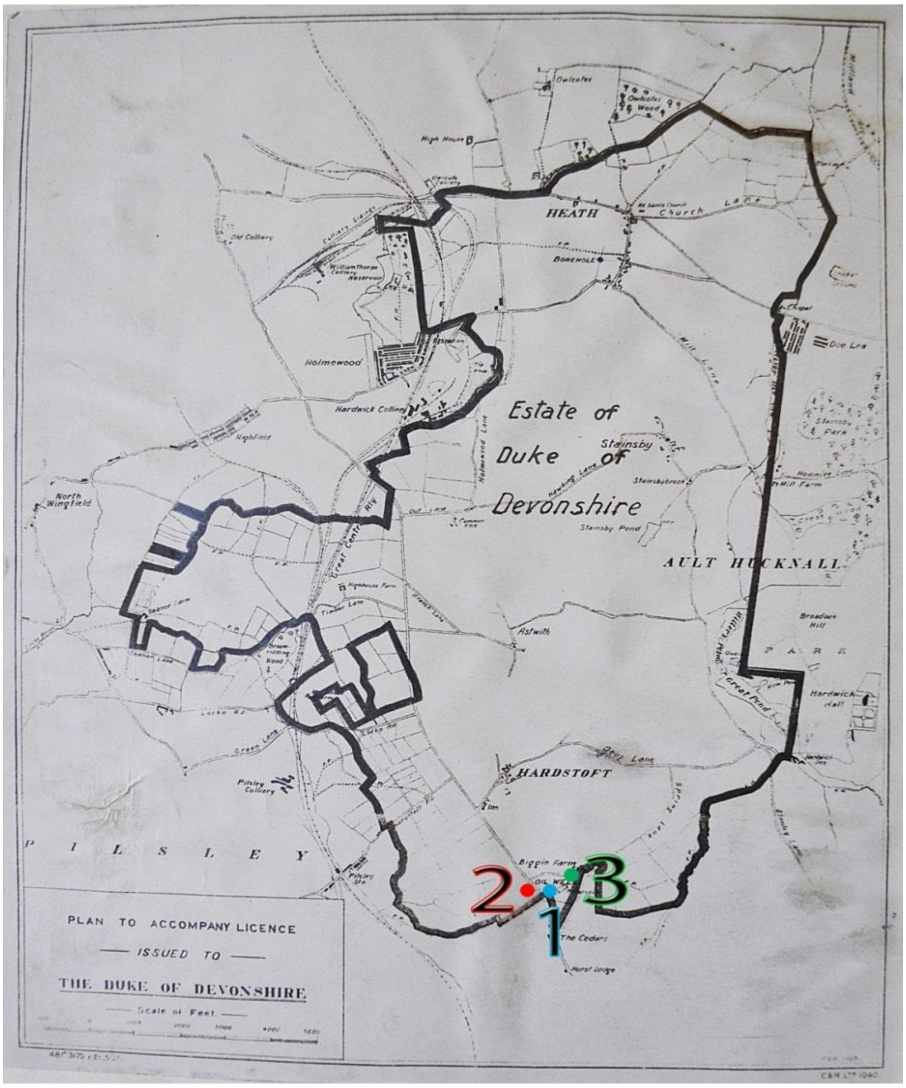
[166] Untitled notebook giving details of Hardstoft wells 1, 2 and 3. No date. CEA. Box "Hardstoft oil (1) drillers reports.

for existence" (Illing, 1919, p. 291). It would be the search for truth and the tantilising prospect of domestic oil offered by Hardstoft No. 1 that would fuel renewed interest in domestic oil in the interwar period and beyond.

For his services to the country John Cadman was knighted in 1918. He left his state duties in 1921, prior to the Duke of Devonshire taking over ownership of the oil well, becoming Technical Adviser to the APOC on the recommendation of the British government, who argued the company should promote him in light of his "knowledge of both government oil policy and of the oil industry" (Gibson, 2012, p. 193). In May 1922 Cadman was made Director of the APOC's main prospecting subsidiary, the D'Arcy Exploration Company Ltd, established in 1914 with the remit of global oil exploration outside of Persia. In 1925 he was made Deputy Chairman and in 1927 Chairman of the APOC, a position he retained until his death (Jones, 1981, p. 224; Yergin, 1990, p. 262). Following World War One the APOC embarked upon a worldwide expansionism programme. With the backing of the British government, the Admiralty acquired additional shares totalling £3,000,000, taking its total shareholding in the APOC to £5,200,000, which was, according to Winston Churchill, worth £23,600,000 by December 1927.[167]

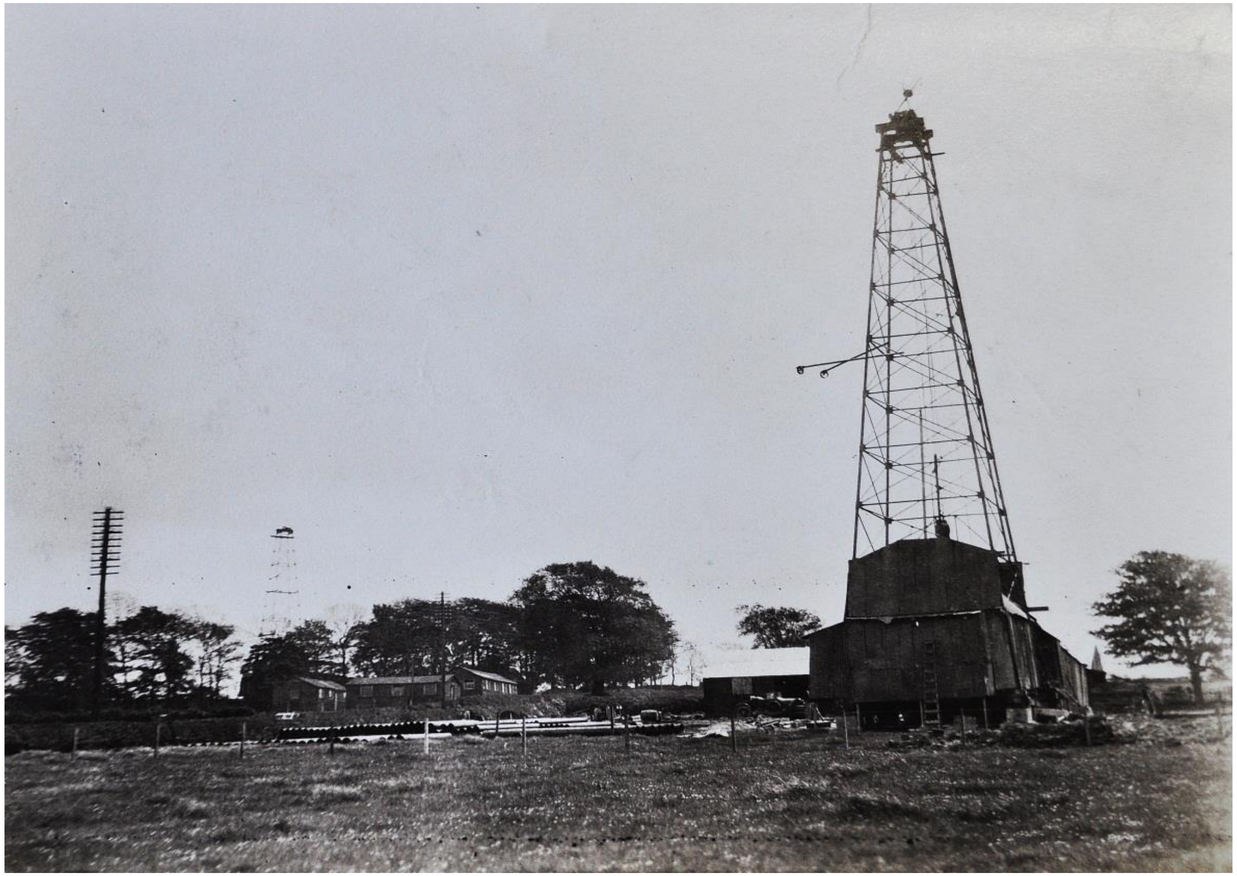
[167] HC Deb 08 April 1927 vol 211 cc1573-4.

Figure 4.11: Locations of Hardstoft No. 1, 2 and 3. Note close proximity to the Duke of Devonshire's boundary.



Source: *Andrew Naylor, August 2011. From: In-depth "Pamphlet" on the known occurrences of petroleum in the Carboniferous system of England. Large black folder contained within: CEA: Hardstoft Oil (2) correspondence.*

Figure 4.12: Showing Hardstoft No. 1 (right) and 2 (left), with workers' accomodation and drill pipes shown in the background.



Source: *Andrew Naylor, August 2011. From: CEA: Box: Hardstoft oil (1) drillers' reports.*

4.8 Conclusion

This chapter has investigated the first successful attempt to exploit oil on a commercial scale in Britain. Hardstoft No. 1 exemplified the country's entry into a new age of global energy dependency and security; one which was beginning to move away from coal – a static, cumbersome, low energy fuel source - in preference for a more adaptable, mobile and higher energy alternative in the 20th century. The outbreak of World War One provided a catalyst for the development of onshore hydrocarbon exploration in Britain. In the space of two decades oil had become the codifier of 20th century development; representing power, control, mobility, access and security in a rapidly changing and increasingly hostile world. As the war continued, oil security increasingly became an issue of national importance. However, the landed gentry staunchly refused to accept terms put before them by the state. Aligning to their long established traditions, landowners believed they owned the oil beneath their territories. Even with DORA in place, the Duke of Devonshire continued to influence policy, for example, by stating that no oil drilling pads would be sited within 2,000 yards of Hardwick Hall.

The geography of onshore oil exploration during World War One was shaped by geological experts working on behalf of Cowdray. Their primary technique was based on transposed geological principles from known oil-bearing strata overseas. This principle is described by Yarborough (cited in Burke, 1985, p. 1) as "exploration by analogy", whereby geological experts assess whether or not a sedimentary basin is likely to be exploitable for commercial quantities of oil. According to Burke, the "explorationist (either consciously or unconsciously) interprets the tectonic, sedimentary, climatic, structural and thermal conditions of the unexplored area in terms of similarities to and contrasts with areas he knows" (Burke, 1985, p. 1). The concept of analogy was based on the life-paths of geological experts, whose overseas geological field trips provided them with the background knowledge required to make objective decisions on the likelihood of oil-bearing geological structures. International travel and embodied experience in the field was therefore essential to the development of the onshore oil industry in the British East Midlands.

The events this chapter describes involved meetings between landowners, state officials, geologists, mineral agents and politicians, during which licence terms, ownership, royalties, projections of fluid volumes, profits and losses as well as access to surface and subsurface territories were negotiated and contested. These face-to-face meetings are described by Mason as "events collectives", which sought to reconcile policy objectives across the oil network, including at the local and national scales (Mason, 2015, P. 326). Such meetings were framed by Britain's social and political positioning, as well as being limited by scientific understanding and technological infrastructure. These event collectives, which occurred within solicitors' offices, the Duke of Devonshire's home, and in the field demonstrate how scientific practice was moved from the traditional setting of the laboratory to typically non-scientific settings, thrusting the magical name of oil into "institutional and cultural discourses outside of the traditional arenas of scientific discussion and practice" (Dunnett, 2012, p. 289).

The discovery of oil in the British East Midlands vindicated scientific hypotheses, suggesting that the transposition of exploration paradigms could result in the identification of oil-bearing geological structures. Exploratory drilling proved that the geological characteristics of the Carboniferous rocks of the Pennine ridge system were capable of producing oil at a rate commensurate with extraction figures in Pennsylvania. However, unlike Pennsylvania, where oil was found to be plentiful, the Hardstoft oil strike was something of a fluke. Wells 2 and 3 failed to produce oil in commercial quantities, confirming that the oil reservoir was limited in vertical and lateral extent. Although oil was found; its physical qualities, namely its high viscosity due to its rich paraffin base, made oil exploration a high maintenance, low income venture, particularly when coupled with high volume water ingress, which added a further process to oilfield development.

Although a small amount of oil was found in commercial quantities at Hardstoft, "questions of law, order, rule, authority, profit, and property [were] all subject to intense forms of contestation and opposition" (Watts, 2015, p. 216). Oil won at Hardstoft represented the manifestation of collaborations between multiple stakeholders, including landowners, entrepreneurs (Lord Cowdray), geologists, mineral agents, solicitors and politicians. Each group acted with their own vested interest, ultimately resulting in an extremely long gestation. So long in fact, that the original purpose – the discovery of oil to supplement allied energy reserves and to safeguard Britain during World War One – passed before oil was found.

At the centre of this complex network was John Cadman, whose role metamorphasised over the nine years examined during the chapter. Cadman's interest in oil was inextricably linked to his childhood, as he was raised in a world dominated by mineral extraction and exploitation in Staffordshire. Cadman travelled extensively throughout his life, both above and below ground. His personal involvement in the British coal industry and later selection as government official placed him in an ideal position to reconcile the opposing views of landowner and state. In Scotland and Trinidad he viewed oil in its natural state. Whilst this was important in cementing his love affair with oil, these early experiences provided Cadman with an insight into the administration of governments, and in particular how one solved complex litigation cases. Cadman stood by his beliefs and pursued ambitions with gusto, clearly and elegantly offering solutions to challenges. He was a robust individual, able to withstand criticism and make changes where necessary in order to fulfil objectives. This was clearly demonstrated when he revised the mathematical equation presented in his draft oil lease to the Duke. Cadman's life was multi-layered and interwoven; by the time he was invited to act as the

Duke of Devonshire's advisor he already had a large armoury of skills and experiences, built on international travel to oil-rich territories throughout the world.

Cadman's private letters to the Duke of Devonshire demonstrate that he was able to simplify even the most complex of problems. His ability to maintain good relations with landowners stands testament to his tact, tenacity and diplomacy. He was also a gifted academic, acquiring a sound knowledge and understanding of mining and geology during his undergraduate and postgraduate studies. As Professor of Mining at the University of Birmingham he was allowed to pursue his ambition of offering the world's first Petroleum Mining degree. Such a task required a detailed understanding of the oil industry from exploration through to processing and distribution.

The Hardstoft episode exposed the technological deficiencies of subsurface quantification in the early 20th century, as well as demonstrating the practical limitations in attempting to drill to thousands of feet in unchartered subsurface territories. Even with the supervision of BGS staff, percussive drilling techniques made it extremely difficult to record and interpret samples. Without geophysical methods, petroleum geoscientists had to rely on BGS maps, local colliery records and only a handful of dated texts by the likes of Farey and Whitehurst. Colliery records had played an integral role in siting boreholes; however, even with such seemingly detailed plans drilling often proceeded through coal workings, suggesting that even at the micro scale little was known of the three-dimensional territories owned and worked by multiple stakeholders.

Drilling progressed extremely slowly - often over several months - with equipment failures thwarting many of the Derbyshire boreholes. The large derricks were cumbersome to erect and suited to deep drilling in proven Persian fields, rather than relatively shallow exploration boreholes in Derbyshire. With no manufacturers capable of producing replacement items, drilling was dependent on imported goods from America. Even if a field was proven to exist the replacement of perishable goods would have been lengthy, owing to the distance they had to travel on-board ships.

Despite being slow and punctuated by setbacks, the very fact that drilling commenced at all marked an important juncture in 20th century geological science. Drilling proved the presence of anticlinal features with trap and cap features, while geochemical analysis had revealed the composition of oil. Secondary recovery systems had improved yield, while the presence of water, albeit unwanted, had provided geologists and drillers with an insight into what might be expected elsewhere within Britain. In short it was the absence of scientific results and the tantalising and enigmatic possibilities presented by Hardstoft No. 1 that would attract the attention of subsequent geologists. Unanswered questions, for example, included: how could subsurface visualisation be improved? Given the knowledge gained from the initial campaign, where would be the logical location for subsequent exploration campaigns? And how could the drilling process be expedited?

The passing of the Petroleum (Production) Act 1918 was the first UK legislation to address undiscovered hydrocarbons. Under the terms of the Act, exploration and production was prohibited, other than by the Crown or under licence from the Crown. The Act did not, as was feared by landowners, nationalise oil, meaning that local controversies, including access issues and royalty payments, still existed. With Lord Cowdray no longer wishing to pursue the potentialities of British onshore oil, John Cadman, who became Technical Advisor of the APOC in 1921, was at liberty to apply pressure to the government to revise restrictive oil legislation. Having established himself as Britain's leading petroleum geologist, Cadman would continue to play a central role in British oilfield development, adapting to the increasingly technological nature of the industry.

Chapter 5 – Technologies of exploration: the role of geophysics in British onshore oil exploration during the interwar period

5.1 Introduction

This chapter covers the period from 1922 to 1939 and is split into six sections. The first section identifies a number of problems associated with the Petroleum (Production) 1918 Act, which were deterring companies from undertaking oil exploration in Britain. The second investigates Britain's first geophysical surveys, undertaken at Keele, Staffordshire, before moving on to look at the series of events that led to the formation of Britain's first School of Geophysics at Imperial College, London. The third section begins by investigating the use of isopachytes in oil exploration, before moving on to trace the life of George Martin Lees, who led the D'Arcy Exploration Company's systematic search for oil across Britain during the interwar period. The fourth reconnects with John Cadman, who, during the late 1920s and early 1930s lobbied for changes to the 1918 Petroleum Act. The fifth chronicles D'Arcy's widespread search for oil across Britain during the late 1930s, tracing the numerous geophysical surveys and drilling attempts which ultimately all resulted in failures. The final section examines the role of Peter Kent, a geologist appointed by the APOC (which became the Anglo Iranian Oil Company (AIOC) in 1935) who, following a series of postings, successfully located oil in Eakring, Nottinghamshire on the brink of World War Two.

The main thrust of this chapter concerns the fundamental role that geophysical investigation played in reviving onshore oil exploration during the interwar period. Its focus, therefore, is primarily technological. Whereas Chapter 4 emphasised the central role of a human actor (John Cadman) in British onshore oilfield development, this chapter emphasises the non-human, and in particular the pivotal role of a single piece of technology developed by Hungarian physicist Loránd Eötvös (1848 - 1919). The Eötvös Torsion Balance, field tested in Persian oilfields during the first two decades of the 20th century would play a key role in the identification of oil-bearing strata in Britain, resulting in the discovery of a major oilfield in Eakring, Nottinghamshire on the brink of World War Two. This single piece of technology would also play a central role in the passing of the Petroleum (Production) Act 1934 and the establishment of Britain's first School of Geophysics at Birmingham University.

Like any other technology, the Eötvös Torsion Balance required human operators to undertake field surveys and interpret results. While the chapter emphasises the role of non-human actors, it continues to trace John Cadman's contribution to the industry, as well as introduce two petroleum geologists, George Martin Lees (1898 – 1955) and Peter Kent (1913 – 1986), who both worked for the D'Arcy Exploration Company and drew on their spatial life-histories to ultimately locate oil in Nottinghamshire. George Martin Lees would act at a national scale, while Kent would add site micro-scale resolution, pinpointing exactly where to drill in Nottinghamshire, based on the results of detailed site reconnaissance and geophysical investigation.

5.2 Onshore licensing: barriers to oil exploration

The UK's first drilling episode had been highly speculative, though it provided concrete proof Britain had commercial oil deposits. Geologists now recognised the hydrocarbon potentialities of Great Britain, with the BGS publishing a revised Memoir "Special Reports on the Mineral resources of Britain" in 1920, which included details of Britain's oil prospects. World War One had revolutionised resource utilisation. Combustion engines had mechanised the industrial superpowers, and coal had been superseded by oil modernity. As stated by Johnson, *et al*., (2014, p. 16) war "had highlighted the vulnerability of relying on international oil supply chains and [demonstrated] the strategic importance of liquid fuels". Despite the growing acceptance that Britain should investigate the potentialities of domestic oil, exploration stagnated during the interwar period. From 1918 to 1933 only seven licences were granted to three groups under the 1918 Act - the Duke of Devonshire (26th March 1926 in Derbyshire), Henry King Hiller (16th December 1930 near Heathfield, Sussex) and the H. M. D Syndicate Ltd (July 20th, 1931, Three Bridges, Sussex). None of the licences were held by recognised oil companies and the 1918 Act was imposing damaging restrictions.

Royalties, precedent, land ownership and the fear of monopolisation were seen as impenetrable barriers to domestic oilfield development. However, during the interwar period the British government increased fuel duties for imported oil, rising from 4d in 1928 to 8d in 1931 and ultimately a pre-war increase of 9d in 1938, thus making domestic oil exploration a viable commercial enterprise (Johnson, *et al*., 2014). Despite its low yield of oil, Hardstoft No. 1 led to optimistic speculation that domestic oil could ameliorate unemployment amongst the mining population. However, C. N. Bromehead, BGS Geologist in charge of the Yorkshire, Derbyshire and Nottinghamshire oilfields, who had supported the World War One campaign, was less supportive of renewed attempts to search for oil in Britain. On Thursday 24th January 1929 he gave an address to the Royal Institution at Hull entitled "The Derbyshire Oil Borings" stating that "personally, he did not think there was any prospect of getting more (oil), although there was always the possibility of small quantities being found here and there" (*Nottingham Evening Post*, 25th January, 1929).

In the interwar period, land nationalisation remained a prominent feature of the Labour Party manifesto. For example, bills to abolish private property in land were proposed in 1921, 1922 and 1923 to make the state landlord of all surface territories (Tichelar, 2002). Pre-war, the Party had attempted to tackle the centralisation of land ownership by taxing wealthy landowners on taxation of land values (Tichelar, 2002). This, it was hoped, would generate revenue to tackle Britain's rising social problems, notably rapid urbanisation and unemployment. During the 1920s the Labour Party looked towards the continental small holdings paradigm, which would be controlled by Local Authorities. This "back-to-the-land" policy was extremely difficult to regulate given the complexity of surface land ownership and tenancy regimes (Tichelar, 2002). Consequently, the Party shifted its land objectives towards the control of physical natural capital for production purposes, beginning with agricultural land, which was viewed as an essential rural industry (Tichelar, 2002). Broadly speaking, the Party moved away from attacking landowners' private rights. However, this was not the case for oil, to which prospects of vast fortunes were attached.

State interventionism permeated the oil industry during the early 20th century, with nationalisation spreading from Latin America (Rodríguez-Padilla, 2004). Nationalisation was largely connected to energy security threats, with western countries fearing monopolisation and cartelisation by the oil majors. Nationalism, therefore, represented the state's reactive approach to defend sovereignty, which extended to subsurface territories and in turn the resources contained within them (Rodríguez-Padilla, 2004). As discussed by Yergin (1990), energy security became a policy issue tied to the supply of oil for the military in the early 20th century. Following World War One a number of factors combined to significantly increase the demand for oil. An improved liquid fuel distribution network developed during World War One, which gave rise to increased motor car ownership and a rise in road freight, aviation, naval and marine mercantile sectors following the war, signalling a global, cultural acceptance of the oil age (Johnson, *et al*., 2014).

In 1921 D'Arcy contacted the Petroleum Department with a view to revising the Petroleum (Production) Act 1918. The department responded by forwarding a revised licence for drilling in Britain, which made the Petroleum (Production) Act 1918 exercisable by the Petroleum Production (Transfer of Powers) Order 1921.[1] The model licence was considered totally inadequate by D'Arcy, leading them to temporarily abandon British oil exploration. Over the next few years the Mines Department sought to appoint a responsible Minister to act on the company's behalf, while the Petroleum Department proposed to make amendments to the Mines (Working Facilities and Support) Act, 1923 so that it met the essential requirements put forward by D'Arcy. The scope of the Act could, they argued, be easily modified to cover oil, while other articles could be revised to render field exploration practicable.

A. T. Wilson of the APOC contacted Sir Henry Payne of the Board of Trade arguing that the Mines and Working Facilities Act would not meet the company's requirements, even if

[1] Letter dated 22nd May 1922 from the Petroleum Department to F. G. Watson of the D'Arcy Exploration Company Ltd. BPA: ArcRef 44196.

the term “minerals” was to include petroleum.[2] The fact that the Petroleum (Production) Act 1918 was still “on the Statute Book” made the situation extremely complex, particularly as it necessitated applications to both the Board of Trade and the Railway and Canal Commission. Even if both parties agreed on the proposals, the legal position would still not be clear, as the legislative provision applicable to stratified mineral deposits was not easily transposed to liquids under pressure, which could be derivable from subsoil areas at some distance from the surface over which legal rights where held. Consequently, A. T. Wilson stated the APOC’s decision was “to bide [its] time, until the matter [could] be dealt with more comprehensively, perhaps in connection with a general question in royalties on unproved minerals”.[3] H. Payne agreed that as of 1926 it did not appear favourable to discuss the question of subsoil rights to petroleum in Britain.[4] With this, the question of domestic oil faded once more.

5.3: Geophysics in Britain

When the International Geological Congress of 1923 met in Brussels, very little was known on geophysical prospecting. However, at the 1927 Congress held in Madrid a special section was devoted to the emerging field, being one of the most debated at the meeting.[5] During the mid-to-late 1920s branches of Swedish, French and German prospecting companies including German “Seismos” and French “Schlumberger” developed geophysical surveying techniques, spawning a new arm of economic geology.[6] Geophysical technologies gave geologists the tools to visualise the physical forms of buried subterranean structures, without the need for physical samples and/or ocular examination. Moreover, they offered new research prospects for both pure and applied science (Barton, 1927). In the beginning, geophysics was regarded as a pure science. However, scientists soon began to appreciate the practical application of the technique, particularly by those prospecting for metal ores, and later oil companies wishing to locate oil-bearing structures. In order to better understand measurements made at the surface, geophysical companies began to incorporate resistivity information from deeper formations, lowering probes down well holes. “Electrical coring” grew rapidly, enabling geologists to “see” what was down the well hole.

Early on, most geophysical surveys were performed by gravimetric methods using the Eötvös Torsion Balance, invented in 1888 by Hungarian physicist Loránd Eötvös (1848-1919). This measured the unequal vertical variation in the force of gravity resulting from the heterogeneous distribution of light and heavy rocks through the earth’s crust. During the

[2] Letter dated 30th June 1926 from A. T. Wilson to H. Payne. BPA: ArcRef 41067.
[3] Letter dated 30th June 1926 from A. T. Wilson to H. Payne. BPA: ArcRef 41067.
[4] Letter dated 1st July 1926 from Sir Henry Payne to A. T. Wilson. BPA: ArcRef 41067.
[5] Report on the progress of geophysical surveying. Date unknown. BGSA: GSM/PY/A/12.
[6] An in depth discussion on the history of geophysical surveying is given by Barton (1927).

interwar period the Eötvös Torsion Balance located approximately one billion barrels of oil (Speake, *et al*., 2001). In all, 79 previously unknown geological structures were attributed to the method (Bell and Hansen, 1998).

At a meeting with the Geological Survey Board in autumn 1925 John Cadman discussed the problems the APOC were having in carrying out geophysical surveys in Persia. Cadman duly acknowledged the strong ties between the APOC and the BGS, thanking BGS Director Sir J. S. Flett for "the kind and valuable assistances which the Members of the Geological Survey Board, you (Flett), and your staff have from time to time given to the officers of the Company in their work".[7] He suggested the BGS send one or two of its officers to Persia with a view to "examining on the spot the work which has been done".[8] He offered to cover all expenses and promised to arrange transport and accommodation. The field trip would last approximately nine to ten weeks, giving three full weeks in the field. Flett responded "your generous offer to arrange for two of our staff to visit your field parties in Persia appeals strongly to me and I have recommended the Department of Scientific and Industrial Research to accept it".[9] Geologist Dr W. F. P. McLintock and Mathematician Dr James Phemister of the BGS were selected on the basis that the results would assist the Geological Survey Board in coming to a decision on the possibility of carrying out official gravity survey tests in Britain.

On 3rd June 1926 the two men commented on how impressed they were in Persia with the "extraordinary facilities put at [their] disposal", acknowledging the wonderful layout and complete organisation of the field sites, high quality geological mapping and systematic manner in which the data was being reconfigured for economic purposes.[10] They also celebrated the APOC's "progressive policy of adopting the Torsion Balance as the most up to date method of detecting [subsurface] structure[s]".[11]

The pair's results were presented at the 25th meeting of the Geological Survey Board, held on 9th July 1926. Phemister was not present at the meeting; however, Dr McLintock conveyed their results using a combination of "text and diagrams".[12] Their preliminary report, which was in the beginning strictly confidential but later published (see McLintock and Phemister, 1928), was celebrated as being "very helpful in the consideration of the complicated factors involved in making use of the Gravity Balance as an adjunct to the normal methods of geological investigation".[13] Later in the meeting, attention shifted from Persia to the possibility of undertaking geophysical experiments in Britain. BGS Director J. S. Flett stated:

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[7] Letter dated 20th February 1926 from J. Cadman to Sir J. S. Flett. BGSA: GSM/XG/0/1-19S2/869.
[8] Letter dated 20th February 1926 from J. Cadman to Sir J. S. Flett. BGSA: GSM/XG/0/1-19S2/869.
[9] Letter dated 22nd February 1926 Sir J. S. Flett to J. Cadman. BGSA: GSM/XG/0/1-19S2/869.
[10] Letter dated 3rd June 1926 to J. Cadman. BGSA: GSM/XG/0/1-19S2/869.
[11] Letter dated 3rd June 1926 to J. Cadman. BGSA: GSM/XG/0/1-19S2/869.
[12] Letter dated 3rd June 1926 to J. Cadman. BGSA: GSM/XG/0/1-19S2/869.
[13] Letter dated 28th July 1928 from the Chairman, Geological Survey Board. BGSA: GSM/XG/0/1-1992/869.

a. “This country did not provide the best of fields for this kind of test
b. The recent International Geological Congress in Madrid had formed a special section to deal with the use of these methods of surveying
c. Apparatus was developing, and
d. Much literature on the subject would soon be appearing”.[14]

John Cadman later stated the APOC were continuing in their use of geophysical methods in Persia, assuring the Board he would furnish them with new information as it became available. At the 26th meeting of the Geological Survey Board, the discussion again turned to a suitable location for home deployment.

Gravity surveys detect sudden changes or discontinuities in subsurface conditions; therefore it was desired to select field sites with known anomalies. The subsurface had to be flat or gently sloping without hummocks, and sufficiently well known in order to cross reference existing data. Drift-filled channels were postulated as ideal geological features to test gravity surveys as they present as distinct and bounded homogeneous structures.

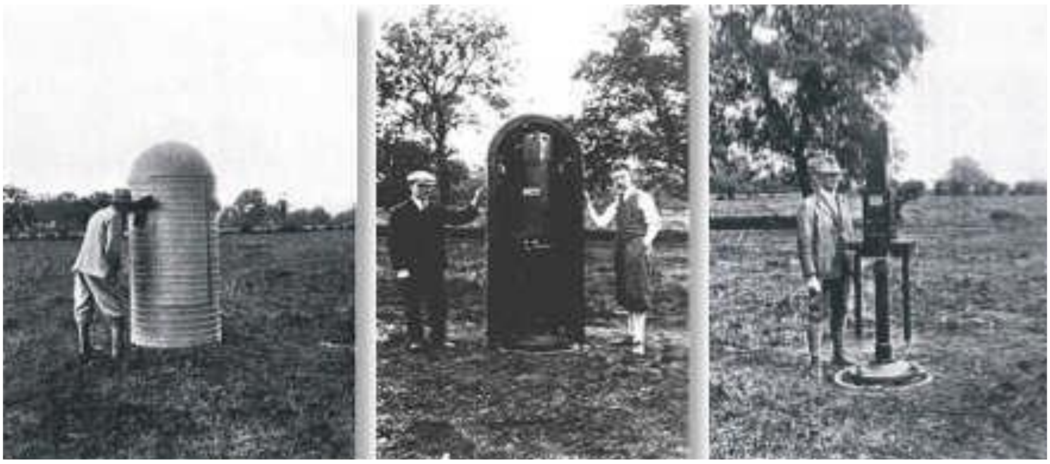
In Scotland, several areas of karst land were suggested, but all were disregarded due to the presence of unfavourable topographic and geological conditions, including the presence of dips, faults and irregular ground conditions. C. H. Dunham, BGS Geologist concluded “for these reasons…I am doubtful whether any drift-filled channels in Scotland would yield unequivocal results to an Eötvös Survey”.[15] In England, iron ore deposits in the Forest of Dean were advocated as suitable targets due to the high specific gravity difference between the ore and the surrounding bedrock. However, this was ruled out by Phemister who argued dense woodland interfered with the equipment. Discussions adjourned and it was left to the BGS to draw on the experiences of its regional geologists to investigate possible field sites.

In 1928 the BGS selected the Swynnerton-Butterton Dyke near Keele in Staffordshire to undertake Britain’s first geophysical examinations on account that the geological feature exhibited all of the necessary requisites to maximise the likelihood of credible results (see figure 5.1). The BGS purchased a Torsion Balance (Torsion Balance No. 20417) with tent from Messrs L. Oertling, Ltd of London (the only manufacturer producing them in Britain at this time) on 29th March 1927 for £950.[16] It was built to undertake photographic and visual observations and worked well under laboratory conditions. However, it suffered several defects in the field. The main problem was protecting the extremely sensitive equipment from meteorological conditions. Despite being encased, fluctuations in temperature, moisture, solar radiation and

[14] Extract from minutes of 25th meeting held on 9th July 1926. BGSA: GSM/XG/0/1-19S2/869.
[15] Extract from minutes of 25th meeting held on 9th July 1926. BGSA: GSM/XG/0/1-19S2/869.
[16] Proposal request form to purchase “One Eötvös Torsion Balance for visual and photographic recording, with tent. Dated 29th March 1927. BGSA: GSM/PY/A/10.

vibration led to significant data inaccuracies. The balance performed differently during the day and night, which was attributed to faulty design. Nonetheless, Phemister and McLintock's pioneering geophysical work, published in 1928, helped guide geoscientists as to how to non-invasively explore Britain's subsurface geographies. Phemister remained at the forefront of this new frontier of scientific exploration, extending his research interests to the whole of the British Isles.

Figure 5.1: Torsion balance in use at Swynnerton-Butterton Dyke close to Keele, Staffordshire. Date unknown.



Source: *Keele University (2015, np).*

BGS Director J. S. Flett was vexed by the poor performance of the Oertling Eötvös balance and declared "I am diffident about accepting makers' statements about the performance of their particular balances and should prefer to make a recommendation based on definite trials by Dr. Phemister and myself under field conditions".[17] The only other type of instrument available in Britain at this time was the "Gradiometer" designed by Mr Lancaster-Jones and Captain Shaw of the Science Museum and manufactured by the Cambridge Instrument Company. However, it was not considered suitable as it did not produce curvature values essential in deducing certain geological phenomena. The BGS had limited experience with a smaller "Suss" balance, made in 1925 by Dr Pekar. Following appeals for funding, the BGS purchased a Pekar-Suss Torsion Balance (serial No. 37201) in spring 1930. It was manufactured

[17] Report entitled "Reference G.E.11/6/1 Director" dated 7th February 1930. BGSA: GSM/PY/A/17.

by the Ferdinand Suss Institute for Precision Mechanics and Optics Company Ltd[18] for a total cost of £1373.6.8 (balance £973.6.8 and two tents £400).[19]

On 21st March 1929 the Institution of Mining and Metallurgy directed its discussions to the general principles, possibilities and limitations of geophysical survey methods.[20] A series of specialists were invited to speak for twenty minutes each on the emerging branches of geophysical surveying. Professor Alexander Oliver Rankine of Imperial College, London discussed seismic methods, Mr Edge electrical methods, McLintock and L. Jones gravitational and Mr S. H. Shaw magnetic. In the same year the Department of Scientific and Industrial Research (DSIR), which, from 1915 to 1956 was "chiefly responsible for the support and direction of research in technology and the physical sciences in Britain" (MacLeod and Andrews, 1970, p. 23) appointed a Geophysical Survey Research Committee under the Chairmanship of Sir Henry Lyons, which was charged with carrying out research on seismic and electric methods.[21]

The Committee's scope also extended to encouraging the study of geophysical survey methods in universities and the manufacture of geophysical instruments in Britain. Several mining schools were said to be interested in the practical and intellectual implications, though the expense of instrumentation was putting many off. J. S. Flett intimated it was his intention to demonstrate the use of geophysical balances in universities to allow students to gain practical experience in geophysical surveying.[22] He believed it was essential to encourage the study of geophysical methods in Britain as foreign countries were undoubtedly ahead both in the production of instruments and their practical application in the field.[23] In the early 1930s Broughton Edge, Director of the Imperial Geophysical Experimental Survey of Australia, argued geophysical methods were limited to five to ten per cent of the world's mining fields owing to site specific prerequisites. In order to stimulate the use of geophysical tools within the British Empire it was seen to be essential to train geophysicists to move pure science into the field.[24]

The Geophysical Research Committee suggested courses be introduced to elevate the scientific status of Britain's lagging departments, so as to produce suitably qualified experts "in

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[18] Certificate for Eötvös Double Torsion Balance No. 37201. BGSA: GSM/PY/A/13.
[19] Letter dated 12th February 1930 entitled "Memorandum on an application by the Director of Geological Survey and Museum for an additional allocation towards the purchase of a Pekar-Suss Torsion Balance. BGSA: GSM/PY/A/13.
[20] Letter dated 13th March 1929 from C. Gilbert Callis to BGS Director J. S. Flett. BGSA: GSM/PY/A/12.
[21] Letter dated 19th September 1929 from BGS Director J. S. Flett to the Director, Geological Survey Office, New Zealand. BGSA: GSM/PY/A/17.
[22] Report entitled "Reference G.E.11/6/1 Director" dated 7th February 1930. BGSA: GSM/PY/A/17.
[23] Report entitled "Reference G.E.11/6/1 Director" dated 7th February 1930. BGSA: GSM/PY/A/17.
[24] Report dated 6th May 1931 entitled "Memorandum on the suggested formation of a school of applied geophysics at the Imperial College of science and technology". BGSA: GSM/PY/A/17.

the various geophysical methods of surveying underground structures".[25] The Committee recommended the Imperial College of Science and Technology as the most suitable centre in Britain and suggested a School of Applied Geophysics be established to deliver post-graduate courses.[26] The recommendation was submitted to the Advisory Council during the 1929 to 1930 session, including a plan to equip the School subject to the financial sanction of Parliament, who, it was hoped would make a grant at the initial stages.[27]

The first memorandum, submitted to the rector of Imperial College allocated £1,500 for equipment (torsion balance, seismograph and recorder, magnetometer and a number of electrical instruments)[28] and an annual grant of £500 for research for up to four years, as well as the continuous services of three research assistants.[29] The scheme was considered experimental (to ascertain the viability of a geophysical course in Britain) with the BGS agreeing to loan its geophysical equipment for the four year period.

The new School of Applied Geophysics would be attached to the Department of Physics and concentrate its teaching "on the application of physical methods for the elucidation of underground structures and the detection of underground deposits"[30], though it would collaborate with the geology and mining departments. A. O. Rankine would be relieved of other teaching duties to concentrate solely on the development of the new department. The additional cost to establish the department stood at £1,200. However, with provision for only six students per year charged at £60 each the expense was considered totally disproportionate and angered some academic staff.[31]

J. S. Flett was initially unsure of loaning the Survey's expensive geophysical instruments to the new School, and so sought the opinions of the Vice Chancellor of The University of Reading who stated "In ordinary circumstances I should be very reluctant to see the Geological Survey abandoning geophysical work… [however] I think you might well help the proposed School of Geophysics at the Imperial College by handing over the equipment now in your possession".[32] In 1933 the BGS moved into new premises in London, meaning staff

[25] Report dated 6th May 1931 entitled "Memorandum on the suggested formation of a school of applied geophysics at the Imperial College of science and technology". BGSA: GSM/PY/A/17.
[26] Report entitled "Memorandum on the development of the study of applied geophysics". BGSA: GSM/PY/A/17.
[27] Report entitled "Memorandum on the development of the study of applied geophysics". BGSA: GSM/PY/A/17.
[28] Memorandum by the rector of the Imperial College on the formation at the College of a School of Applied Geophysics. Date unknown. BGSA: GSM/PY/A/17.
[29] Report dated 6th May 1931 entitled "Memorandum on the suggested formation of a school of applied geophysics at the Imperial College of science and technology". BGSA: GSM/PY/A/17.
[30] Memorandum by the rector of the Imperial College on the formation at the College of a School of Applied Geophysics. Date unknown. BGSA: GSM/PY/A/17.
[31] Memorandum by the rector of the Imperial College on the formation at the College of a School of Applied Geophysics. Date unknown. BGSA: GSM/PY/A/17.
[32] Letter dated 12th June 1931 from The Vice Chancellor of The University of Reading to J. S. Flett, BGS Director. BGSA: GSM/PY/A/17.

members were temporarily unable to undertake geophysical field surveys. Rather than have the equipment lie idle, Flett agreed to loan the geophysical equipment to the College authorities. He even went so far as to state that the instruments could be retained beyond the initial four year trial period should the course prove successful.[33]

Imperial College received its first cohort of geophysics students in autumn 1931. In November 1931 A. O. Rankine stated "I am now in the midst of the lectures…and am gaining experience as I go along. I intend towards the end of the present session to publish a much more detailed syllabus in anticipation of the courses in October 1932".[34] The course was an immediate success. By 20th November 1931 the Director of the Geological Survey, Federated Malay States enquired whether it would "be made possible for Officers of a Colonial Geological Department to take a shortened course at the new school of applied geophysics".[35] Over time the course's popularity grew, with "geophysics attached to the Physics department until 1955, when it moved to geology under John McGarva Bruckshaw" (Gay, 2007, p. 154).

5.4 Scientific breakthroughs, conflict and controversy

In July 1929 John Cadman wrote to the Secretary of the Petroleum Department, explaining how, over the past four years numerous private parties had asked the APOC to carry out exploratory work to test the oil-bearing potentialities of the United Kingdom. The problem, he remarked, was the issue still surrounding the acquisition of surface and subsurface rights from numerous private landowners, which was making it difficult to justify the expense of speculative drilling.[36] He argued the company still did not feel any revisions made to the Mines Working Facilities and Support Act, 1923 would be satisfactory for enabling widespread exploration. However, he hoped that as the government was considering reviewing legislation affecting subsurface rights of subterranean minerals, they would consider petroleum as part of their evaluation.

The APOC were undoubtedly the largest and most influential proponent of domestic oil exploration in Britain from the interwar period onwards, though they were not alone. Stratigraphical geologist F. H. Mackintosh, W.G.A Ramsay Fairfax, A. Wade (former Advisor to the Australian government) and H. N. G. Cobbe from the Fuel Research Department had written to the APOC in the summer of 1931 with a view to boring for oil in Britain. Over several

[33] Letter dated 29th June 1931 from The Department of Scientific and Industrial Research to J. S. John Flett, BGS Director. BGSA: GSM/PY/A/17.
[34] Letter dated 17th November 1931 from A. O. Rankine to J. S. Flett, BGS Director. BGSA: GSM/PY/A/17.
[35] Letter dated 20th November 1931 from E. S. Willbourn, Acting Director, Geological Survey, Federated Malay States to J. S. Flett. BGSA: GSM/PY/A/17.
[36] Letter dated 16th July 1929 from J. Cadman to the Secretary of the Petroleum Department, Department of Mines. BPA: ArcRef 41067.

years Mackintosh's group had mapped the whole of the south of England using the relatively new "isopachytes" method, selecting an area of approximately fifteen by ten miles in the south of England which they believed had oil potential.[37] Using their method the group had produced a detailed map of the UK, showing the locations of superficial features and geological sequences, which they would sell to the British government for £5,000 in addition to receiving a royalty on any oil found.[38]

The isopachyte method was a low cost method of surveying vast swathes of territory, which according to the group could practically eliminate all chances of failure. They argued "the cost of a misplaced borehole, perhaps one…of 5,000 feet, can be insured against by incurring the comparatively small expense of a geophysical survey within the limitations of our denoted areas".[39] Isopachyte mapping uses geophysical data to produce contour lines showing geological units of equal thicknesses, which are in turn added to two dimensional maps. By analysing parallelisms in isopachyte distribution earth movements over geological time are deduced to "[show] in graphic and measurable form the geographical conditions under which any geological formation was accumulated. Thus they [brought] under control what would otherwise be very free speculation as to past geological times".[40]

These inferences indicated depositional environments by analogue of known overlying characteristics, therefore negating the need for capital intensive and physically invasive drilling. Like drilling, geophysical surveys require access to vast areas of territory. Although non-invasive, the same difficulties apply insofar as multiple landowners are involved in granting access to the land surface. Aware of the "tiresome and expensive business"[41] of access to property, and the historically bureaucratic complexities of surface mineral rights and ownership, the group suggested…the government should [use] its prerogative as to entry for purposes of survey".[42]

Makintosh and his group presented their findings to the APOC, hoping to gain support for their novel exploration technique. The APOC considered the group's proposals, and appreciated the time and resources spent by the group, however, regrettably, as a commercial firm APOC thought their findings to be highly speculative. Though their theories were legible,

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[37] Four page discussion on the group's plans for isopachyte mapping 30th November 1931. BGSA: GSM/XG/0/1-19S2/859.
[38] Letter dated 4th November 1931 from the Director of the BGS to the Petroleum Department (Mines Department. BGSA: GSM/XG/0/1-19S2/859.
[39] Letter dated 19th October 1931 from H. N. G. Cobbe for the signatories to the Director, Petroleum Department (Mines Department). BGSA: GSM/XG/0/1-19S2/859.
[40] Excerpt from a report by Professor Morley Davies dated 3rd November 1931. BGSA: GSM/XG/0/1-19S2/859.
[41] Four page discussion on the group's plans for isopachyte mapping dated 30th November 1931. BGSA: GSM/XG/0/1-19S2/859.
[42] Letter dated 19th October 1931 from H. N. G. Cobbe for the signatories to the Director, Petroleum Department (Mines Department). BGSA: GSM/XG/0/1-19S2/859.

there was no way of knowing the depth, formation and structure of the geology other than by drilling. Consequently, “whilst thanking [them] for having again brought the matter to [their] notice, [they did] not feel justified in carrying the matter further”.[43] Failing to win over APOC, F. H. Mackintosh wrote directly to the Permanent Secretary to the Admiralty at Whitehall declaring:

“For some time past we have been interested in the possible discovery of natural oil in England, as quite distinct from the extraction of oil from coal or shale and have narrowed our searches to individual targets for drilling based on geologically favourable conditions”.[44]

They described their discussions with APOC, arguing it had acted in diffidence on commercial grounds. Appealing to the Admiralty, they stated:

“at the present time there appears to be no capital available for enterprise we refer to, at least not from the usual channels, and we therefore address ourselves to your department of His Majesty’s government, the one that is perhaps the most concerned [with the issue of domestic oil security]”.[45]

The group argued their principles “almost certainly show[ed] (subterranean) dome and anticline occurrences [which justified] immediate geophysical prospecting and drilling at or around these points” particularly as these structures were analogous with oil-bearing territories in France.[46] They argued that if exploratory work was neglected in England but successfully undertaken in France, Britain could become an importer of French oil, rather than an exporter of domestic oil.

H. N. G. Cobbe, on behalf the group, contacted the Director of The Petroleum Department “convinced that a case [existed] geologically and from an economic point of view…for the immediate prospecting for natural oil in England”.[47] He stressed that commercial oil exploration was better undertaken by the government and reiterated the intensive (and costly) research involved to date. He argued that:

“Since there does not appear any of the usual city or such like sources of funds available for a full investigation of our subject …it is appropriate we put our special information before

[43] Letter dated 26th August 1931 from A. T. Wilson of the APOC to F. H. Makintosh. BGSA: GSM/XG/0/1-19S2/859.
[44] Letter dated 18th September 1931 from W. G. A. Ramsay Fairfax, A. Wade, H. N. G. Cobbe and F. H. Mackintosh to The Permanent Secretary of The Admiralty. BGSA: GSM/XG/0/1-19S2/859.
[45] Letter dated 18th September 1931 from W. G. A. Ramsay Fairfax, A. Wade, H. N. G. Cobbe and F. H. Mackintosh to The Permanent Secretary of The Admiralty. BGSA: GSM/XG/0/1-19S2/859.
[46] Letter dated 18th September 1931 from W. G. A. Ramsay Fairfax, A. Wade, H. N. G. Cobbe and F. H. Mackintosh to The Permanent Secretary of The Admiralty. BGSA: GSM/XG/0/1-19S2/859.
[47] Letter dated 19th October 1931 from H. N. G. Cobbe to the Director of the Petroleum Department. BGSA: BGSA: GSM/XG/0/1-19S2/859.

you…we hope that your technical advisors…will see we have a programme based on very careful examination of the subject".[48]

If the technical advisors of the Admiralty felt it warranted expenditure, the group would prepare a:

"Suitably-equipped geophysical party of surveyors [to be] sent out to the districts…to prepare the usual plans of underground structure[s]". Although they would not disclose the two locations, they elucidated "anywhere in the south of England there may be found very trifling amounts of petroleum".[49]

After carefully reviewing F. H. Mackintosh's proposals the Director of the Petroleum Department concurred that although he found the method highly ingenious, the results were far from convincing and at the present oil exploration could not be regarded as anything more than wildcatting and certainly not a "suitable enterprise for the expenditure of public money".[50] He concluded by arguing that while a geophysical survey would probably be an indispensable preliminary, it would be costly and troublesome, if inefficiently conducted. And while it might give evidence regarding structure it could not possibly indicate either the presence or absence of oil deposits that would repay the cost of the development.[51]

Whilst these scientific discoveries and developments were taking place the APOC had appointed 32 year old George Martin Lees (Lees joined the APOC on 1st November 1930) as its Chief Geologist (see figure 5.2). Lees was born at Dundalk in 1898 and was educated at St Andrew's College, Dublin before moving to the Royal Military Academy, Woolwich to embark on his World War One training. As reviewed by Arkell (1955), he gained a commission in the Royal Artillery whilst serving in France, before being transferred to the Royal Flying Corps where he won the Military Cross. His service duties saw him tour Egypt and Mesopotamia (now Iraq), where he was shot down behind Turkish lines at Kirkuk. Lees returned to Britain in 1921 and studied geology at the Royal School of Mines. This led to his appointment as Assistant Geologist at the APOC.

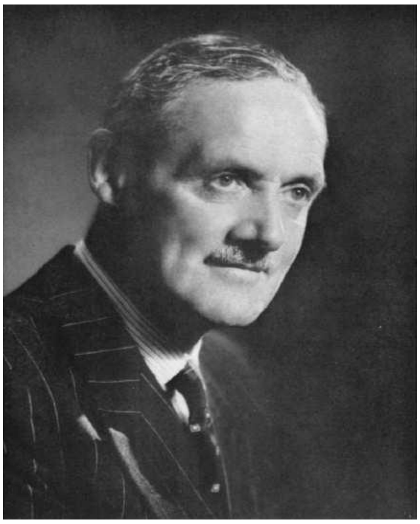
During 1924 he undertook a tour of south-west Persia with geologist Hugo De Böckh, discovering several oilfields. During 1925 and 1926 Lees surveyed Oman with K. Washington Gray, presenting their ground-breaking findings to the Geological Society of London, which became standard reference texts until revisions in the 1950s. From 1928 to 1930 Lees explored for oil in Canada, Germany, Egypt and America and surveyed extensive oilfields in

[48] Letter dated 19th October 1931 from H. N. G. Cobbe to the Director of the Petroleum Department. BGSA: BGSA: GSM/XG/0/1-19S2/859.
[49] Letter dated 19th October 1931 from H. N. G. Cobbe to the Director of the Petroleum Department. BGSA: BGSA: GSM/XG/0/1-19S2/859.
[50] Letter dated 6th November 1931 from the Director of the BGS to the Director, Petroleum Department (Mines Department). BGSA: GSM/XG/0/1-19S2/859.
[51] Letter dated 6th November 1931 from the Director of the BGS to the Director, Petroleum Department (Mines Department). BGSA: GSM/XG/0/1-19S2/859.

Kermanshah and Iraqi Kurdistan, selecting 100,000 square miles of territory for detailed exploration. In Iran and Iraq he undertook detailed fieldwork on the Zagros mountain range, which he believed was analogous to geological conditions in the British East Midlands.

Lees undertook an extensive survey of the British Isles during the early 1930s, transposing the geological principles he had developed in Iran and Iraq (Arkell, 1955). His research was assisted by members of the BGS, the Petroleum Department and palaeontologists of the Natural History Museum. Kent (1985, p. 56), notes that “Lees compiled a case which led the Anglo-Persian Oil Co. Chairman Lord Cadman to introduce an Act simplifying ownership of mineral oil and gas deposits to make British onshore prospecting practicable”.

Figure 5.2: George Martin Lees.



Source: *Arkell (1955, p.162).*

Shortly after the appointment of Lees, John Cadman wrote again to the Petroleum Department stating “I have for some time been considering whether it would not be worthwhile to examine certain areas in England where there may be the possibility of oil existing in quantity”.[52] Although he admitted the possibility of commercial oil was slim, he felt the question could not be passed up without thorough geological investigation. He had several areas of Britain in mind, but suggested the main thrust would be concentrated on an area of 30,000 acres in North Yorkshire.

The first task was to ascertain the major landowners and contact them independently. By March 1933 the APOC had drafted its own form of agreement for land and mineral rights.

[52] Letter dated 24th October 1932 from J. Cadman. Addressee unknown. BPA: ArcRef 44191.

It followed the same terms drafted by Cadman in 1915, whereby hypothetical person(s) x "owned specified land and mineral rights, and person(s) "y" was "desirous of searching for, and if available in commercial quantities, of producing and carrying away for sale, etc…coal, iron, petroleum, salt and potash salts".[53] Section seven of the nine section document was titled "Fixation of royalty" which transposed the "a x b/c" paradigm, whereby "a" represented the net royalty from minerals extracted over a defined area, "b" was the area of "person(s) "x's" land and "c" was the "aggregate of the defined areas".[54]

Following a period of consultation, Cadman revised his initial proposals and included a second county in England. He subsequently contacted F. C. Starling, Chairman of the Petroleum Department arguing the two counties would be explored gradually, systematically, "successively and not concurrently" with as little publicity as possible.[55] Only the largest landowners in the two regions would be contacted, so as to avoid public exposure, which he believed might prejudice the scheme – as had been the case during the World War One episode. Cadman requested the government give the company contingent and prior rights to drill in the areas defined by them (and on estates developed in the future), arguing that although the likelihood of domestic oil was slight, the company did not wish to lose out on the possibility of proving whether commercial oil did, or did not in fact exist in Great Britain. He stressed the APOC was reliant on the government and vice versa if Britain were to gain domestic oil security. F. C. Starling replied, granting Cadman the assurance that the government would not consider any other applications put forward in the defined areas, pending evidence that the APOC had secured rights to explore and bore for petroleum.[56] However, he added it was not in accordance with current legislation to grant rights over such large areas. Once again the size of the concessionary area looked set to hamper progress. However, F. C. Starling optimistically added that the Secretary for Mines welcomed interest from the company and did not wish to place unnecessary barriers in their way. The letter was followed up with formal discussions held on 14th June 1933, attended by John Cadman, APOC Chairman Sir William Fraser, Mr Hearn, Sir G. Faulkner and Starling.[57]

Lees meanwhile, submitted a ten page internal report which gave three (and not two as has been purported by Cadman) possible and unrelated blocks of territory he believed might contain oil, being "the Carboniferous Limestone of Derbyshire, Limestone Shales and Coal Measures and Permian Magnesian Limestone of Yorkshire and the Jurassic of the South of

[53] Draft Agreement entitled A. Agreement: land and mineral rights. Date unknown. BPA: ArcRef 44191.
[54] Draft Agreement entitled A. Agreement: land and mineral rights. Date unknown. BPA: ArcRef 44191.
[55] Letter dated 25th May 1933 from J. Cadman to the Director, Petroleum Department – F. C. Starling. BPA: ArcRef 44191.
[56] Letter dated 1st June 1933 from the Director, Petroleum Department – F. C. Starling to J. Cadman BPA: ArcRef 44191.
[57] Report conducted on behalf of the D'Arcy Exploration Company Ltd entitled "A search for oil in the British Isles dated 21st June 1933. BPA: ArcRef 44191.

England".[58] Developments in geophysical methods had, he argued made it easier to identify better and larger structures hidden by unconformable blankets of rocks. Lees paid relatively little attention to the Carboniferous system of England and Scotland, though did state the Midlands could not be discounted on the basis of negative World War One results.

D'Arcy, operating as a subsidiary of APOC, went on to investigate the Permian Magnesian Limestone in Yorkshire, thought to have been deposited by seas stretching from the Durham coast in Eastern England to the Thuringian basin of Northern Germany where commercial oil deposits had been found in the Volkenroda rocks.[59] The porous rocks of Durham were considered to be exceptionally favourable, with outcropping rocks smelling of oil. Coal and salt borings in the Tees valley had also given rise to oil and gas shows. A detailed examination in the region indicated two possible anticlines. The first was situated on the Cleveland axis at Eskdale and the second was at Robin Hood's Bay. Empirical evidence was conflicting; however, Lees recommended initial test drilling at Eskdale. Moving to the Jurassic rocks of Southern England, Lees elucidated Jurassic and Liassic rocks had produced oil shows throughout England, Northern France and North Germany. All oil in Germany (excluding the Volkenroda) was then produced from Jurassic or Lower Cretaceous sands.[60]

In the South of England possible source rocks were considered to have suitable thickness and lateral extent, with potential reservoir rocks having suitable structure and cover. Almost all drilling undertaken in the area, however, had been confined to the eastern half of the Weald in the Carboniferous coal, where thick oil shows had been encountered in the Upper Jurassic Portlodian. These wells had been located on the edge of Jurassic basin and thus could not be regarded as suitable tests to validate the presence of oil. One well, however, drilled over a period of 2.5 years by an oil-boring Syndicate led by Mr Norman Dudgeon, had encountered a small show of oil at 1,876 feet in the thin limestones of the Purbeck, offering a slim hope of success.[61]

The Jurassic basin was considered to be continuous from Southern England to Northern France, prompting the French government to drill a well at Pay de Bray in 1925. This though, was abandoned at 3,300 feet in crystalline rocks having failed to encounter oil. Lees believed the centre of the Jurassic sedimentary basin lay just south of the Isle of Wight and was thus considered more favourable than any locations in Kent. A detailed examination of rocks along the Dorset coast indicated the Jurassic sands had contained liquid oil leading him to suggest

[58] Report conducted on behalf of the D'Arcy Exploration Company Ltd entitled "A search for oil in the British Isles dated 21st June 1933. BPA: ArcRef 44191.
[59] Report conducted on behalf of the D'Arcy Exploration Company Ltd entitled "A search for oil in the British Isles dated 21st June 1933. BPA: ArcRef 44191.
[60] Report conducted on behalf of the D'Arcy Exploration Company Ltd entitled "A search for oil in the British Isles dated 21st June 1933. BPA: ArcRef 44191.
[61] Report conducted on behalf of the D'Arcy Exploration Company Ltd entitled "A search for oil in the British Isles dated 21st June 1933. BPA: ArcRef 44191.

drilling into structures at Portsdown and on the Isle of Wight, with Portsdown having the highest potential owing to better structural closure.

5.5: The nationalisation of British oil

Early in 1934 the government continued its discussions with John Cadman and other interested parties as they attempted to draw up equitable terms for domestic oil exploration. The aim was to produce a regulatory system which was fair on licensor and licensee alike.[62] In the House of Commons Walter Runciman, President of the Board of Trade announced the government were taking steps to stimulate the search for oil in Great Britain, as rapidly increasing importation had deemed it essential to "find some solution to [a] very complicated and increasing obstacle".[63] He added The Act was "the only way in which it [was] possible to simplify [ownership] matters".[64] Removing complicated exploration obstacles could, he believed only occur if oil was vested in the Crown i.e. if oil were to be nationalised.

During one parliamentary debate in the House of Lords the Conservative Party argued nationalising oil was an infringement on landowners' liberties.[65] They reminded the house that in the 1909 Finance Act the Commissioners of the Inland Revenue, acting on behalf of the Liberal government had construed form "IV" so that any landowner failing to answer an optional question "W" was in fact surrendering their mineral rights to the state. This had meant potentially one-fifth of the nation's capital value in unworked mineral resources could be sold or leased to the government. Ultimately the Court of Appeal and the House of Lords acting in its judicial capacity unanimously agreed the "contention of the government was ultra vires" and landowners having not answered optional question "W" could not be prejudiced.[66] The Act was seen as analogous to one submitted in Russia, which effectively seized all minerals before selling them off for great profit. The Labour Party pointed out that as gold and silver were already vested in the state; landowners' private property rights had already been infringed. Moreover, all coal existing beneath high-water mark or at levels below low-water mark was His Majesty's land, i.e. the property of the Crown. These examples highlighted the "inroads made into the doctrine of private property".[67]

In Britain rights to a limited number of subsurface minerals had been decided centuries ago. For example, in 1278 Edward I passed the Apex law, which enabled a surface owner to

[62] Report entitled "England". Date Unknown. BPA: ArcRef 44067.
[63] In Daily Mail 23rd (month unknown) 1934. Article entitled "New quest for oil: M. P.s surprised by government plan". BGSA: GSM/XG/0/1-19S2/859.
[64] In Daily Mail 23rd (month unknown) 1934. Article entitled "New quest for oil: M. P.s surprised by government plan". BGSA: GSM/XG/0/1-19S2/859.
[65] HL Deb 19 April 1934 vol 91 cc661-93.
[66] HL Deb 19 April 1934 vol 91 cc661-93.
[67] HL Deb 19 April 1934 vol 91 cc661-93.

extend exploration into a neighbour's territories should he find tin and lead on his land, subject to compensation for surface rights. In 1568 Queen Elizabeth I had acquired Royal Monopolies to gold and silver in response to the threat of war with Spain. In a debate in The House of Commons on 12th August, 1919 Sir G. Hewart argued "the surface owner is the owner of the oil beneath his land in the sense that he alone has the right on his land to search and bore for oil and becomes the owner of the oil if and when he gets it".[68] However, due to the depth at which oil is found, it was thought beyond the realms of capability for a private individual to explore for, extract and "enjoy" oil himself. Consequently oil had no value to a landowner. However, Lord Hartington (the son of the Duke of Devonshire) argued that nationalisation made the prospect of land ownership a less attractive proposition in Britain, reducing the "sense of security in ownership of land".[69] In turn this would reduce the flow of capital into the land, significantly affecting its agricultural development and government policy.

In The House of Lords Sir Arnold Wilson, who had overseen the discovery of the Masjid-i-Suleiman oil well in Iran in 1908 and had become resident Director for the APOC in the Persian Gulf, argued that without a solid Bill, domestic oil exploration could not proceed.[70] In World War One, he stated, Germany had injected subsidies and grants into its own domestic oil situation. However, due to the problems of multiple smallholders, Germany had only been able to extract 130-150,000 tons of oil. Micro-scale controversies were directly attributable to the economy of the nation and its failure to maximise oil production. In opposition, Mr John Tinker, Labour MP for Leigh, Greater Manchester, argued that it was bad practice to grant 20th century mortal rights to a natural asset laid down millions of years before his/her occupancy.[71] Domestic oil was a question of reconciling individuals' private rights against public policy.

Following several debates the government finally introduced the Petroleum (Production) Act 1934 on 12th July 1934, vesting petroleum and natural gas in the Crown (LGU, 2016). Under the Act, the Railway and Canal Commission was charged with ensuring local amenities were not adversely impacted by operations and that operators acted in a sympathetic manner whilst using and occupying the land.[72] The Petroleum (Production) Act 1934 was followed by the Petroleum (Production) Regulations Act 1935, made by the Board of Trade on 15th May 1935 and which came into force on 17th June 1935 (McBeth, 1985, p. 126), which prescribed and explained the conditions under which oil exploitation would be carried out. Section two of the Act stated "For the purpose of this Act the expression "petroleum" includes any mineral oil or relative hydrocarbon and natural gas existing in its natural condition in strata, but does not include coal or bituminous shales or other stratified deposits from which oil can be

[68] HC Deb 12 August 1919 vol 119 c1128W.
[69] HC Deb 19 June 1934 vol 291 cc213-319.
[70] HL Deb 19 April 1934 vol 91 cc661-93.
[71] HC Deb 19 June 1934 vol 91 cc661-93.
[72] HC Deb 19 June 1934 vol 291 cc213-319.

extracted by destructive distillation". The regulations would be implemented within 28 days should neither House impose a negative resolution.

The regulations issued two types of licence. The first covered exploration, referred to as the "Prospecting Licence". The second, "Mining Licence", covered the extraction and exploitation of hydrocarbons. Following the announcement of the new regulations, D'Arcy scrutinised its ramifications, which they documented in a report entitled "England" from which the following information is taken.[73] The prospecting licence covered a period of three years with the possibility of two extensions of one year, granted up to a maximum of five years for exploration in a single area. A Prospecting Licence cost £25 with a bond of £6 per square mile (but no less than £400). It covered an area of no more than 200 square miles but no less than eight square miles. Rents were charged as a Minimum Annual Payment (MAP) payable in advance to and agreed with the Board of Trade, calculated on the size of the royalty area. The Prospecting Licence granted exclusive rights to prospect in a defined area and made provisions for extensions to be granted if desired. A company or individual could apply for multiple licences, with the option to end the licence on giving three months' notice, or two months' notice to surrender a portion of the licence area. A Prospecting Licence would always be issued prior to the granting of a Mining Licence. A Mining Licence cost £40 with a bond of £20 per square mile (not less than £1,000). It lasted 50 years with the option to extend for a further 25 years. It covered no more than 100 square miles and not less than four square miles. MAPs were agreed by negotiation and payable in advance, again calculated on the size of the area.

The details of each new licence holder and the geographic extent of each area granted would be published in both the *London Gazette* and the *Edinburgh Gazette*. Royalties would be revised periodically, the first scheduled in 1951. The operations had to be undertaken in a workmanlike manner, in accordance with good oilfield practice. All harmful methods of working had to be avoided, and provisions made to prevent the waste of petroleum. Damage to proximal localities was prohibited both above and below ground, in particular damage to adjoining petroliferous strata. Finally, development could not interfere with local amenities.[74]

During the interwar period there was great public interest in petroleum. In 1930 John Cadman gave a series of six BBC broadcast lectures collectively titled "*The Romance of Oil*". Each lasted roughly 20 minutes and discussed exploration, refining and processing, the geographical distribution of mineral petroleum, world economics, oil during World War One and oil exhaustion. In his final broadcast, Cadman proclaimed oil was the arterial system of the civilised world and that "romance [is] still with us, still alive, still vital, in all that has been made

[73] Report entitled "England". Date Unknown. BPA: ArcRef 44067.
[74] Report entitled "England". Date Unknown. BPA: ArcRef 44067.

possible to the ingenuity, the enterprise, and the courage of man by the discovery of petroleum" (Cadman, 1930, p. 27).

Following the announcement of the Petroleum (Production) Act 1934 the British media issued a series of headline reports on Britain's domestic oil situation. Across Britain the atmosphere reached fever pitch as the population became fascinated by geology and fixated by the magic name of oil. On 23rd March 1934 The *Daily Mail* promulgated "much surprise was caused among MP's tonight by the government's announcement of legislation to take over the ownership of any petroleum which may be discovered in Great Britain".[75] The following day they added "Geologists have now learned a great deal more concerning the probability of oil being found in certain underground formations and this has encouraged the hope that fresh borings in selected sites might lead to oil in marketable quantities".[76] They pointed out the new provisions protected the British taxpayers, as revenue generated from hydrocarbons would go to the Treasury. The *Daily Telegraph* acknowledged the alertness of the government to "these drastic proposals" and expressed the opinion that the legislation would prevent an "oil rush".[77] *The Observer* drew attention to "Hidden oil in Britain"[78] while the *Sunday Chronicle* optimistically reported on "a vast underground sea, equally as rich as the Texan or Persian fields".[79] The *Evening Standard* interviewed Captain Penrose on behalf of the Duke of Devonshire, Mr King Hiller and Mr Norman Dudgeon – the latter both holding four square mile licence areas in Sussex. Captain Penrose stated "We sunk two other wells eight or nine years ago, but had no success. Considering it was sunk in 1918 it is marvellous that the Hardstoft wells should be producing now. It means we have never got to the proper source".[80] K. Hiller was certain oil would be found in Heathfield, Sussex though had not carried out any boring. N. Dudgeon intimated his well was progressing satisfactorily and hoped to encounter the Portland oil sands at 1,970 feet.

The *Daily Express* reported in May 1935 (see figure 5.3) that prospectors were now ready to begin the hunt for Britain's underground oil "lakes", stating "a nation-wide search for oil under Britain will begin in June… [as] almost the whole of Britain will be mapped into oil areas".[81] Heightened media coverage and the prospects of rags to riches fame put a huge

[75] *Daily Mail* 23rd March 1934. Article entitled "New quest for oil". BGSA: GSM/XG/0/1. IGS2/858.
[76] *Daily Mail* 24th March 1934. BGSA: GSM/XG/0/1. IGS2/858.
[77] *Daily Telegraph* 23rd March 1934. Article entitled "Fostering the search for British oil". BGSA: GSM/XG/0/1. IGS2/858.
[78] *Observer* 25th March 1934. Article entitled "Hidden oil in Britain: Are there petroleum fields? Experts opinion". BGSA: GSM/XG/0/1. IGS2/858.
[79] *Sunday Chronicle* (May 1935). Article entitled "Oceans of oil beneath Britain". BGSA: GSM/XG/0/1. IGS2/858.
[80] *Evening Standard* 23rd March 1934. Article entitled "Searching for oil in Sussex and Derbyshire: Men who hold licences under 1918 Act: Government proposals". BGSA: GSM/XG/0/1. IGS2/858.
[81] Daily Express (1935 exact date unknown). Article entitled "Licences for searches". BGSA: GSM/XG/0/1. IGS2/858.

pressure on the BGS, who were inundated with reports and samples, which “in nine cases out of ten…[were] not oil at all”.[82]

Figure 5.3: Report by *Daily Express* in May 1935 showing proposals for subsurface licencing to search for domestic oil in Britain during the interwar period.

LICENCES FOR SEARCHERS—*Official*

Country Divided Into £20 “Plots”

Prospectors Ready To Begin Hunt

STRUBE PROPHESIED IT. What he drew in the “Daily Express” of March 24 last year.

UNDERGROUND “LAKES”

“Daily Express” Political Correspondent.

A NATION-WIDE SEARCH FOR OIL UNDER BRITAIN WILL BEGIN IN JUNE. ALL OVER THE COUNTRY MEN WILL GO OUT OVER THE FIELDS DIGGING, DRILLING, HOPING TO DISCOVER THE FIRST DARK-HUED TRICKLE IN THE EARTH WHICH GOES BEFORE A “GUSH.”

***Source:** Andrew Naylor, February 2012. From: Daily Express (May 1935). Article entitled “Licences for Searches”. BGSA: GSM/XG/0/1. 19S2/858.*

In October 1935 the *Daily Express* reported that “the great oil companies of Britain have made more than fifty applications for licences to drill beneath the soil of England” and were set to allocate £3,500,000 to prospect for oil in Britain. Boreholes, they stated would be drilled to an average depth of 5,000 – 6,000 feet at a cost of £4 per foot in Derbyshire, Sussex and Kent.[83] It was anticipated that oilfield developments would generate large contracts for British firms. Drilling equipment for example, was being made at Cheadale Heath, Stockport.

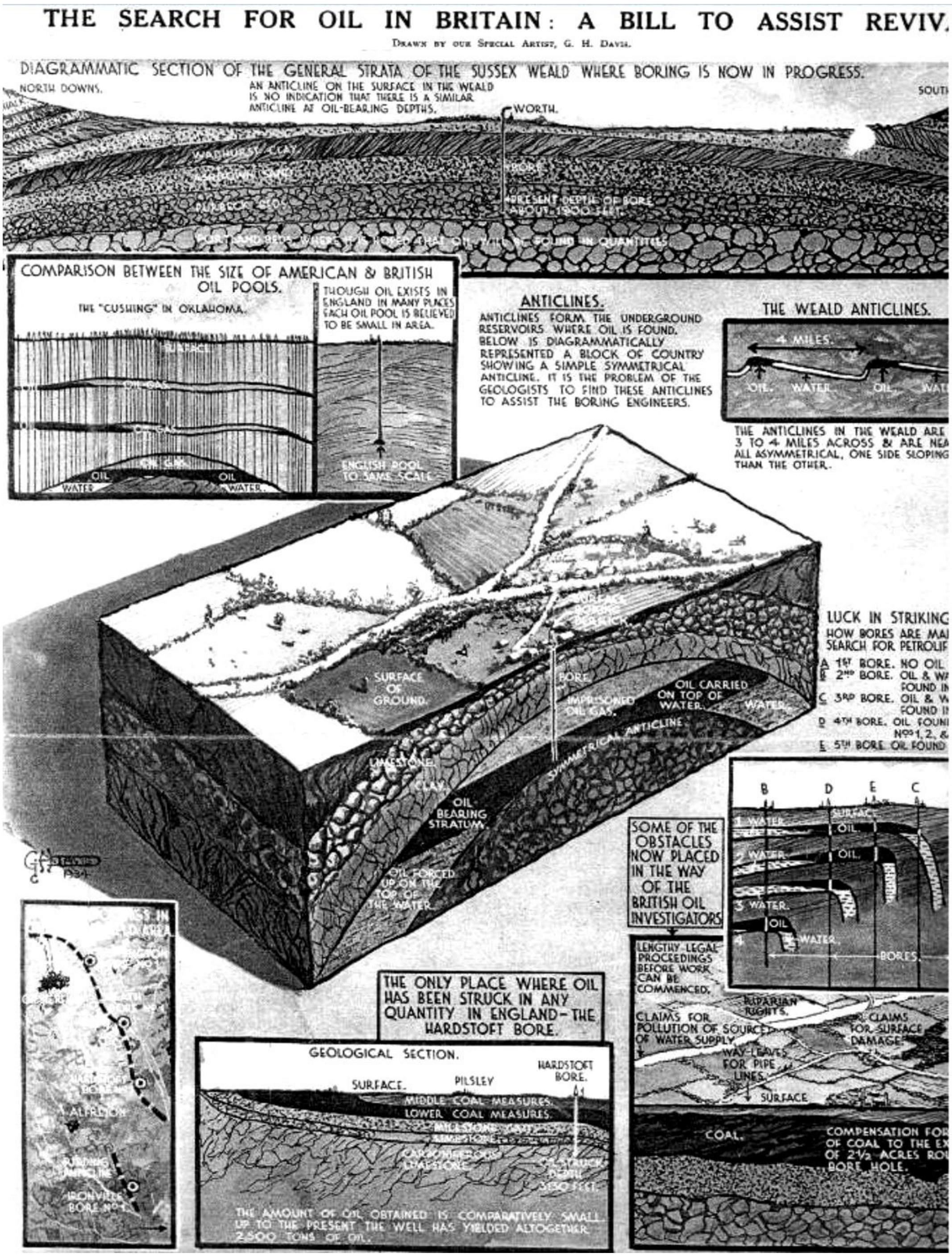
[82] Letter from J. S. Flett to F. C. Starling dated 9th June 1934. BGSA: GSM/XG/0/1. IGS2/857.
[83] Daily Express 23rd October 1935. Article entitled “£3,500,000 will be spent in drilling for oil in Britain”. BGSA: GSM/XG/0/1. IGS2/858.

It would be the downstream processing of oil, i.e. refining and processing which would provide the greatest employment opportunities. The *Evening Standard* reported on 4th April 1936 that "in a line stretching due west from the coast across Lincolnshire, a party of men tanned with the sun of Persia is to-day searching for underground rock formations which may indicate the presence of oil".[84] It went on to state that highly sensitive instrumentation was being used in the search, while a portable drilling rig, capable of being deployed quickly and drilling shallow test wells was being utilised in the vicinity of Pevensey.

On 7th April 1934 the *Illustrated London News* published a fascinating image demonstrating the understanding of oilfield development in Britain (see figure 5.4). It identifies Britain's heterogeneous geology, which led to small, discrete oil accumulations rather than vast "oil pools" like those found in Oklahoma. In the centre of the image is a three-dimensional diagram of a symmetrical anticline, demonstrating the typical conditions in which oil is found. Hardstoft No. 1 is shown to the bottom right, drawing attention to the "obstacles now placed in the way of the British Oil Investigators", including lengthy legal proceedings, way leaves and claims for surface damage, compensation for loss of coal, pollution and riparian rights. The illustration celebrated and acknowledged the successful collaboration between international oil experts and demonstrated the working relationships between energy producing companies, the state and the general public.

[84] Evening Standard 4th April 1936. Article entitled "Rock which may be dome of an oilfield". BGSA: GSM/XG/0/1. IGS2/858.

Figure 5.4: Image published on 7th April 1934 by the *Illustrated London News* showing three-dimensional geographies of onshore oil exploration within Britain.



Source: *Andrew Naylor, February 2012. From: BGSA: GSM/XG/0/1-19S2/858.*

5.6 D'Arcy Exploration Company's search for British onshore oil

Petroleum licensing stimulated large scale hydrocarbon exploration in Britain. Prior to the regulations, the APOC, renamed the Anglo Iranian Oil Company in 1935 and therefore referred to as AIOC hereafter, had narrowed its searches to individual geological features. Succeeding them it marked out larger blocks of territory straddling multiple geological structures.[85] Following a review of the regulations D'Arcy added targets in Yorkshire, Lincolnshire, Wiltshire and Surrey.[86]

As discussed in an internal report by geologist P. T. Cox, by March 7th 1935 D'Arcy proposed to acquire rights to 7410^2 miles of UK territory.[87] By November 1935 it had acquired 39 prospecting licences covering 6,964 square miles.[88] As part of its licensing agreements D'Arcy consented to fulfil a number of legal obligations, which included a schedule for deep drilling (four wells to a depth of 4,000 feet), shallow drilling and geophysical surveys. In 1936 Lees presented the results of D'Arcy's deep drilling programme to the Geological Society (Lees and Cox, 1937). Although it was welcomed on scientific merits, geologists nonetheless volunteered "to drink any oil discovered!" (Kent, 1985, p. 58).

In Scotland, D'Arcy had originally applied for a seven mile area of land covering the D'Arcy-Cousland structure. Following preliminary results it increased this to 30 square miles, and added a further 30 square miles along the Pentland Hills boundary fault. In North Yorkshire a 56 square mile area was increased to 200 square miles. The most significant addition, however, was made in Lincolnshire, South Yorkshire and Nottinghamshire, where D'Arcy added a 4,500 square mile area (covered by 24 licences). Here the company planned to use geophysical surveys to investigate whether oil retaining structures were present in the Carboniferous beds.[89]

In Hampshire and Sussex a block of 1,500 square miles was marked out, including areas in Lewes-Pevensey, Stenying, Portsdown, Singleton, Littlehampton, Petersfield, Winchester and East Dean. D'Arcy proposed to drill a minimum of one well per district, with provisions for ten wells in total. In Dorset 33 square miles of territory were added to explore the Hampshire syncline, increasing the licence area to 500 square miles in the region. In Wiltshire and Surrey 500 square miles covering the Vale of Pewsey pitching and the Ham, Kingsclere, Peasemarsh

[85] Secret "Memorandum for discussion" prepared by G. M. Lees on behalf of the D'Arcy Exploration Company Ltd dated 7th March 1935. BPA: ArcRef 44191.
[86] Secret "Memorandum for discussion" prepared by G. M. Lees on behalf of the D'Arcy Exploration Company Ltd dated 7th March 1935. BPA: ArcRef 44191.
[87] Report by P. T. Cox entitled "The search for oil in Great Britain by D'Arcy Exploration Company Ltd: Progress in 1936". BPA: ArcRef 44191.
[88] Report by P. T. Cox entitled "The search for oil in Great Britain by D'Arcy Exploration Company Ltd: Progress in 1936". BPA: ArcRef 44191.
[89] Secret "Memorandum for discussion" prepared by G. M. Lees on behalf of the D'Arcy Exploration Company Ltd dated 7th March 1935. BPA: ArcRef 44191.

and Godalming structures was recommended for geophysical examination only. Finally, the whole of the Isle of Wight was added.[90]

Table 5.1: Legal obligations placed on D'Arcy in respect of widespread search for hydrocarbons in Britain as of 7th March 1935.

To carry out drilling obligations	
Region	**Area – Square miles**
Scotland	60
North Yorkshire	200
Hampshire-Sussex	1,500
Isle of Wight	150
To carry out combined drilling and geophysical survey obligations	
Dorset	500
To carry geophysical survey obligations only	
Lincolnshire, South Yorkshire and Nottinghamshire	4,500
Wiltshire, Hants and Surrey	500
TOTAL	**7,410**

Source: *Secret "Memorandum for discussion" prepared by G. M. Lees on behalf of the D'Arcy Exploration Company Ltd dated 7th March, 1935. BPA: ArcRef 44191.*

D'Arcy began its geological and geophysical investigations in 1936, which in turn prompted BGS Director B. Smith to ask to see the prospecting licences, in order to add the boundaries to the Survey's geology maps.[91] The concessions, Smith stated would be added to the Survey's one-inch maps using a coloured line, with the site of each borehole added as and when required to track and monitor exploration.[92] D'Arcy used internal staff to undertake the majority of the geological survey work but contracted some of the geophysical work to outside

[90] Report by P. T. Cox entitled "The search for oil in Great Britain by D'Arcy Exploration Company Ltd: Progress in 1936". BPA: ArcRef 44191.
[91] Letter from B. Smith to F. C. Starling entitled "Borings for oil" dated 21st January 1936. BGSA: GSM/XG/0/1. IGS2/857.
[92] Letter from B. Smith to Mr Dewy (BGS Assistant Director) entitled "Oil: Prospecting Licences" dated 3rd February 1936. BGSA: GSM/XG/0/1. IGS2/857.

organisations. According to an internal report[93] torsion balance surveys were undertaken by the Geophysical Prospecting Company Ltd under the instruction of Mr J. C. Templeton.

P. T Cox's internal report[94] shows that the company's first deep well was located at Portsdown, near Paulsgrove, Hampshire. In February 1936 *The News of The World* announced that 1,000 tons of machinery, including a 136 feet derrick, roads and buildings had been installed by a 53 man strong crew. Should oil exploration be successful, "a new oil-town will arise".[95] The publication drew attention to the importance of oil as part of British defences, and in providing many thousands of new jobs, particularly indirectly through the production of pipes and casing, refining, handling and transportation. In the same article, *The News of The World* stated that between 1,800,000,000 and 2,000,000,000 gallons of oil were imported into Great Britain, costing £30,000,000. Domestic oil "would [therefore] render our defences independent of sea-borne supplies".[96]

Henfield, West Sussex was D'Arcy's second planned well, scheduled for 19th June 1936. Pevensey, East Sussex was third, with plant erection planned for June 16th 1937. Finally, Cousland in Scotland was earmarked for 19th December 1937. Four shallow boreholes were due to commence in the Pevensey district by June 1936. Combinations of geological, geophysical and or drilling operations were to be arranged at the company's discretion for the remaining areas, i.e. within the three year prospecting licence.[97] Geophysical surveys were scheduled for at least ten of the prospecting licence areas. In East Sussex a three and a half month survey was undertaken in Pevensey and Lewes to determine the level of closure, extent of anticlines and the geological boundaries in the Wealden beds. Six shallow boreholes were drilled, ranging from 76 to 307 feet, resulting in the discovery of a closed anticline in the Pevensey-Hailsham area.[98]

In Dorset a surface and subsurface examination of the coastal area from Abbotsbury and Swanage began in October 1936 and aimed to establish the structure of the Jurassic beds south of the Ridgway Fault Zone. A shallow borehole was also drilled into Corallian beds at Kimmeridge bay, Broad Bench to establish whether facies correlated with oil impregnations found in outcrops near Osmington Mills. In Yorkshire a two month survey was carried out in

[93] D'Arcy Exploration Company Ltd U.K. Drilling summary of expenditure to February 28th, 1939. Schedule No. 2. BPA: ArcRef 44197.
[94] Report by P. T. Cox entitled "The search for oil in Great Britain by D'Arcy Exploration Company Ltd: Progress in 1936. BPA: ArcRef 44191.
[95] *The News of The World* article entitled "Great search for oil in Britain starts". Date unknown. BGSA: GSM/XG/0/1-IGS2/858.
[96] *The News of The World* article entitled "Great search for oil in Britain starts". Date unknown. BGSA: GSM/XG/0/1-IGS2/858.
[97] Report by P. T. Cox entitled "The search for oil in Great Britain by D'Arcy Exploration Company Ltd: Progress in 1936. BPA: ArcRef 44191.
[98] Report by P. T. Cox entitled "The search for oil in Great Britain by D'Arcy Exploration Company Ltd: Progress in 1936. BPA: ArcRef 44191.

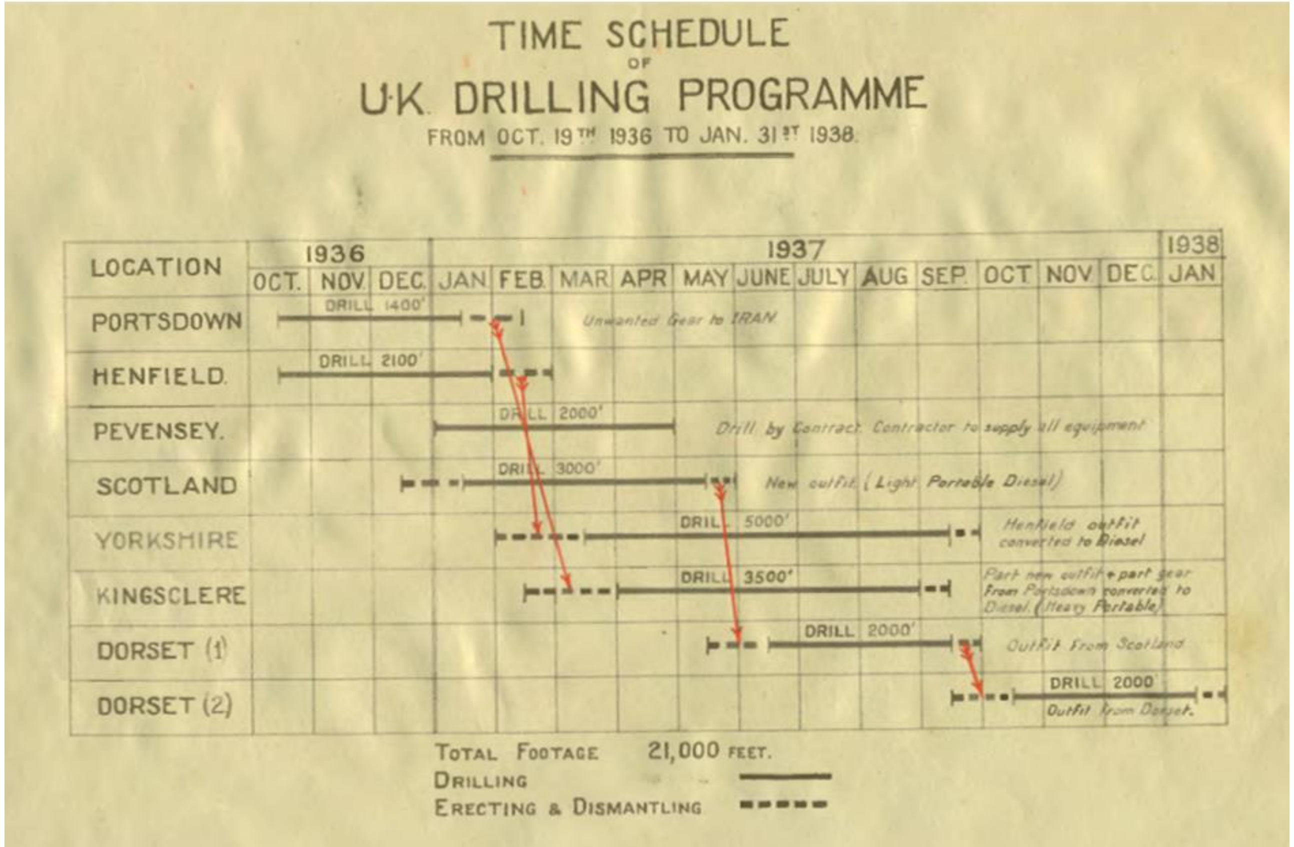
the Eskdale-Robin Hood's Bay area to validate structural conclusions. In Scotland a survey in the Cousland area resulted in the suggestion to drill a test well south of Cousland village .By June 30th 1936 D'Arcy had invested £104,689.3.6 on its UK exploration programme, including £72,538.10.11 on drilling equipment, £23,535.17.11 on drilling, £3,367.0.10 on geological surveys and £2,970.4.1 on licences and annual payments.[99]

A range of geophysical surveys were performed in the Nottinghamshire, Lincolnshire and East Yorkshire licence area. Cox reported that initially, gravitational methods were performed via a series of east west Torsion Balance traverses made near to Lincoln.[100] Gravitational methods were followed by magnetic surveys, which suggested a pronounced gravity high south east of Lincoln. Lastly, seismic reflection methods were carried out.[101]

The first survey traced the east-west torsion balance traverse. It extended eastwards from Kelham in Nottinghamshire where J. Ford had discovered oil in the Carboniferous Limestone in 1908 (see Chapter 4). As the surveys advanced D'Arcy modified its geophysical methods where necessary and located test wells to validate seismic data. At this stage the company felt "there [was] a chance that an oilfield may be present in this area, on a scale considerably greater than could occur in any of the other prospects available in Great Britain".[102] In Staffordshire, D'Arcy planned to examine the Biddulph structure to calculate the thickness of cover overlying a large anticline.[103] Collectively, D'Arcy's drilling programme (see figure 5.5) for 1937 and 1938 involved drilling 41,000 feet of wells, more than twice that (38,000) drilled by Pearson's during the first onshore drilling campaign.[104] This marked increase was attributed to rotary drilling methods, which replaced percussive methods used at Hardstoft.

[99] Report entitled "D'Arcy Exploration Company Ltd. U. K. Drilling: Summary of expenditure to June 30th 1936. BPA: ArcRef 44197.
[100] Report by P. T. Cox entitled "The search for oil in Great Britain by D'Arcy Exploration Company Ltd: Progress in 1936. BPA: ArcRef 44191.
[101] Report by P. T. Cox entitled "The search for oil in Great Britain by D'Arcy Exploration Company Ltd: Progress in 1936. BPA: ArcRef 44191.
[102] Report by P. T. Cox entitled "The search for oil in Great Britain by D'Arcy Exploration Company Ltd: Progress in 1936. BPA: ArcRef 44191.
[103] D'Arcy Exploration Company Ltd. Operations in the UK. Minutes of meeting No. 7 held on 17th March 1937. BPA: ArcRef 44197.
[104] Report by P. T. Cox entitled "The search for oil in Great Britain by D'Arcy Exploration Company Ltd: Progress in 1936. BPA: ArcRef 44191.

Figure 5.5: GANTT chart illustrating D'Arcy's UK drilling programme from October 1936 to January 1938.



Source: *Andrew Naylor, April 2012. From: "Time Schedule of UK drilling programme: From Oct 19th to Jan 31st 1938". BPA: ArcRef 44199.*

Soon after the Petroleum (Production) Act 1934 was passed, the Council for the Preservation of Rural England and its constituent bodies announced its intentions to ensure the amenities of the countryside were protected during exploration and drilling operations. D'Arcy, Steel Bros and the Anglo American Oil Company agreed to keep the various groups fully informed of their respective schedules, so as to preserve and protect the natural beauty and archaeological interest of the numerous regions and "ensure the minimum injury to amenities".[105] Writing to Sir Lawrence Chubb, President of the Commons, Open Spaces and Footpaths Preservation Society, Cadman added his personal assurances that D'Arcy would take all necessary steps to minimise the impact on the local environment. He stressed "we are no less anxious than you to preserve the amenities of our public open spaces and beauty spots; and you may be reassured that throughout our operations the views…expressed will never be absent from our minds".[106]

The segregation of government departments under the DSIR meant each was charged with communicating its findings on the boreholes to the other departments. BGS Director B. Smith stressed he was "sure that we (the departments) [would] work well together, and…give all help possible, but with four departments in the field – Fuel Research, Petroleum Department, Board of Trade and the Geological Survey – there is some danger of overlap".[107] He went on to argue "it appears to me to be essential…that cores or sizable fragments should not be removed before we have chance to examine them (and take representative specimens if necessary); otherwise geological evidence of vital importance may be overlooked or misunderstandings may arise as to the actual formations or geological horizons reached".[108]

Dr Frank Sturdy Sinnatt, Director of Fuel Research, expressed his optimism towards what he hoped would be an holistic scientific enterprise. He instructed his staff "to avoid touching any coal seams that may be passed through [and inform the BGS] if any are met with.[109] He also agreed to ensure samples of coal were preserved for laboratory analysis to "enable us [the BGS] to investigate the spore development through a vertical series of coal seams, in a way that cannot otherwise be carried out".[110] B. Smith stated any results obtained would be retained indefinitely by the BGS (as stipulated in the 1935 regulations) and would

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[105] Letter dated 30th September 1937 from The Council For The Preservation of Rural England. BPA: ArcRef 44201.
[106] Letter dated 23rd January 1936 from John Cadman to Sir Lawrence Chub. BPA: ArcRef 44201.
[107] Letter dated 23rd December 1935 from B. Smith to Dr F. S Sinnatt entitled "Anglo Iranian Bores". BGSA: GSM/XG/0/1. IGS2/857.
[108] Letter dated 23rd December 1935 from B. Smith to Dr F. S Sinnatt entitled "Anglo Iranian Bores". BGSA: GSM/XG/0/1. IGS2/857.
[109] Letter dated 30th December 1935 from Dr F. S. Sinnatt entitled "Anglo Iranian Bores". BGSA: GSM/XG/0/1. IGS2/857.
[110] Letter dated 30th December 1935 from Dr F. S. Sinnatt entitled "Anglo Iranian Bores". BGSA: GSM/XG/0/1. IGS2/857.

furnish the Department of Fuel Research and Development with all available information "provided that the seams were cored out and not chiselled away".[111]

Oil prospecting companies were instructed to take samples as frequently as possible (preferably every five feet) using wire mesh sieves to trap larger particles (as at Hardstoft).[112] By analysing changes in the specific gravity of drilling mud, changes in strata could be recorded. Licensees had to ensure samples were correctly labelled and suitably preserved to retain their original characteristics, and had to produce and maintain detailed downhole logs of all strata passed through.[113] Oil analysis fell to the BGS (and to a lesser extent the Fuel Research and Development Department) who were instructed to send reports to the Petroleum Department. This accompanied verbal communications within and between the government departments as and when required. The Board of Trade had the right to acquire representative specimens and all associated documentation, while Inspectors of the Petroleum Department would visit the boreholes frequently to acquire samples.[114]

As well as the need to preserve samples of coal for post-field analysis, the drilling programme provided an opportunity to learn more about Britain's aquifers – their shape, size and position in the subsurface. William Mackintosh, writing to Sir Kingsley Wood, Minister of Health argued that some arrangement should be made with the Petroleum Department and the Ministry of Mines to record the location of any water-bearing strata passed through during the operation. He pointed out "for close to 30 years I have been drilling or in charge of drilling operations in various parts of the world for both water and oil and can speak from actual experience the value of such records if they are properly recorded".[115] He drew attention to the drilling operations, "the likes of which has never been seen in this country".[116] The drilling apparatus, he remarked, was "capable of drilling to very great depths and it is more than likely that several water bearing strata's will be drilled through before oil is encountered or the work abandoned".[117] Additionally, geologists also measured gas pressures emitted from the wells alongside rock temperatures.[118]

[111] Letter dated 29th November 1935 from B. Smith (Director of the BGS) to the Director of Fuel Research. BGSA: GSM/XG/0/1. IGS2/857.
[112] Letter dated 29th November 1935 from B. Smith (Director of the BGS) to the Director of Fuel Research. BGSA: GSM/XG/0/1. IGS2/857.
[113] Letter dated 29th November 1935 from B. Smith (Director of the BGS) to the Director of Fuel Research. BGSA: GSM/XG/0/1. IGS2/857.
[114] Letter dated 29th November 1935 from B. Smith (Director of the BGS) to the Director of Fuel Research. BGSA: GSM/XG/0/1. IGS2/857.
[115] Letter dated 22nd April 1936 from W. Mackintosh to K. Wood. M. P. Entitled "Drilling for oil". BGSA: GSM/XG/0/1. IGS2/857.
[116] Letter dated 22nd April 1936 from W. Mackintosh to K. Wood. M. P. Entitled "Drilling for oil". BGSA: GSM/XG/0/1. IGS2/857.
[117] Letter dated 22nd April 1936 from W. Mackintosh to K. Wood. M. P. Entitled "Drilling for oil". BGSA: GSM/XG/0/1. IGS2/857.
[118] Memorandum of a meeting with Dr Haldane to consider the taking of temperature in boreholes dated 11th August 1919. BGSA: GSM/XG/0/1. IGS2/857.

5.7 Peter Kent and the discovery of oil at Eakring, Nottinghamshire

D'Arcy's widespread search for oil was carried out by a nucleus of geological experts, who moved from site to site and region to region. One such individual was Percy Edward (Peter) Kent, (see figure 5.6) who was born in West Bridgford, Nottingham in 1913. In 1931 Kent was awarded a Nottingham Education Committee Studentship, which enabled him to enter University College Nottingham where he was encouraged to study geology by H. H. Swinnerton.[119] Kent was one of only two geology students at Nottingham in 1931, which reflected the small number of British geologists undertaking pure geology degrees in the interwar period. Later on in the 1930s the Nottingham University geology department separated from geography, with one full time geology Lecturer – S. G. Clift, who had research experience on Coal Measures and the Permian, and who taught "crystallography, petrology and sedimentology".[120] Under Swinnerton Kent became interested in the Jurassic rocks of Eastern England and the Cretaceous rocks of Lincolnshire – where water well drilling was then taking place.

As an undergraduate Kent examined the geology of Lincolnshire, attempting to deduce the deep geological structure of the region by investigating surface rocks. In 1934 he sat examinations as an external candidate for a London BSc and he was urged by Swinnerton to apply for a Research Studentship from the DSIR, choosing the stratigraphy of Lincolnshire limestones as his topic. Following his graduation he replaced K. P. Oakley (who accepted a post at the British Museum) as assistant to Professor P. G. H Boswell on an archaeological expedition led by hominid palaeontologist L. S. B. Leakey in East Africa (Western Kenya and Northern Tanganyika).[121] During the expedition Kent mapped the local geology, drew sections and collected rock specimens, adding considerably to the geological understanding of the areas examined (Leakey, 1974).

On returning from Leakey's archaeological expedition Kent learnt the AIOC was undertaking geophysical surveys in Lincolnshire. Encouraged by Swinnerton, Kent contacted "Anglo Iranian's erudite and dynamic Chief Geologist, Dr G. M. Lees, asking about possible collaboration".[122] Following a meeting with Lees in London, Kent was offered a position with the AIOC commencing on "5th October 1936 at a salary of £30 per mensem".[123] Kent was subsequently dispatched to the south of England to apply his "specialist knowledge of Mesozoic

[119] University days - 1931-34. HLUNMSC: 43.5.93/A.5 1931-36 p. 9.
[120] University days - 1931-34. HLUNMSC: 43.5.93/A.5 1931-36. p. 4.
[121] University days - 1931-34. HLUNMSC: 43.5.93/A.5 1931-36. p. 7.
[122] The later Thirties - early years with BP (1936-1940). HLUNMSC: 43.5.93/A.7/1.
[123] Letter to P. E. Kent from the Manager of the Staffordshire Branch of the AIOC dated 26th September 1936. HLUNMSC: 43.5.93/A.130 1935-1937.

stratigraphy and outcrops of Southern England".[124] The company believed that large anticlinal structures found in Dorset (Lulworth) and Sussex (Pevensey) could be analogous with oil-bearing structures of the Zagros mountain range, Iran. Their hypothesis was corroborated by the presence of oil sands and by the discovery of an oil seepage at Osmington near Weymouth by AIOC Senior Geologist A. H. Taitt. Kent's first posting was to Portsdown and shortly afterwards, Henfield, West Sussex. At Portsdown No. 1 (officially opened by the Minister of Fuel and Power in January, 1936), under the direction of Taitt, Kent learnt the basic principles of onshore oil exploration, including the problems of well control (geologists were then responsible for the viscosity of drilling mud and associated testing) and the "philosophy of oil exploration operations".[125]

Figure 5.6: Peter Kent in the garden of his West Bridgford home.

Source: *Falcon and Dunham (1982, p. 348).*

Following Portsdown No. 1 Kent was sent to Henfield, 60 miles east to oversee drilling operations there for approximately six months. In line with recent developments in drilling, the team used rotary drilling methods rather than "cable-tools" as used at Hardstoft. The rig had a "square derrick tower, built piece by piece by steel erectors, and was assembled on the spot by the drilling staff themselves, with a layout controlled by the terrain".[126] Kent's assistant, William Mitchell, a micro-palaeontologist dated the succession of micro-organisms, adding

[124] The later thirties - early years with BP (1936-1940). HLUNMSC: 43.5.93/A.7/2**.**
[125] The later thirties - early years with BP (1936-1940). HLUNMSC: 43.5.93/A.7/2**.**
[126] The later thirties - early years with BP (1936-1940). HLUNMSC: 43.5.93/A.7/3**.**

considerably to the knowledge of the chalk sequence of the South of England.[127] A large proportion of the Portsdown sequence was cored to understand the deep geology of the region, while a running correlation was kept with Henfield to extrapolate stratigraphic data. The total expenditure for Portsdown up to 30th June 1936 (2,285 feet drilled) was £13,688.3.6, while Henfield had cost the company £3,566.18.6 over the same period for 512 feet drilled.[128]

As discussed by Kent, rock classification was maintained by the BGS's "borehole inspector" Andrew Templeton, an expert on comparable beds in the Cotswolds.[129] Drilling progressed slowly, at only two feet per hour. Portsdown was sited on a strong anticlinal feature with Upper Cretaceous rocks at the surface (BP, 1953). The team penetrated the entire Jurassic succession, completing in Triassic rocks to a depth of 6,556, but only encountered a small pocket of oil in the Upper Jurassic rocks. Henfield also penetrated the Jurassic, encountering a small amount of gassy water but no oil. The well was abandoned at a depth of 5,105 feet in Carboniferous rocks.[130]

Ultimately, neither Portsdown nor Henfield were economically viable. The stratigraphic sequence indicated poor development of reservoir beds, which, alongside regional scale evidence led D'Arcy to relocate to Kingsclere, near Newbury to the north. At the same time the Anglo American Oil Company (AAOC) and Gulf Company were exploring for oil in the south – AAOC at Grove Hill near Halisham and the Gulf Company at Penthurst in Kent. None of the wells proved to contain oil in commercial quantities. However, despite the failings, Lees viewed the AIOC's results as having national importance and ordered the results to be published, which fell to Taitt and Kent (1958).

By December 1937 D'Arcy had increased its licences from 39 to 52, covering a combined area of 9,233 square miles of territory (see table 5.2).[131] A further 2,338 miles were covered by 18 licences held by the AAOC, 1,277 miles (nine licences) by the Gulf Company and 350 square miles (two licences) by Steel Bros. Collectively, the four companies held licences for 13,198 square miles of territory - 12.4% of the total UK landmass. As a result of its preliminary findings D'Arcy planned to obtain a further three licences (one in Scotland and two in the Midlands, collectively totalling 341 square miles) and was seeking to surrender two licences in the south totalling 354 square miles.

At this stage, D'Arcy had spent almost two years in the south of England examining 3,400 square miles of the Cretaceous and Jurassic. It had drilled 22,000 feet (the Anglo

[127] The later thirties - early years with BP (1936-1940). HLUNMSC: 43.5.93/A.7/3.
[128] Report entitled "D'Arcy Exploration Company Ltd. U. K. Drilling: Summary of expenditure to June 30th 1936. BPA: ArcRef 44197.
[129] The later thirties - early years with BP (1936-1940). HLUNMSC: 43.5.93/A.7/3 - A.7/4.
[130] The later thirties - early years with BP (1936-1940). HLUNMSC: 43.5.93/A.7/5.
[131] Report entitled "The search for oil in Great Britain". By J. A. S Jameson and A. C. Hearn dated 13th December 1937. BPA: ArcRef 44199.

American had drilled 3,500 feet) resulting in negative results. Aside from a small amount of shallow drilling using a portable outfit the company had no further plans to drill in the area, unless a planned well by the Gulf Company in Kent proved successful.[132]

Table 5.2: Hydrocarbon licensing by company as of 13th December 1937.

<table>
<tr><th colspan="4">D'Arcy Exploration Company Ltd</th></tr>
<tr><th>Region</th><th>Drilling objective</th><th>No. Licences</th><th>Square miles</th></tr>
<tr><td>South of England</td><td>Lower Cretaceous/Jurassic</td><td>19</td><td>3419</td></tr>
<tr><td>North Yorkshire</td><td>Permian Limestone</td><td>1</td><td>178</td></tr>
<tr><td>Scotland</td><td>Carboniferous</td><td>1</td><td>71</td></tr>
<tr><td>Midlands</td><td>Carboniferous</td><td>7</td><td>1095</td></tr>
<tr><td>East</td><td>Carboniferous</td><td>24</td><td>4470</td></tr>
<tr><td>Total</td><td>NA</td><td>52</td><td>9233</td></tr>
<tr><th colspan="4">Anglo American</th></tr>
<tr><th colspan="2">No. Licences</th><th colspan="2">Square miles</th></tr>
<tr><td colspan="2">18</td><td colspan="2">2,338</td></tr>
<tr><th colspan="4">Gulf</th></tr>
<tr><td colspan="2">9</td><td colspan="2">1,277</td></tr>
<tr><th colspan="4">Steel Bros</th></tr>
<tr><td colspan="2">2</td><td colspan="2">350</td></tr>
<tr><td colspan="2">Total licences held by other companies 29</td><td colspan="2">Total area (square miles) held by other companies 3,965</td></tr>
</table>

Source: *Report entitled "The search for oil in Great Britain" by J. A. S Jameson and A. C. Hearn dated 13th December 1937. BPA: ArcRef 44199.*

During the summer of 1937 Peter Kent became resident geologist at Poxwell near Weymouth and latterly at the AIOC's first well in Kimmeridge Bay at Broadbench.[133] Poxwell No. 1 was spudded on 24th May 1937. Its objective was to test the Corallian sands in which oil seepages had been reported. It was completed on 29th July 1937 at a depth of 1,666 feet in the Middle Jurassic (Fuller's Earth) having encountered only salt water.[134] On 17th July 1937 the

[132] Report entitled "The search for oil in Great Britain". By J. A. S Jameson and A. C. Hearn dated 13th December 1937. BPA: ArcRef 44199.
[133] The later thirties - early years with BP (1936-1940). HLUNMSC: 43.5.93/A.7/5.
[134] Report entitled "The search for oil in Great Britain: Summary". Date unknown. BPA: ArcRef 44199.

company spudded Eskdale No. 1 into the trias near Whitby. Drilling advanced to 5,040 feet during which almost pure methane was encountered in the Upper Limestone, issuing at 2.5 million cubic feet per day (BP, 1956). This was not used initially but plans were made to use it for industrial purposes (BP, 1953).

Broadbench was spudded into the Kimmeridge clay cliffs on 1st September 1937. As discussed by Kent, the drilling rig was designed to drill to only 200-300 feet - depths at which W. J. Arkell, acting as the AIOC's consultant, had predicted would encounter the Corallian oil reservoirs.[135] The shale caprock was thicker than expected but at 820 feet a thin sandstone showed small traces of oil. Kent telephoned his report to London, where it was met with considerable scepticism. A small sample was forwarded for analysis, validating its origin as an oil sand. However, operating far beyond its limits the rig broke down, and with no replacement rig available, drilling ceased. The area subsequently fell into wartime occupation meaning it was over a decade before exploration could recommence. Using heavier equipment, Kimmeridge No. 1 later penetrated the shale caprock to become the first oil-producing well in the South of England and for many years served as Britain's most prolific onshore oil well.[136] In 1973 the nationalised British Gas Corporation discovered the Wytch Farm oilfield in the same region, which first produced oil in 1979 (Huxley, 1983).

Kent was dispatched to Scotland in 1938, replacing A. H. Taitt, who was called to London to supersede P. T. Cox as Chief Geologist in charge of the UK exploration programme as lead geologist in the region.[137] He oversaw Cousland No. 1, situated on a well-defined anticlinal ridge extending nine miles north east from Gorebridge to Prestonpans (Anderson and Simpson, 1938) near Dalkeith (which had encountered a small pocket of gas)[138] and Cousland No. 2, transposing his knowledge of Jurassic rocks and fossils to the Carboniferous rocks of central Scotland.

Investigations along the D'Arcy-Cousland ridge had been undertaken in the summer of 1936 by Dr Archibald Allison, who had produced a structure-contour map of the area (Wyllie, 1938). Drilling began on 5th September 1937 and proceeded to penetrate an oil saturated sandstone, though it failed to be commercially viable. The AAOC located a small oilfield in the region, with two wells producing oil at a very small scale for some years after. According to a D'Arcy report, by the end of 1937 the company had drilled six deep wells totalling 19,700 feet and fourteen shallow tests totalling 3,800 feet.[139] The company had undertaken geological surveys over 12,000 square miles of territory and geophysical surveys over 4,000 square miles.

[135] The later Thirties - early years with BP (1936-1940). HLUNMSC: 43.5.93/A.7/6.
[136] The later Thirties - early years with BP (1936-1940). HLUNMSC: 43.5.93/A.7/6.
[137] Scottish Interlude 1938-9. HLUNMSC: 43.5.93/A.7/9.
[138] After many years negotiations with the local gas authorities the gas was used to heat hot-houses near Musselburgh.
[139] Report entitled "The search for oil in Great Britain: Summary". Date unknown. BPA: ArcRef 44199.

Geophysical surveys had included 1,100 torsion balance observations, 200 magnetic, pendulum and gravimetric observations and 150 seismic records giving an aggregate expenditure of £539,908 to the end of October 1937.

Following Cousland No. 2 Kent was assigned to the Firth, running a shallow drilling campaign on the Balfour anticline near Kirkcaldy. He spent the winter of 1938 to the summer of 1939 attempting to reconcile the failings of the meagre Cousland shows while considering other hydrocarbon prospects in the Midland Valley.[140] By December 1938 D'Arcy had drilled a cumulative total of 19,638 feet at a cost of £119,839, giving rise to a drilling cost of £6.2.0 per foot (see table 5.3).

Table 5.3: Itemised breakdown of D'Arcy Exploration Company's drilling programme to December 1938.

Completed Wells			
	Footage (feet)	**Cost (£)**	**Cost per foot (all in £)**
Portsdown	6556	52,157	7.19.1
Henfield	5105	28,676	5.12.4
Poxwell	1666	6,178	3.14.2
Drilling Wells			
Kingsclere	3568	15,384	4.6.3
Eskdale	2034	11,968	5.17.8
Cousland	709	5,476	7.14.6
TOTAL	**19638**	**119.839**	**Average 6.2.0**

Source: *Tabulated from: "The search for oil in Great Britain: Summary". Date unknown. BPA: ArcRef 44199.*

Towards the end of 1939 Kent was seconded to Formby in mid Lancashire where BGS field geologist Dr Wolverton Cope reignited the potential of oil exploration, having encountered an extensive oil seepage in peaty fenland one mile west of Formby.[141] According to Kent, AIOC consultant Professor G. Fearnsides of Sheffield University recalled his father's grocers shop in west Yorkshire selling firelighters manufactured from peat soaked in the crude oil.[142] G. M.

[140] Scottish Interlude 1938-9. HLUNMSC: 43.5.93/A.7/10.
[141] The last summer of peace – Formby 1939 (and after). HLUNMSC: 43.5.93/A.7/13.
[142] The last summer of peace – Formby 1939 (and after). HLUNMSC: 43.5.93/A.7/13.

Lees, Kent states, visited the site finding an oily yellow scum floating in the weedy ditches on the Downholland Moss fen, which, following laboratory analysis was found to be a light crude.[143] Peter Kent was subsequently sent to the area to oversee a small drilling crew.

Using a large scale map Kent located Formby G. 1 at the side of Thirty Acre Lane, where oil had accumulated in partially sealed Keuper sands (BP, 1953). Kent stated the well was spudded in on 2nd March 1939 and extended to 1,300 feet, failing to encounter oil despite being located only feet from a surface seepage.[144] This vexing failure prompted him to ponder the subsurface structures of the area. The flat featureless topography comprised a blanket of peat, silt and bolder clay, masking the Triassic beds so that the drilling team were effectively drilling blind. Formby G.2 was drilled two to three hundred yards to the north, again drilling through the superficial peats, modern silts and bolder clay. At only 100 feet they encountered oil in the Triassic beds of a faulted monocline (BP, 1956) which would become Britain's shallowest oilfield. According to Kent, the operation was largely left to its own devices; "visitors were rare, and the management were satisfied with brief reports and with a telephone call if serious decisions were involved".[145] Despite the growing inevitability of war during the summer of 1939, Kent found it hard to be depressed at Formby "with an interesting job, good company and warm sunny weather".[146] On Friday 1st September 1939, however, Britain issued its ultimatum to Germany.

Following successive failures in the South of England D'Arcy concluded drilling had been unsuccessful.[147] It subsequently shifted its focus to targets in the Midlands, where Steel Bros were investigating the potentialities of the Carboniferous Limestone at Edale. The first well, drilled at Gun Hill, a prominent anticline in the western Pennines (thought to be analogous to accumulations found in Iran, then Persia), near to Buxton failed to encounter oil.[148] As stated in the *Derby Daily Telegraph,* (26th November, 1939, p. 4) following the search for oil in the Peak District "prospectors [were]…turning their attention to neighbouring county of Nottinghamshire [at] the agricultural village of Eakring…already a depth of 200 feet has been reached. No oil has yet been brought to the surface…but expectations increase as the work proceeds". Following the declaration of war Kent relocated to Eakring, Nottinghamshire on a temporary basis to investigate the same Carboniferous Limestones that had been drilled by J. Ford at Kelham in 1911. Kent stated that a succession of failures had forced the directors of the

[143] The last summer of peace – Formby 1939 (and after). HLUNMSC: 43.5.93/A.7/13.
[144]The last summer of peace – Formby 1939 (and after). HLUNMSC: 43.5.93/A.7/13.
[145] The last summer of peace – Formby 1939 (and after). HLUNMSC: 43.5.93/A.7/15.
[146] The last summer of peace – Formby 1939 (and after). HLUNMSC: 43.5.93/A.7/15.
[147] Report entitled "The search for oil in Great Britain: Summary". Date unknown. BPA: ArcRef 44199.
[148] A review of the exploration of Edale No. 1 is given by Gluyas & Bowman (1997), which also discusses the roles of Professor William George Fearnsides (1879-1968), Robert George Spencer Hudson (1895-1966) and Geoffrey Cotton (1904-1992), who graduated from Birmingham University having achieved a First Class Honours in Petroleum Technology, thus reaffirming the importance of Birmingham University in the search for British onshore oil.

Oilfields of England to progressively change their objectives from the Midlands to as far off as Portugal![149] The staff followed, he stated, leaving local farmers and landowners perplexed by their behaviour. D'Arcy, Kent argued, was met with considerable suspicion from people fearing a repeat of the earlier episode.

D'Arcy studied objectives in the Derbyshire limestone, looking to the east of the outcrop where cover rocks increase in depth and the subsurface rocks of the exposed coalfield dip evenly towards the sea. Geophysical tests were undertaken in the area, including gravity, magnetic and seismic refraction. By February 28th 1939 it had invested £63,815 on geophysical surveys as well as £11,025 on geological surveys and £19,068 on shallow drilling, giving a total UK expenditure of £449.639 (total drilling amounted to £261,135).[150]

Petroleum exploration benefited enormously from the opening of collieries in the central part of the concealed Nottinghamshire coalfield in the 1930s. Prior to these workings subsurface structures were little known. As discussed by Kent, Professor W.G Fearnsides highlighted a belt of NW-SE anomalies in the Coal Measures on the eastern side of the coalfield near Bilsthorpe, based on new colliery evidence.[151] Kent then drew attention to a faulted anticline at Ollerton using a detailed cross section drawn by his former Nottingham University lecturer S. G. Clift.

Kent visited Ollerton Colliery (Butterley Coal & Iron Co.), Thoresby Colliery (Bolsover Colliery Co.) and Bilsthorpe Colliery (Stanton Ironwork Company Ltd) in order to reconstruct a structural subsurface hologram of the vicinity.[152] He used detailed contour maps (originally produced to ascertain the location of Top Hard coal) to deduce the area was part of a large anticline – its highest point lying directly beneath the village of Eakring. Based on Kent's findings D'Arcy undertook targeted seismic reflection surveys and shot refraction arcs, which showed the structural rise of the anticline extended a quarter of a mile further south by the Wesleyan Chapel at Eakring. By August 1938 D'Arcy's geophysical work at Ollerton suggested a Carboniferous structure with at least 800 feet closure.[153] D'Arcy consequently located Eakring No. 1 on Pond Farm, at the foot of Kirklington road, which by 28th February 1939 had cost £585.00.[154] A breakdown of the stratigraphic sequence of Eakring No. 1 is given in table 5.4.

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149 Oil at Eakring, Nottinghamshire, 1939. HLUNMSC: 43.5.93/A.7/20.
150 Report entitled "D'Arcy Exploration Company Ltd: Summary of expenditure to February 28th, 1939". BPA: ArcRef 44197.
151 Oil at Eakring, Nottinghamshire, 1939. HLUNMSC: 43.5.93/A.7/19.
152 Report entitled "Note on the structure of the Ollerton district [Notts]" by Kent, 5pp typescript + maps, 11 April 1938. HLUNMSC: 43.5.93/B.1.
153 Memorandum from A. H. Taitt to B. R. Jackson dated 5th August 1938. BPA: ArcRef 44199.
154 Report entitled "D'Arcy Exploration Company Ltd: Summary of expenditure to February 28th, 1939". BPA: ArcRef 44197.

Table 5.4: Stratigraphic sequence at Eakring.

Lithology	Description	Depth encountered
Keuper	Red and green marls with gypsum bands and sandy bands	0-277 feet
Bunter	Coarse red and yellowish water bearing sandstones, with pebbles overlying mixed red marls and sandstone	277-880 feet
Permian	Red and green shales and sandstone, overlying grey dolomitic limestone. Grey shales with a conglomeratic "breccia" at the base	880-1,179 feet
Coal measures	Alternating grey shales, sandstones, coals and fireclays; oil-impregnated sandstones, 1,868-1,882 feet	1,179-1,914 feet
Millstone Grit	Thick groups of coarse sandstone, richly oil-impregnated in parts, separated by thick groups of black silts	1,914-2,643 feet
Carboniferous Limestone	Dense grey limestone with rare shale partings	From 2,643 feet

Source: *Tabulated from BP (1956, p. 8).*

On the 6th June 1939 Eakring No. 1 struck oil in a thick sandstone of the basal Coal Measures and Millstone Grit[155], giving an immediate yield of 12 tons per day. Dukes Wood Oil Museum states that the oil was found in three sands in the basal Coal Measures and three horizons in the Millstone Grit (Rough Rock – 60 feet thick; Longshaw – 25th thick and Chatsworth Grit) though later drilling confirmed that oil was contained in small quantities in the Kinderscout Lower Grit (Dukes Wood Oil Museum, 2013a). In a statement issued on 29th June 1939 D'Arcy stated the oil had been encountered at 1,914 feet, giving a yield of over 100 tons per week (*Derby Daily Telegraph*, 30th June, 1939, p. 16).

5.8: Conclusion

This chapter has investigated the progress made in British onshore oilfield development during the interwar period from 1926 to 1939. It has shown that following the discovery of the modest Hardstoft oilfield, oil exploration stagnated during the 1920s, amidst ongoing fears of resource nationalisation, restrictive legislation, royalty payments to landowners and localised controversies surrounding surface and subsurface ownership rights. The chapter has highlighted

[155] And not in the Carboniferous Limestone as originally predicted.

the risks and uncertainties of oil exploration, with the D'Arcy Exploration Company only locating oil after hundreds of geophysical investigations had been undertaken, across thousands of miles of British territory, and thousands of feet of boreholes had been drilled. The period also highlighted the use of isopachyte mapping, which failed to excite the minds of AIOC or the British government but would later become an important tool to the petroleum geologist.

The episode, largely devoid of oil was, however, crucial to the future of the onshore oil industry. The interwar period saw the development of geophysical techniques, Britain's first School of Geophysics, legislative reform and national and international collaborations involving the state, private companies, research institutions, oilfield technologies and human actors. From remote working in Persia, to Britain's first geophysical surveys in Keele, board meetings to sensationalised media reports, the 1930s was a period of knowledge exchange and dissemination, which imprinted the magic name of oil on the imaginations of the British public. Significantly, the Petroleum Production Act 1934, which vested hydrocarbon rights in the Crown, prohibited drilling without a licence, preventing the type of wildcatting that had been problematic in America. It also saw the British government take responsibility for the onshore oil industry, establishing a set of working practices and assigning roles and responsibilities to a number of government departments who were to work closely with private companies.

Changes to legislation were only possible once earth scientists were able to draw sonic distinctions between solids and liquids at depth, using high-tech geophysical instrumentation. The Eötvös Torsion Balance, for example, gave earth scientists the opportunity to remotely visualise, map and model the earth's internal structure, enabling geologists to predict the nature of deep subsurface structures, the likes of which had been proven to contain oil in other parts of the world. Oil exploration during the interwar period involved topographic and subsurface exploration, which, as stated by Watts (2014, p. 195), involved using a range of "Spatial technologies and spatial representations…foundational to the oil industry: seismic devices to map the contours of reservoirs…and…the map to determine subterranean property rights. Non-invasive geophysical methods significantly improved understanding of the earth's composition and evolution, stimulating widespread discussion within the scientific community. Geological theories began to emerge, including, for example, what processes in earth's history had resulted in the formation of anticlines and synclines, petroleum systems and basins, faulting and folding and so forth. Earth magnetism was one of the single most important scientific discoveries of the 20th century, leading to the accepted theories of continental drift and plate tectonics (Le Grand 1998; Frankel, 1998).

As discussed by Good (2000, p. 232), terrestrial magnetism became fragmented into several divergent specialisations during the 20th century, including "palaeomagnetism, work on the geo-dynamo, crustal conductivity, and ionospheric and magnetosperic", offering geologists a number of career options at a time when science was moving out of the laboratory and into the field. This was also a time when oil exploration and extraction was becoming increasingly complex, requiring the input of specialist geologists trained to operate, interpret and disseminate graphical forms of geological data.

Archival research has shown the series of events that led to the establishment of the country's first School of Geophysics at Imperial College, London. Communication networks were essential to the establishment of this new school, with John Cadman once again occupying the central position within the oil assemblage. Using his position of authority within the AIOC, Cadman was able to negotiate a path towards the home deployment of geophysical methods which, for the first time, offered earth scientists a tantalising insight into the earth's interior, enabling them for the first time, to be able to state with some certainty, whether an area was thought to be petroliferous. This represented a huge technological leap forward from Hardstoft, which used only transposed American analogues to locate oil. Geophysical investigations, however, take place only after field reconnaissance, requiring the skills and expertise of geological experts.

Lees and Kent operated on two scales - Lees the regional scale, Kent on the local or micro-scale. Drawing on the experience gained from his international oil expeditions, Lees presented to Cadman a number of areas in Britain for detailed geophysical investigation. His geobiography was therefore essential to the shaping of his understanding of petroliferous systems, resulting in the publication of his early investigations into Britain's hydrocarbon prospectivity - see Lees and Cox (1937); Lees and Taitt (1945).

As had been the case at Hardstoft, (where Pearson's geologists transposed their knowledge of Pennsylvania onto the Pennine ridge) Lees transposed his own model of exploration (exploration by analogy – see Chapter 4), based on the Zagros mountain range of Iran and Iraq. Kent and Lees relationship was inextricably linked to the University of Nottingham through Henry Hurd Swinnerton. Not only did Swinnerton suggest Kent study geology, he also recommended Kent write to Lees in London, which led to his appointment with the APOC. Like Lees, Peter Kent's understanding of Britain's petroliferous potential was refined through travel. His numerous postings to different regions of the UK allowed him to build an imaginary model of Britain's subsurface, ultimately resulting in the discovery of oil at Eakring, Nottinghamshire.

British onshore oil exploration underwent a revival during the interwar period, in part due to rising duties on oil imports, from 4d in 1928 to 8d in 1931 and ultimately a pre-war increase of 9d in 1938 (Johnson, *et al*., 2014). A second factor was the temporary collapse of the so called D'Arcy concession in 1933. Granting the APOC exclusive rights to explore for oil, the 60-year agreement with Iran made in 1909 provided Britain with a substantial and seemingly secure supply of oil. Although a new agreement was reached, it highlighted the global instability of the industry and dependence on territories outside of British control (Johnson, *et al*., 2014).

In Britain, Cadman's lobbying added considerable impetus to domestic oil security. The passing of the Petroleum (Production) Act 1934, which gave the state ultimate ownership of its mineral oil resource, was a landmark moment in British history, reported in the media through a series of headline stories. Media reports accurately represented Britain's subsurface territories, engraining oil into the imagination of the British public, who became acquainted with the places and spaces in which oil exploration had occurred, and was expected to occur in the future. Three-dimensional representations of Hardstoft, for example, rendered a once private place very much public. Oil, therefore, became visible almost overnight, evolving into the popular discourse of the mid-1930s. Sensationalised media reports depicted oil frontiers as three-dimensional blocks of territory, overlain with territorial concessions which had the potential to interrupt exploration activities. The British public were introduced to oilfield terminology, presented with geological sections, told of the depths at which oil is found, as well as the volume of oil extracted at Hardstoft.

The D'Arcy Exploration Company was the largest company searching for oil in the interwar period. Anglo American, Gulf and Steel Bros held only 29 licences between them, equating to 3,965 square miles of territory, compared to D'Arcy's 52 licences and 9,233 square miles of territory. During the 1920s and 1930s the APOC, or AIOC from 1935 onwards was engaged in exploration throughout the world, focussing heavily on prospects in the Middle East. Netton (1998, p. 5), intimates that "in 1928 and 1932 joint marketing companies were formed with Shell, covering the 'consolidated area (Southern and Eastern Africa, parts of the Levant and the Western and Southern littoral of Arabia) and the UK". The APOC, had interests in the Iraq Petroleum Company, discovered oil in Iraq in 1927 and was a partner in the Kuwait Oil Company, which located oil in Burgan in 1938 (Netton, 1998). These discoveries and concessions made the APOC, renamed the Anglo Iranian Oil Company (AIOC) in 1935 an extremely cash rich company. Unlike Shell, which at the time was investing money into researching the anti-knocking potential of petroleum additives, the AIOC invested its wealth into extraction and refining, establishing its first laboratory in Sunbury-on-Thames in 1917.

By the 1920s the major oil companies were becoming leaders in the application of science to industrial problems due to their large research budgets (More, 2009, pp. 58-63). This was at a time when other industries were struggling to survive the Great Depression. The size and profitability of the AIOC meant it could absorb losses more easily, without it having a detrimental impact on the future of the company. British oil exploration became part of an international oil assemblage, with monetary and intellectual capital flowing from the Persian to the British oilfields.

Rotary drilling technologies using drilling mud, for example, were developed in Persia and brought to Britain during the 1930s. These oilfield developments replaced the old percussion methods used at Hardstoft and gave rise to a significant increase in drilling speeds, allowing wells to be completed much more efficiently. The increasing complexity of exploration and refining meant that large companies, such as AIOC had to invest more into research, establishing research centres throughout the world. This will be the main focus of Chapter 6, which will examine the central role of the Kirklington Hall research station, based in Eakring, Nottinghamshire.

Chapter 6 - Eakring Nottinghamshire: new frontiers in war and peace

6.1 Introduction

This chapter covers the period from 1939 to 1964 and is set in Eakring, Nottinghamshire. After many years of widespread field reconnaissance, geophysical surveying and unsuccessful drilling attempts in the south of England, the D'Arcy Exploration Company had finally located oil in commercial quantities on the eve of World War Two. Ironically, this was only a few miles from where Mr J. Ford, Mining Engineer of The Coal and Iron Development Syndicate had suggested oil would be found in 1911. While Chapter 4 focused on a human actor (John Cadman), and Chapter 5 a piece of oilfield technology (Torsion balance) this chapter examines the significance of the D'Arcy Exploration Company's Research Headquarters, which was moved from London to Eakring following the discovery of oil at the start of World War Two. The construction of workshops, laboratories and offices from 1939 onwards supported a large workforce, including petroleum engineers and research scientists, administration staff and oilfield workers.

The chapter is split into five sections, plus a conclusion which discusses the main findings, in line with the conceptual framework outlined in Chapter 2. The first section examines D'Arcy's response to the discovery of oil in Nottinghamshire, including continued geophysical investigations, which led to the discovery of three further oilfields (Dukes Wood, Caunton and Kelham Hills) in addition to the erection of buildings to house oilfield equipment. The second section investigates surface, and subsurface agreements, which involved private individuals, venture capitalists and also the state. The third section traces the geobiography of Phillip Archibold Southwell, who would travel to Oklahoma in 1942 to recruit an American workforce. It was hoped a team of 44 experienced oilfield workers would significantly increase oil production within the Nottinghamshire oilfields. The fourth section begins by elucidating the implementation of secondary recovery systems within the Nottinghamshire oilfields, which temporarily increased oil output but would ultimately shorten the life of the oilfields. The section moves on to examine Kirklington Hall Research Station, Eakring, which would become a global centre of calculation for oilfield development during the 1940s, 50s and 60s. The final section, before an overall conclusion, chronicles the work of Frank Whittle, who, during the early 1960s field trialled a novel concept in oilfield drilling. Whittles "turbo-drill", based on a Russian concept, would suffer operational deficiencies under field testing; however, it would go on to perform arguably the world's first multi-directional borehole, which had significant implications for oilfield drilling, the potentialities of which were not fully realised until the 1990s.

As with Chapters 4 and 5, this chapter continues to trace the lives of key individuals, as well as introducing new protagonists. John Cadman, exhausted by his exceptionally large workload, died of a heart attack in 1941. His legacy, however, would continue through Phillip Southwell, Cadman's former Birmingham University student. As the chapter explores, Southwell's life trajectory was largely mapped by Cadman, who, as the Chairman of the AIOC, would send Southwell on a number of global oil expeditions. Southwell's spatial life-history would prove vital to his role within the Nottinghamshire oil assemblage, as he negotiated a path towards energy security during a resource-stretched episode in global history.

6.2 The D'Arcy Exploration Company: quantifying the oil resource at Eakring, Nottinghamshire

Following the discovery of oil from Eakring No. 1, a second test well, Eakring No. 2, gave a yield of approximately 20 tons per day (Fraser and Gawthorpe, 1990). A third well provided strong evidence of the presence of an oilfield with a vertical column of 150 feet and an area of 200 acres, with geophysical surveys suggesting a more extensive oilfield occupying up to 1,000 acres.[1] In 1939 D'Arcy developed a proximal area of land where it built workshops and semi-permanent buildings to house geotechnical equipment (drill pipes, bits, dewaxing apparatus, laboratory equipment etc. D'Arcy's "production site" would serve all of AIOC's onshore oil concerns (see figure 6.1 and 6.2).

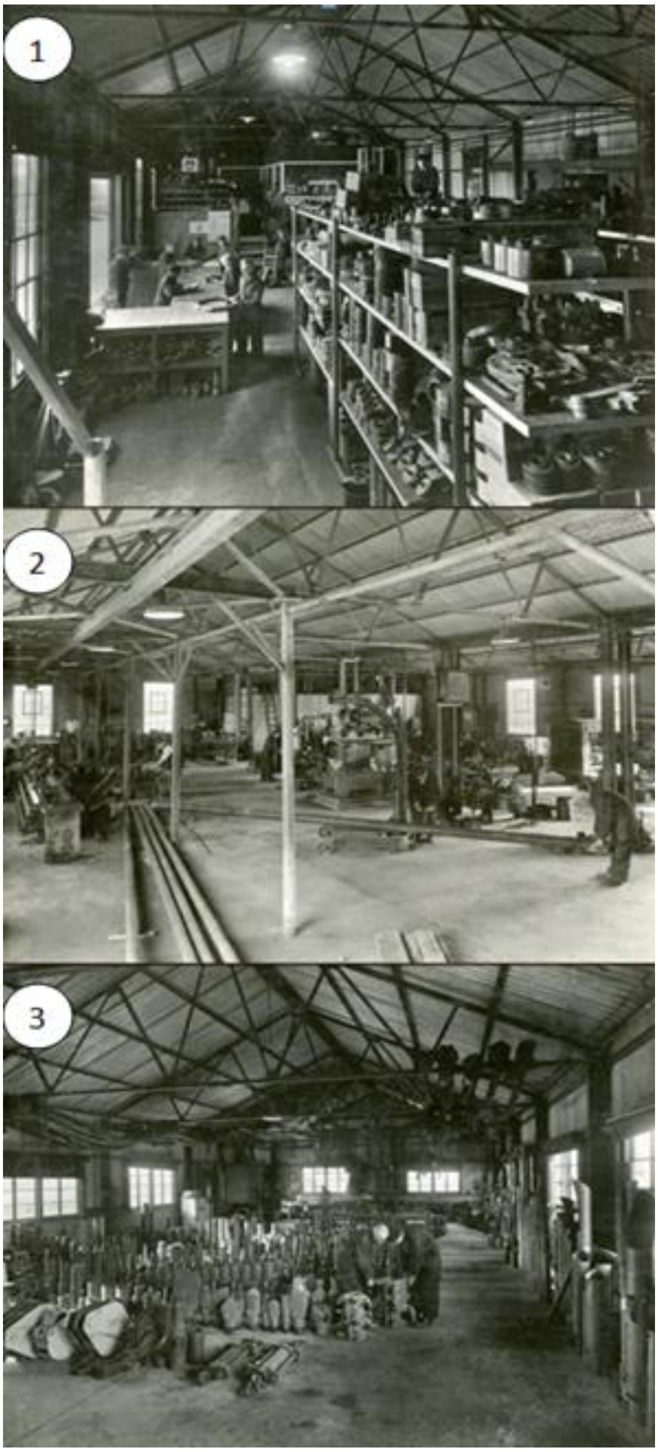
During World War Two Kent was enlisted into the RAF, temporarily curtailing his involvement in British onshore oil exploration. However, his knowledge of oil installations was put to use as he analysed aerial photographs.[2] Stationed at RAF Medmenham and attached to the Photographical Reconnaissance Unit, Kent interrogated numerous aerial photographs, looking for German oil installations in Norwegian Fjords and the Ruhr, as well as scouring for numerous synthetic oil-producing plants, and later on in the war drill sites.[3]

[1] Report entitled "Memorandum to the finance committee D'Arcy Exploration Company Ltd – estimates 1940 23rd September 1940" written by J. A. Jameson BPA: ArcRef 44199.
[2] See NCUACS 43.5.93/A.8 1944-1945.
[3] Germany had no domestic supply of oil therefore relied on synthetic or captured oil to fuel its war machine.

Figure 6.1: D'Arcy Exploration Company's workshops during World War Two. Note camouflaged buildings and stockpiles of drill casing in the foreground.

Source: *Andrew Naylor, April 2012. From: BPA: ArcRef 111344. Date unknown.*

Figure 6.2: Three different perspectives from within the AIOC's workshops at Eakring showing drill bits, casings and ancillary plant.



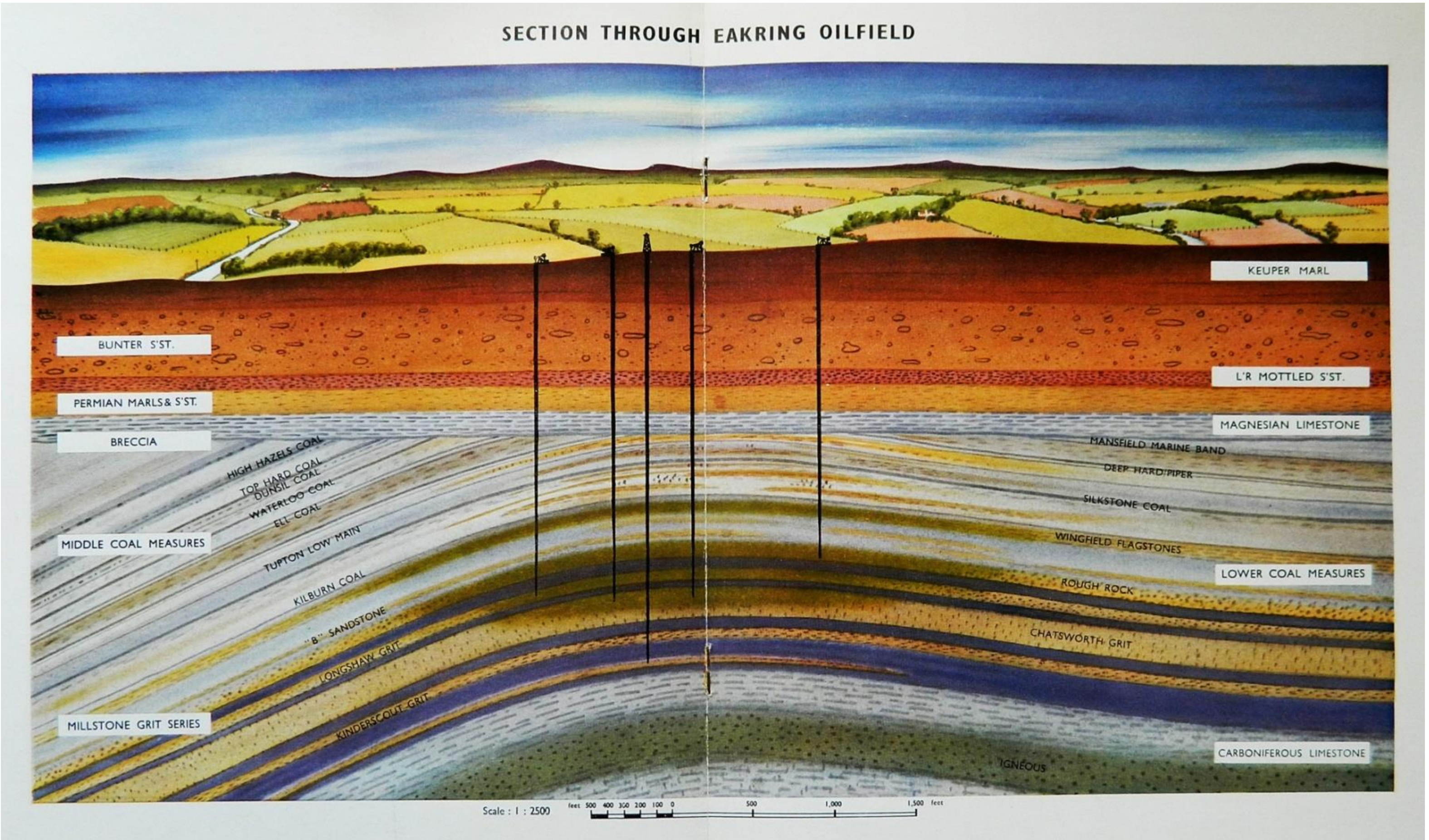
Source: *Andrew Naylor, April 2012. From: BPA: ArcRef 111344. Date unknown.*

Returning to the Midlands, based on preliminary results, D'Arcy's initial drilling programme at Eakring was for thirty wells by the end of 1940.[4] This, based on an average of seven tons of oil per day per well, gave an expected yield of 40,000 tons by the end of 1940. Extreme weather conditions during the winter of 1939, coupled with rising costs of around 30% for labour and materials, meant drilling operations and oil output was significantly lower than anticipated. By the end of 1939 production at Eakring stood at 3,500 tons (Huxley, 1983).

By the end of August 1940, 14 wells had been completed, of which two were unproductive. Wells 5, 6, 12 and 13 indicated the productive area at Eakring was only 100 acres and not 1,000 as previously thought. D'Arcy then deepened[5] well No. 1, discovering that the Lower Carboniferous Limestone was not oil-bearing at Eakring. By late September 1940, ten wells were together producing approximately 50 tons of oil per day, leading D'Arcy to revise its original estimates to 20,000 tons per annum, which they hoped would be stabilised for a period of three years. The company planned to maintain production using two drilling outfits until October 1940, at which point they planned to build a third rig. With rail freight costs then decreasing, D'Arcy believed that the operation would return a profit if output were to stabilise. By the end of August 1940 Eakring had produced 10,124 tons of oil, which, alongside 1,711 tons from Formby and 479 tons from Hardstoft gave a British production of 12,314 tons (DWOM, 2013b, np). As drilling activities proceeded D'Arcy was furnished with an abundance of detailed geological data, enabling the company to build an accurate map of Eakring's subsurface (see figures 6.3 and 6.4).

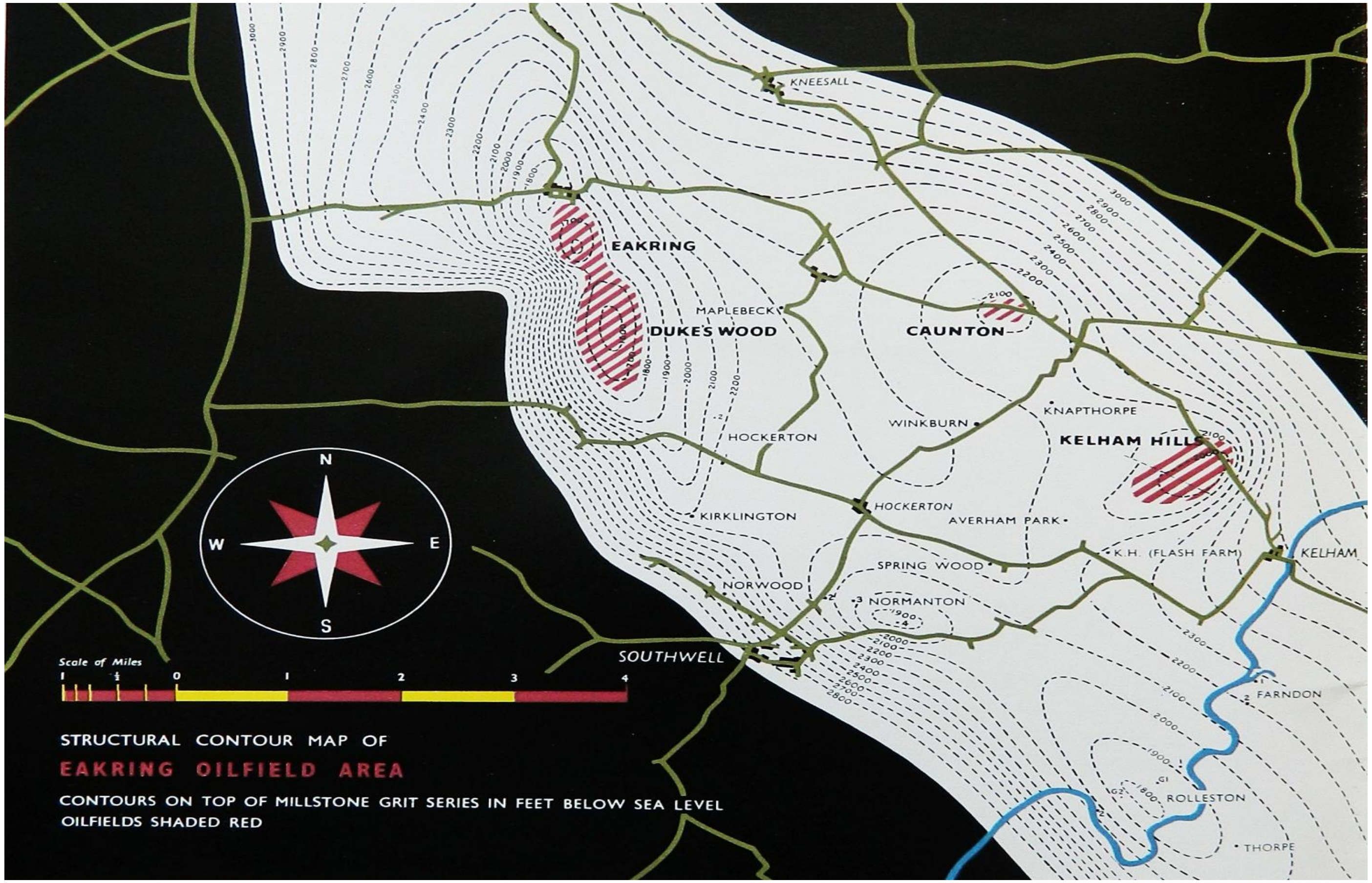
[4] Report entitled "Memorandum to the finance committee D'Arcy Exploration Company Ltd – estimates 1940 23rd September 1940" written by J. A. Jameson. BPA: ArcRef 44199.
[5] The deepest well across the Nottinghamshire oilfields was well 146, which penetrated the limestone strata in the interest of science, completing at a depth of 7,473 feet (DWOM, 2013a, np).

Figure 6.3: Subsurface geographies of Eakring showing anticlinal structure and main stratigraphic horizons.



***Source:** BP (1956, p. 16-17).*

Figure 6.4: Map showing the four Nottinghamshire oilfields – Eakring, Dukes Wood, Caunton and Kelham Hills discovered in an east to west succession.



Source: *BP (1956, p. 10).*

Having located oil-bearing strata, D'Arcy undertook further geophysical surveys in and around Eakring during 1940, drilling step out wells radiating from the crest of the main anticline. Working south East from Eakring village, three further domes were discovered; Dukes Wood (adjacent to Eakring but located in older Carboniferous Limestone), Caunton (four miles east of Eakring) and Kelham Hills (six miles to the south east). The fields all contained commercially viable oil lenses trapped in short vertical columns of 50-200 feet, with the Eakring and Dukes Wood reservoirs located mainly in Westphalian A to Namurian B siliciclastics (Storey and Nash, 1993, p. 1527). The heavily fractured geology meant the company would have to drill multiple wells in order to maximise oil output. Collectively the oilfields covered 830 acres – Eakring and Dukes Wood 600 acres, Kelham Hills 180 acres and Caunton 50 acres (see figure 6.4). Aware of the pressing need for oil, D'Arcy suspended its UK exploration programme in order to maximise output from the proven Midlands fields.

Mr Doug Wallace (born in Eakring in 1926) and his partner Sivyl remember D'Arcy's arrival in the village. Mr Wallace recalled:

"1938, [was] when we first got the test drilling rigs which were mounted on lorries. They call them PDOs which is Portable Drilling Outfits… [it] was something new you know, at that time it was a very rural area here, very little traffic…I used to go up and watch them drilling. They were only drilling to about 2,000 feet, that's where the oil was produced from at that depth".[6]

Following the discovery of oil, D'Arcy made provisions to build a siding on land owned by the Stanton Colliery Company at Bilsthorpe. L. M. Lefroy of D'Arcy met with Mr Todd, Colliery General Manger and Mr Kerr, land agent of Stanton on 13th April 1941 to discuss purchasing or leasing options.[7] Stanton had originally purchased the agricultural land for £60-£70 per acre. It offered field 282, which amounted to 10.95 acres at £125 per acre (aggregate value £1350) and 25 acres of field 413 for £50 per acre (total £1,800). Stanton did not desire to rent the land as they believed it would no longer be suitable for agricultural use post-exhaustion. The company justified the inflated price on the grounds that D'Arcy desired to "select for industrial purposes the pick of their land … [having] excellent road access".[8] However, D'Arcy pointed out that it was probably associated with a £3,000 agricultural fee placed on them by the coalition government.[9] D'Arcy proposed a counter offer of either £100 per annum rent for ten years, or £1,000 to purchase the fields outright. Though the debacle remains unclear, the siding was ultimately built during 1941. It acted as an important artery facilitating the flow of oil direct

[6] Interview with Mr and Mrs Wallace. Interview conducted at the couple's home in Eakring on 6th February 2011.
[7] Letter dated 13th April 1940 to Sir William Fraser "Land for siding – Eakring. BPA: ArcRef 70893.
[8] Letter dated 13th April 1940 to Sir William Fraser "Land for siding – Eakring. BPA: ArcRef 70893.
[9] Letter dated 2nd February 1943 from G. W. Lepper to R. G. W. Eadie of Coal Tar Control. TNA: POWE 33/1738.

from the Nottinghamshire oilfields to Ellesmere Port and Pumpherston refineries, with further refining of lubricating oil taking place at a Shell refinery at Stanlow.

The discovery of oil was widely publicised. *The Exeter and Plymouth Gazette* (9th June, 1939, p. 20) stated "the Anglo-Iranian Oil Company announced last night that its prospecting subsidiary, the D'Arcy Exploration Company Ltd, has struck oil in its test-well Eakring No. 1, near Bilsthorpe, Nottinghamshire…the well is now being prepared for production tests". *The Times* (30th June, 1939, p. 24) added:

"Some 50 feet of "oil sand" has been penetrated, and additional drilling is now to take place to ascertain the further extent of this sand …when this is has been done, the well will be put on a further production test….the preliminary test conducted during the past week has resulted in the production of over 100 tons of crude oil of excellent quality".

On previous attempts to locate oil in Britain, John Cadman told *The Times* (27th June 1939 p. 22):

"We have…had disappointments and failures; but on June 7 prospects took a much more favourable turn as a result of a strike of oil in a well which we were drilling at Eakring, in Nottinghamshire…We may have found oil of importance in Great Britain…The discovery at Eakring, I should add, heightens the potentialities of areas to the east over which we hold licences".

The decision to publicise the Nottinghamshire discoveries risked national security. German knowledge of Britain's domestic oil supply could have made the fields a target for Luftwaffe bombing raids. The reports would, however, shortly cease as a veil of secrecy fell over the discovery. No subsequent reports were published until September 1944 when a series of "exclusive" reports were published in British tabloids.

6.3 Governing the Nottinghamshire oilfields above and below ground

Historically, the village of Eakring lay within the boundaries of the Rufford Estate, an important seat of nobility in Nottinghamshire until 1938. It was never owned by a Duke; therefore was never technically classed as one of the four Nottinghamshire "Dukeries" - Clumber (Duke of Newcastle) Thoresby (Duke of Kingston, Earl Manvers) Welbeck (Duke of Portland) and Worksop (Duke of Norfolk). As discussed by Kempson (2006), George Talbot, the 6th Earl of Shrewsbury built the first residence, Rufford Abbey in the grounds of the estate. Following the marriage of Lady Mary Talbot to George Savile of Thornhill Hall, West Yorkshire in 1616 the estate passed to the Savile family, who made significant changes to the Abbey.

In 1931 the 2nd Baron Savile died, leaving a 12 year old heir. His death coincided with major political and economic strife throughout Britain. The 1930s were a difficult time for all landed estates amidst the dismal prospects of the Great Depression. Furthermore, estates whose wealth had been acquired through mineral exploitation became asphyxiated by the passing of the 1938 Coal Mines Act, which nationalised mineral deposits without the payment of compensation (Smith, 2002b). This manoeuvre was part of a broader state goal to better control its territories and capitalise on the nation's mineral deposits. The interwar period also brought elevated taxation to the very rich, who were subject to an upper threshold of 60 per cent.

Following the death of Baron Savile, the trustees of George Halifax Lumley-Savile, the 3rd Baron Savile, decided to sell the Nottinghamshire estate on account of death duties. The total land area amounted to 18,700 acres, this included 70 farms and numerous cottages and small holdings. According to Walker (2000, p. 47), the estate was split into 479 lots, 97 of which lay within the parish of Eakring. The Eakring portion contained 13 farms, 31 cottages and building plots reserved for bungalows. The entire 18,700 acres was purchased privately by Nottinghamshire industrialist and former Lord Mayor of Nottingham, Sir Albert Ball, who proceeded to sell off fragments of the estate through his Bradford Property Trust Limited turning a quick profit (Walker, 2000).

By October 1939 many of the auction lots remained unsold. Unsure of the quantity of oil available and the expected life of the oilfield, D'Arcy contacted Scottish Oils Limited enquiring into the land situation in Scotland.[10] Two avenues were typically employed; "Feuing" (purchasing the land in its entirety) or leasing. The decision depended on the probability of turning a substantial return and the associated timescales. Scottish Oils Limited would normally seek to become the absolute permanent tittle holder, which might also include a small annual "feudity" or ground rent. When leasing the land, they aimed for a 31 year period or less, depending on the volume of shale in the area. R. W. Meikle of Scottish Oils Limited at first suggested D'Arcy lease the land at Eakring. If a reasonable rent could not be arranged, D'Arcy would have the right to appeal to the Railway and Canal Commission under the Petroleum (Production) Act 1934. However, he stressed that if a reasonable rate could be calculated based on the agricultural value of the land, it may be better to purchase.[11]

L. M. Lefroy met the Chairman of the Bradford Property Trust Limited in October 1939 and went on to draft terms based on £9 per acre per annum, concluding "we are very backward in England…the land Register is optional over a great part of the country, and registration is not encouraged naturally by the solicitors!"[12] The land question was made more complex due

[10] Letter dated 23rd October 1939 to R. W. Meikle of Scottish Oils Limited from L. M. Lefroy of D'Arcy. BPA: ArcRef 44201.
[11] Letter dated 25th October 1939 from L. M. Lefroy of D'Arcy to R. W. Meikle of Scottish Oils Limited. BPA: ArcRef 44201.
[12] Letter dated 28th October 1939 from L M. Lefroy to R. W. Meikle. BPA: ArcRef 44201.

to D'Arcy technicians being uncertain as to where to site roads for wells.[13] Of the original 479 lots D'Arcy elected to purchase 777 acres of the Eakring estate on 5th June 1940 at a cost of £12,000, becoming freeholders of the land, together with farmhouses, messuages, outbuildings, private accommodation and roads and or tracks adjoining or leading to any of the parcels of land.[14] The sale excluded the ownership of all minerals on or beneath the land's surface, which were being worked by several lessees prior to the sale of the estate. Tied to the 777 acres of land was a land tax of £58 10s 0d and a redemption annuity (in lieu of tithe rent charge) of £315 3s 10d which D'Arcy also agreed to pay.[15]

At Eakring, the land surface was divided into a patchwork mosaic of discrete parcels of land, each one managed by private tenants who paid a total annual rent ranging from a maximum of £100 per annum to a minimum of one shilling. The terms of tenancy stretched back to 25th March 1899, though most had been agreed during the 1930s. As part of its agreement D'Arcy consented to pay rents under existing tenancies. The company's first mining licence (the first in Britain) covered area A. 60 which included the Eakring and Dukes Wood fields. It also took out prospecting licences for Kelham Hills; area A. 29a, Caunton; Area A. 121a, Formby; Area A. 90a and Nocton, Area A. 30a.[16] In addition to Government licensing, D'Arcy had to make arrangements with mineral protagonists and landowners working in the vicinity of the oilfields.

As part of its agreement with the Minister of Fuel and Power, D'Arcy was granted the right to erect and maintain physical boundary markers defining the topographic extent of the oilfield, which would correlate with maps submitted to the Ministry.[17] If the company desired to extend its territories it had to provide 18 months written notice to the Minister of Fuel and Power. Conversely, should they wish to surrender a portion of their territory they had to give six months' notice.[18]

The Eakring agreements included a plethora of covenants, indemnities and subsurface management clauses which sought to protect mineral owners, surface landowners, colliery companies and D'Arcy. The Coal Commission was responsible for reconciling subsurface rights; legally indemnifying colliery owners so that coal could be left in situ, providing D'Arcy cover the loss of revenue (which had been a major barrier to progress on the Duke of Devonshire's estate). Surface rights were straightforward, with D'Arcy agreeing to pay MAPs

[13] Letter dated 25th October 1939 from L. M. Lefroy of D'Arcy to R. W. Meikle of Scottish Oils Limited. BPA: ArcRef 44201.
[14] Original conveyance dated 5th June 1940. DWOM.
[15] Original conveyance dated 5th June 1940. DWOM.
[16] Report dated 8th February 1943 entitled "Eakring Mining Licence area". TNA: POWE 33/538.
[17] Mining Licence No, 1. Petroleum (Production) Act 1934 dated 16th April 1947. The Minister of Fuel and Power and D'Arcy Exploration Company Ltd. Oil Mining Licence to Search and Bore for and get Petroleum in the County of Nottingham. TNA: POWE 33/1738.
[18] Mining Licence No, 1. Petroleum (Production) Act 1934 dated 16th April 1947. The Minister of Fuel and Power and D'Arcy Exploration Company Ltd. Oil Mining Licence to Search and Bore for and get Petroleum in the County of Nottingham. TNA: POWE 33/1738.

to surface owners. These figures were calculated on acreage, whereby D'Arcy's "defined area" in Nottinghamshire amounted to 4,633 acres charged at 4/3d per acre.[19] In November 1945 D'Arcy requested to reduce the defined area to 3,130 acres, lowering the MAP to £665.2.6.[20] Each month it submitted a plan (on a scale six inches to one mile) to the mineral owners and Stanton showing the locations of boreholes or wells drilled and those planned over the course of the following month. In addition, they provided samples and detailed records of strata passed through to the agents or surveyors of the mineral owners and Stanton.

A fifty year licence agreement imposed baseline royalty figures for domestic oil, which would be reviewed every ten years.[21] A minimum figure of 3/- per ton (2,240 lbs) and maximum of 6/- per ton of crude was set from 1st January 1938 to 31st December 1940. Royalty payments were initially calculated at the end of a "licence year", being the date on which the license was first granted. However, this was later adjusted to 31st December for administration purposes.[22]

A working royalty of four shillings (4/-) per ton of oil (2,240 lbs) was ultimately imposed on the oil won and saved from the Nottinghamshire oilfields. This excluded crude oil and casinghead petroleum used on site, as long as it was utilised for drilling, production operations and pumping to the field storage and refineries. Natural gas was charged at ten per cent, reduced to five per cent if D'Arcy sold the gas to persons holding licences under the Petroleum (Production) Act 1934, so long as it was used to repressurise a natural oil reservoir. D'Arcy's first royalty payment, calculated for the period from 22nd April 1939 to 21st April 1940, based on 4,494.848 tons of oil amounted to £846.9.5.[23]

Subsurface agreements required careful wording and a thorough understanding of the location of underground structures, including who owned them, for how long and exactly where the boundaries between them were. Agreements had to reflect the interplay of subsurface extraction, i.e. coal/metal ores/clay/oil etc. within the defined area and had to be clear and intelligible to non-experts.[24] Coal and mineral exploitation accelerated under wartime conditions as demand for resources increased. This meant subsurface territories could be radically altered by local collieries, which had a duty to increase extraction. At Kelham Hills subsurface regulation was straightforward, with D'Arcy agreeing to supply the colliery owners with borehole logs in exchange for them being allowed to drill through reserved minerals.[25]

[19] Original conveyance dated 5th June 1940. DWOM.
[20] Letter dated 19th February 1946 from G. J. N. Wilkie to The Assistant Accountant of the D'Arcy Exploration Company Ltd. TNA: POWE 33/1738.
[21] Mining Licence No, 1. Petroleum (Production) Act 1934 dated 16th April 1947. The Minister of Fuel and Power and D'Arcy Exploration Company Ltd. Oil Mining Licence to Search and Bore for and get Petroleum in the County of Nottingham. TNA: POWE 33/1738.
[22] Letter dated 7th May 1942 to Giffrard. TNA: POWE 33/538.
[23] Report dated 8th February 1943 entitled "Eakring Mining Licence area". TNA: POWE 33/538.
[24] Letter dated 10th July 1941 from L. M. Lefroy to Sir William Fraser. TNA: POWE 33/538.
[25] Letter dated 27th August 1941 from L. M. Lefroy of D'Arcy to Sir William Fraser. TNA: POWE 33/538.

Bilsthorpe colliery in Eakring, owned by Stanton, had proposals to extract coal under the defined area.

On 5th March 1940, L. M. Lefroy wrote to Sir W. Fraser informing him of "sub-surface problems" at Eakring.[26] Stanton was concerned that D'Arcy might "leave them a roof [in their coal workings] like a pepper pot" as well as considerably depreciate the value of coal in the seams drilled through, making it more expensive to mine than a virgin coalfield as well as restricting its development.[27] In response D'Arcy reminded Stanton of the valuable data they would impart in the location and extent of coal seams, saving the company the expense of drilling two informational boreholes it had planned.

Stanton planned to drive a series of underground roadways, marked A, B, C, D, E and F within the mining licence area[28] (these roadways would not exceed fourteen feet by eleven).[29] D'Arcy agreed not to traverse these and consented to indemnify the mineral owners against any claim for damage caused by the exploration and extraction of oil. Furthermore, it agreed to pay full compensation for coal to be left in situ in support of wells, boreholes and any other works. The company had earlier stated that it had not had a "desire to purchase a ton more of the underlying coal than [was] needed for the support of…wells, or to pay royalties thereon".[30]

The demand for oil during World War Two led D'Arcy to push forward a wartime agreement enabling exploration outside of the defined area. The company was granted a two month window to widen its search for oil in Eakring, provided they pay £50 (maximum) to or on behalf of the mineral owner to the Savile Trustees. The agreement also provided a working definition of "compensatory" and "non-compensatory" coal seams. By definition, "compensatory seams" meant "any seams of coal of two feet six inches or upwards in thickness and lying more than three hundred feet below the base of the Permian Breccia as determined from time to time by the well drilling records of D'Arcy, and agreed by Stanton and the Coal Commission." Whereas "non-compensatory seams" meant "any seams of coal less than two feet six inches in thickness or lying less than three hundred feet below the base of the Permian Breccia as determined from time to time by drilling records of D'Arcy and agreed by Stanton and the Coal Commission".[31] Under the terms of the agreement D'Arcy was free from financial

[26] Letter dated 5th March 1940 from L. M. Lefroy to Sir W. Fraser entitled "Eakring – Coal problems". BPA: ArcRef 70893.
[27] Letter dated 5th March 1940 from L. M. Lefroy to Sir W. Fraser entitled "Eakring – Coal problems". BPA: ArcRef 70893.
[28] Unfortunately, I was unable to locate an accompanying map within The National Archives, Kew.
[29] Agreement made between the Right Honourable Kenneth Fitzgerald Baron Kinnaird and Robert George Hogarth, The Stanton Ironworks Company and the D'Arcy Exploration Company Ltd. TNA: POWE 33/1738.
[30] Letter dated 25th October 1939 from L. M Lefroy of D'Arcy to to R. W. Meikle of Scottish Oils Limited. BPA: ArcRef 44201.
[31] Agreement dated 21st April 1942 between The Right Honourable George Halifax Baron Savile, Right Honourable Kenneth Fitzgerald Baron Kinnaird and Robert George Hogarth, The Coal Commission, The

obligations when drilling into non-compensatory seams. However, it was restricted to a maximum of nine boreholes into compensatory seams, to be located a minimum distance of 75 feet from Stanton's underground roadways. Stanton's roadways were confined to a minimum depth of 900 feet from the surface with a lower level of 2,050 feet.[32]

These subsurface geographies gave both companies areas in which to conduct their respective activities, whilst minimising the possibility of conflict. For D'Arcy to drill into compensatory coal seams it agreed to pay the Savile Trustees £250, which covered a period up to 13th June 1942. After this date the responsibility would shift to the Coal Commission. D'Arcy also agreed to pay the Coal Commission £600 in lieu of the loss of coal to Stanton and agreed to pay Stanton £4,600 for the diminution in value of the minerals left in situ, plus an additional £500 per borehole.[33] Ultimately therefore, should all nine boreholes have been drilled the company would have to pay Stanton £9,100 (£4,600 fixed sum plus 9 x £500 = £9,100).

Subsurface ownership rights were reconciled using the model of unit development. It was perfectly acceptable under the Petroleum (Production) Act 1934 for a competitor to acquire a licence to drill for and get petroleum on lands adjoining the D'Arcy licence area. In order to prevent one company sucking another's territories dry, the Minister of Petroleum would examine the area to investigate whether or not the oilfield was one large underground geological structure or several smaller units. If it was found to be one large underground petroleum structure or "oilfield", from which several licensees were extracting oil, then the Minster would ensure all licensees co-operated to avoid wildcatting or unnecessary competitive drilling, which had been so damaging in the development of the American oilfields.[34] This would protect national interests and ensure the maximum possible recovery of oil from the field. Licensees would be instructed to collaborate and prepare a development scheme that included detailed maps. Should any licensee object to the terms of the development scheme he/she was granted 28 days to refer the matter to an appointed arbitrator in accordance with the 1889 and 1934

Stanton Ironworks Company and the D'Arcy Exploration Company Ltd. TNA: POWE 33/1738. Folder labelled P3/L1/A1.

[32] Agreement dated 21st April 1942 between The Right Honourable George Halifax Baron Savile, Right Honourable Kenneth Fitzgerald Baron Kinnaird and Robert George Hogarth, The Coal Commission, The Stanton Ironworks Company and the D'Arcy Exploration Company Ltd. TNA: POWE 33/1738. Folder labelled P3/L1/A1.

[33] Agreement dated 21st April 1942 between The Right Honourable George Halifax Baron Savile, Right Honourable Kenneth Fitzgerald Baron Kinnaird and Robert George Hogarth, The Coal Commission, The Stanton Ironworks Company and the D'Arcy Exploration Company Ltd. TNA: POWE 33/1738. Folder labelled P3/L1/A1.

[34] Mining Licence No, 1. Petroleum (Production) Act 1934 dated 16th April 1947. The Minister of Fuel and Power and D'Arcy Exploration Company Ltd. Oil Mining Licence to Search and Bore for and get Petroleum in the County of Nottingham. TNA: POWE 33/1738.

Arbitration Acts.[35] Ultimately, however, D'Arcy would be the only company to explore for and extract oil in the vicinity.

The 50 year licence agreement safeguarded the long-term security of domestic oil interests by ensuring exploration/exploitation was controlled by a majority British national.[36] Under clause 32 D'Arcy could not assign the rights to another individual or company if it were not incorporated in Britain or Northern Island, without first acquiring consent from the Minister of Fuel and Power. The agreement contained a significant number of environmental covenants. For example, D'Arcy would ensure it controlled the flow of crude oil so no fraction was wasted or allowed to escape into the licence area. Furthermore, it would prevent damage to adjoining petroleum-bearing strata, prohibit the entry of oil through boreholes and wells into the petroleum-bearing strata, and ensure no hydrocarbons contaminated the local water sources. This was paramount where boreholes penetrated coal seams. Accordingly, D'Arcy would case boreholes to minimise the risk of escape and or ingress. All oilfield equipment, boreholes and wells had to be suitably maintained in order to reduce the risk of possible oil migration. Waste oil and salt water from extraction processes and refuse from gasholders had to be disposed of in an approved manner so as not to flow over or be deposited on any land inside or outside the licence area. Finally, extracted oil would be stored in specially constructed receptacles to avoid possible contamination.

As World War Two progressed the importance of domestic oil increased. On 8th July 1941 the Petroleum Department contacted D'Arcy, explaining "in the present emergency every ton of oil produced in this country is a direct contribution to the national war effort" (cited in Bamberg, 1994, p. 224). Several months before war was announced John Cadman had visited Geoffrey Lloyd - recently appointed Minister for Oil – stating oil production at Dukes Wood had reached 25,000 tons. Lloyd subsequently requested oil production be increased to 100,000 tons per annum in light of the current oil tanker situation (BP, 1944, p. 3). The request came at a time when labour was in short supply, manufacturing had shifted to essential wartime production and Britain lacked trained oil workers at home. This was one of Cadman's final acts in the development of the Nottinghamshire oilfields, as he died of a heart attack on 31st May 1941. His legacy, however, was kept alive by Philip Archibald Southwell (1894-1981), who was to become the next key actor in the East Midlands narrative.

As discussed by Torrens (2004c), Southwell was born in Yorkshire on 6th June 1894, the only son of medical practitioner Charles Southwell and his wife Clare. He was educated at

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35 Mining Licence No, 1. Petroleum (Production) Act 1934 dated 16th April 1947. The Minister of Fuel and Power and D'Arcy Exploration Company Ltd. Oil Mining Licence to Search and Bore for and get Petroleum in the County of Nottingham. TNA: POWE 33/1738.

36 Mining Licence No, 1. Petroleum (Production) Act 1934 dated 16th April 1947. The Minister of Fuel and Power and D'Arcy Exploration Company Ltd. Oil Mining Licence to Search and Bore for and get Petroleum in the County of Nottingham. TNA: POWE 33/1738.

Newcastle under Lyme high school (1904-1912) and had a strong passion for sports, often to the detriment of his studies. Southwell's 18 page autobiography, held at Keele University Special Collections and Archives reveals how his life was shaped by John Cadman, who ultimately placed him at the centre of developments in the Nottinghamshire oilfields.[37] At the age of 14 Southwell accompanied his father's friend, surgeon and Carboniferous geologist Wheeldon Hind, on walks, collecting fossils from the slag heaps of local collieries. Together, Southwell and Hind ventured underground where they…" [studied] the bowels of the earth, [which] intrigued [Southwell] enormously [and] undoubtedly influenced [his] idea…to become a mining engineer".[38]

Following paternal advice, Southwell arranged to visit the closest Professor of Mining Engineering, John Cadman at the University of Birmingham in 1914 (Torrens, 2004c). Despite his minimal academic qualifications, Cadman offered Southwell a place on his newly created Petroleum Mining course, making him one of his first students. From here, Southwell's "future career was to a large extent determined by him (Cadman)".[39] On the outbreak of World War One Southwell joined the Royal Artillery, earning a Military Cross in 1918. He returned to Birmingham University to complete his studies, graduating in 1920. His first permanent position was with S. Pearson and Sons Ltd employed under Lord Cowdray. On awaiting the results of his degree at Birmingham Southwell was told "The Professor [Cadman] wants to see you".[40] Cadman casually stated "I have appointed you as Government Petroleum Technologist to the Government of Trinidad; you take the first boat you can, that is all I have to say".[41]

Southwell found "the oil production problems of Trinidad…extremely difficult and the experience…gained provided [him] with the knowledge which helped throughout the remainder of [his] career".[42] He retained his position as Government Petroleum Technologist for Trinidad from 1922 to 1929 and in 1930 he accepted Cadman's offer of head of oilfield geology and geophysics for the AIOC, becoming a local manager and spending a considerable amount of time in the Persian Gulf (Torrens, 2004c). His appointment lasted until 1940 when Cadman asked if he would consider preparing an office in London for the Kuwait Oil Company (KOC), a 50-50 joint AIOC and Gulf Oil Corporation established in 1934.

Whilst in Kuwait Southwell designed a development programme which functioned under a technically orientated common good – to maximise oil output from the oil sands, avoiding wildcatting and ensuring the fields were developed sustainably. He applied the philosophy of unit development, specifying only one well would be drilled per square mile. In

[37] Phillip Archibald Southwell's unpublished autobiography. KUSCA: UGSD102. pp.1-18.
[38] Phillip Archibald Southwell's unpublished autobiography. KUSCA: UGSD102. p. 1.
[39] Phillip Archibald Southwell's unpublished autobiography. KUSCA: UGSD102. p. 2.
[40] Phillip Archibald Southwell's unpublished autobiography. KUSCA: UGSD102. p. 2.
[41] Phillip Archibald Southwell's unpublished autobiography. KUSCA: UGSD102. p. 2.
[42] Phillip Archibald Southwell's unpublished autobiography. KUSCA: UGSD102. p. 4.

order to increase oil production in Kuwait the AIOC recruited fifty American drillers from Texas, Louisiana. Lulled by exotic stories of swimming pools and a pleasant climate they in fact arrived in a sandstorm with only tents as accommodation. The men almost immediately rioted, wishing to return home post haste. Southwell addressed the men in a marquee arguing the company "had engaged men not boys but…if there were any boys who wanted to return home [the AIOC] would find a place on a plane the next day".[43] Two men took up Southwell's offer, though the remaining 48 successfully increased oil production as planned.

Following Kuwait, Southwell travelled to Australia to discuss the AIOCs proposals to explore for oil in Australia, Papua and New Guinea, where the AIOC was willing to spend one million pounds on the development of oil resources if large scale concessions could be negotiated.[44] While overseas, Southwell acted as a diplomat and advisor, introducing novel secondary recovery systems and overseeing the employment of American expertise to maximise oil output. His dynamism and bullish attitude saw him recalled to Britain in 1940 to drive forward development in the four Nottinghamshire oilfields, where he would apply the skills and experiences learnt while undertaking his various postings around the world. One of his first tasks, however, was to oversee a horizontal drilling experiment undertaken in Newark, Nottinghamshire in September 1940, which successfully destroyed a five foot target 1,000 feet away (Ferrier and Bamberg, 1982).

During World War Two D'Arcy channelled its formerly scattered drilling rigs into Nottinghamshire to maximise productivity in the confirmed oil-producing reservoirs. Here D'Arcy faced several problems. The influx of non-standardised equipment was far from fit for purpose. Drilling and pumping equipment had been designed to perform tasks tailored to local geological conditions. Equipment was produced by several manufacturers, with some rigs and pumping gear running on diesel and others being steam driven (Southwell, 1944, p 5). Additionally, service requirements had taken men from the field to war and steel was largely reserved for ship and munitions building. The movement of drilling equipment was reduced as shipping space was cut and heavy drilling outfits designed to penetrate deep geological structures (<8,000 feet) in Persia were not suited to the rapid rate of drilling required in the shallow Nottinghamshire fields, where oil existed in the heavily fractured reservoir at between 2,000 – 2,500 feet. The derricks were between 94 and 136 feet high and built section by section like giant meccano sets. In 1940 well completion time stood at approximately nine weeks, but by early 1942 this had been reduced to three weeks. Nonetheless, with the addition of two weeks for moving and re-erection this still meant a painfully slow five week turnaround for each well. The problems did, however, lead to ingenious improvisations and a streamlining of drilling

[43] Philip Archibald Southwell's unpublished autobiography. KUSCA: UGSD102. p.12.
[44] Philip Archibald Southwell's unpublished autobiography. KUSCA: UGSD102. p.12.

processes, including the modification of drilling procedures to conserve materials and increase drilling speeds.

6.4 Increasing oil output in the Nottinghamshire oilfields

Oil tankers were prime targets for German U boats and the Luftwaffe throughout World War Two. This led to a serious shortfall in allied oil stocks. Remedying the oil shortfall would fall to Southwell, as he effectively took the reins from John Cadman following his death. A detailed discussion of Southwell's role in British oil exploration in the East Midlands is given by Woodward and Woodward (2002, pp. 11-32). However, it is somewhat biased, utilising material sourced only from the American oil companies involved. Notwithstanding this, it gives a detailed account of the events that led up to what became a massively accelerated exploitation phase.

In August 1942 Britain's Secretary of Petroleum; Geoffrey Lloyd called for an emergency meeting with the Oil Control Board in London. Shortly before the meeting the Admiralty had reported that oil stocks were two million barrels below normal safety reserves and sufficient to meet only two months' supply. Failure to provide oil immediately could lead Britain to surrender. Southwell was present at the meeting and was invited to speak on behalf of the AIOC. He proceeded to inform delegates of Britain's domestic oil supplies. Despite the newspaper coverage, most were unaware of domestic oil. He answered a barrage of questions, avoiding disclosing the location of the field amidst security concerns. All he stated was that the field was inland, away from submarine attack and camouflaged by mature trees. He stated progress in the fields was slow; however, he elucidated America possessed the appropriate drilling equipment and expertise to accelerate oil production (Woodward and Woodward, 2002).

Following the meeting Southwell was selected by the group to travel to Washington D.C to draft terms with the Petroleum Administration for War (PAW) and the Petroleum Industry War Council (PIWC) who were jointly charged with managing America's fuel levels. Following much travelling, deliberation and diplomacy, Southwell convinced Lloyd Noble and M. C. C Forbes of Ardmore, Oklahoma, (president and vice president of the Noble Drilling Corporation - with headquarters in Tulsa, Oklahoma) and Frank Porter, (president of the Fain-Porter Drilling Company, with offices in Oklahoma City) to undertake a 100 well drilling programme. This, he argued, would quadruple oil production in Britain. Following several meetings Southwell secured four drilling rigs which would be shipped to Britain alongside a 44 man strong crew of experienced oilfield workers (Woodward and Woodward, 2002).

In England D'Arcy recruited labour from government training centres, as part of the Minister of Labour's plans to train men and women in a variety of trades.[45] After one year's training, recruits could then earn the union rate for that trade. D'Arcy discussed the company's plans with the Mansfield Labour Exchange, detailing the range of careers they had on offer. The Labour Exchange agreed and pointed out that many of the recruits had previous experience in coal mining (most had been dismissed from the industry on medical grounds). Local recruits accompanied AIOC workers with previous experience in the Persian oilfields giving an overall workforce of 800 men. Training was short and intense due to the pressing need for oil output, though many rapidly advanced to become drillers.

The AIOC's Senior Geologist A. H. Taitt was responsible for designing an appropriate drilling strategy and was allocated a field office on the Eakring oilfield sited next door to a field petroleum laboratory.[46] He originally proposed an "ideal geometric layout"; however, local geologic conditions were found to dictate where wells were drilled.[47] Well spacing had been planned every 500 feet, but this was reduced to one well per two acres on the main producing field at Eakring and Dukes Wood, and one well to every three acres at Caunton and Kelham Hills. Over time an "in-filling" operation was implemented to extract oil from small lenses in the heavily fractured strata. Taitt's spacing was, according to Southwell, considered satisfactory for the oil reservoir characteristics (Southwell, 1944, p. 8).

The PAW expressed the opinion that it was not viable to expend critical resources on shallow close well spacing, particularly as oil yield was often low.[48] Instead, it favoured exploratory drilling and requested data on the proven fields. It argued that not all wells should be cased and "special efforts be made to speed up the testing of individual wells".[49] Southwell intervened, arguing that D'Arcy should review the results of its drilling programme before responding to the PAW. He stated the company:

"Should case and put on production all in-filling wells, even though their production only [amounted] to a few gallons of oil [on account that] by shooting or other means, in due course [it may be possible] to obtain increased production from these wells. [Moreover] we do

[45] Details of discussion dated April 23rd, held on 28th April 1941. BPA: ArcRef 44197.
[46] In December 1942 an explosion and fire occurred in the petroleum office. Although the fire was not serious, it did prompt the AIOC and D'Arcy to ensure all necessary steps had been taken to ensure on site safety. Letter dated 29th December 1942 from G. W. Lepper to P. A. Southwell. TNA: POWE 33/1738.
[47] Letter dated 18th May 1943 from Leffroy to Lepper of Ministry of Fuel and Power (Petroleum Division). TNA: POWE 33/1738.
[48] Letter dated 27th January 1944 from C. A. P. Southwell to the Works Manager at Eakring. BPA: ArcRef 44206.
[49] Letter dated 27th January 1944 from C. A. P. Southwell to the Works Manager at Eakring. BPA: ArcRef 44206.

not know the minimum economic limit of wells on a field already drilled up and on a satisfactory producing basis".[50]

The American drillers were described by L. M. Lefroy of D'Arcy as a "whirlwind which has descended upon us"; drilling wells so quickly (12 hour settling time) that D'Arcy was finding it difficult to keep up to speed with the formal mapping of well sites.[51] For example, the site for Well No. 97 did not have a rig or pump on site by 12.30 on 14th May 1942; however, the Americans had drilled 1,778 feet by 15th May and it had been cemented into place by 17th May 1942.[52] Although difficult to administer, L. M. Lefroy argued the Americans had induced "remarkable [drilling] footage".[53]

The four American rigs, known as Jack Knifes, or Portable Drilling Outfits (PODs), were fitted to the chassis of a low-loader, which could be slewed into place with minimal disturbance to the surrounding environment. They were designed to drill to approximately 5,000 feet using 44 inch long drill pipes. When erected, which involved simply hoisting the drilling mast, they stood at 87 feet tall (Southwell, 1944, pp. 6-7). The drilling process revolutionised onshore oil exploration in Britain. Using this system, move times were reduced to twelve hours, compared with the former two weeks allocated for conventional deep Persian drilling rigs.

Drilling rigs were moved repeatedly, each averaging one completed well per week. The American drilling team initiated several conservation measures which, though simple, significantly increased the speed of the overall operation (Woodward and Woodward, 2012, pp. 246-247). Southwell stated that early in its development, well production in the Nottinghamshire fields ranged from seven to as much as 357 barrels per day (Southwell, 1944, p. 7). The crude was greenish brown in colour and of mixed type. Motor and aviation distillates produced high naphthenic characteristics with a high octane value, with non-knocking properties producing a high grade lubricating oil of a similar quality of the Mid-Continent crudes. The oil contained a high paraffin wax content, at over double that found in average Mid-Continent crudes. Initially, the total recoverable hydrocarbon fraction stood at approximately 75-80%, however, as reservoir pressure fell this decreased to less than 70%. Each well consumed approximately 500 gallons of crude oil per annum. In the royalty year 1941-1942, 15 wells had been sunk thus resulting in 7,500 gallons, or 29 tons of crude oil being used to keep the pumping jacks themselves running.[54]

[50] Letter dated 27th January 1944 from C. A. P. Southwell to the Works Manager at Eakring. BPA: ArcRef 44206.
[51] Letter dated 15th May 1943 from L. M. Leffroy to Lepper. TNA: POWE 33/1738.
[52] Letter dated 15th May 1943 from L. M. Leffroy to Lepper. TNA: POWE 33/1738.
[53] Letter dated 15th May 1943 from L. M. Leffroy to Lepper. TNA: POWE 33/1738.
[54] Letter dated 13th June 1942 entitled "crude oil used to drill in wells during the royalty year 1941-1942 (for Area A. 60a licence area). TNA: POWE 33/538.

Early on in the life of the fields, oil-water separation was a simple process of heating the crude via coils to evaporate off the water as steam. As the fraction increased the oil had to be sent through a wood-wool filtering system which added time (Southwell, 1945, p. 9). As at Hardstoft, the high paraffin wax content made extraction difficult. The paraffin wax would typically build up in the top 700-800 feet of the drill string and on into the two inch overland pipes. This was largely overcome by insulating the top 1,000 feet using wooden insulators and using a portable dewaxing unit (Southwell, 1944, p. 10). Nonetheless, the drill pipe was periodically extracted and dewaxed manually by site labourers. Following treatment, the oil was sent via 13 miles of three inch buried pipelines to Bilsthorpe railway sidings, where it was retained in a small tank farm comprising of four 500 ton tanks before being measured for royalty purposes. Next the oil was transported by rail to the Lobitos refinery at Ellesmere Port before being sent to Pumpherston refinery in Scotland.[55]

In July 1942 a gas adsorption (secondary recovery) plant was installed at Eakring to convert the 160,000 cubic feet of gas per day into a fuel source for D'Arcy's vehicles and field plant.[56] The system cost £4,600 in total and included 17,000 feet of 1" gas line, 4,700 feet of 2" gas line and 8,000 feet of 3" gas line.[57] The plant was designed to convert 1,000 cubic feet of gas into one gallon of fuel, giving rise to a potential 50,000 gallons per annum.[58] The experimental plant failed to live up to expectations, however. By June 1942 only 366 gallons of casinghead motor spirit had been produced. With no storage capacity on site, D'Arcy issued the majority to the Transport Department having used only a very small amount for its own operations.[59]

According to Southwell (1944), drilling in the Nottinghamshire oilfields was frequently interrupted by air raids, and black out restrictions made night time working extremely problematic. Lighting was provided by four large cylindrical tubes fixed into the corners of the derricks, producing small vertical columns of light, which made it difficult to ensure safe working. The relentless drive for oil took its toll on the drilling crews, who became agitated by a perception of ill treatment by the British. The situation reached fever pitch when the American drilling crews vowed to return to America unless their wartime food rations were increased, to reflect the effort expended in the exploitation of oil (Woodward and Woodward, 2000, pp. 160-165). Tragedy followed animosity when, on the 11th November 1942, 29 year old Herman

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[55] Letter dated 13th June 1942 entitled "crude oil used to drill in wells during the royalty year 1941-1942 (for Area A. 60a licence area). TNA: POWE 33/538.
[56] Letter dated 22nd July 1942 entitled "Gas adsorption plant – Eakring". TNA: POWE 33/1738.
[57] Letter dated 24th July 1942 entitled "Charcoal Adsorption Plant". TNA: POWE 33/1738.
[58] Letter dated 22nd July 1942 entitled "Gas adsorption plant – Eakring". TNA: POWE 33/1738.
[59] Letter dated 13th June 1942 entitled "crude oil used to drill in wells during the royalty year 1941-1942 (for Area A. 60a licence area). TNA: POWE 33/538.

Douthit fell to his death[60] from the top of a derrick (Woodward and Woodward, 2002, pp. 210-212).

Drilling activities placed the village of Eakring in increased danger, necessitating additional wartime precautions. Had Germany been aware of the Midlands fields they would undoubtedly have become the focus of Luftwaffe bombing raids. As discussed by Walker (2000), in February 1941 Lees and Southwell addressed almost 100 residents in Eakring to put forward D'Arcy's plans, emphasising the importance of the Home Guard and arguing that efforts should be directed towards protecting the village and surrounding communities (Walker, 2000). They acknowledged D'Arcy's operations would increase the threat posed to the village, but stressed the company would do what it could to minimise risks. According to the oral testimony of Doug Wallace, the village acquired additional auxiliary Fire Services and fire watchers (including children from the local school, one of whom was Doug Wallace himself), with each house provided with sand bags. Thankfully, Wallace stated, only one stray unexploded bomb landed in the vicinity of the oilfields during World War Two.[61]

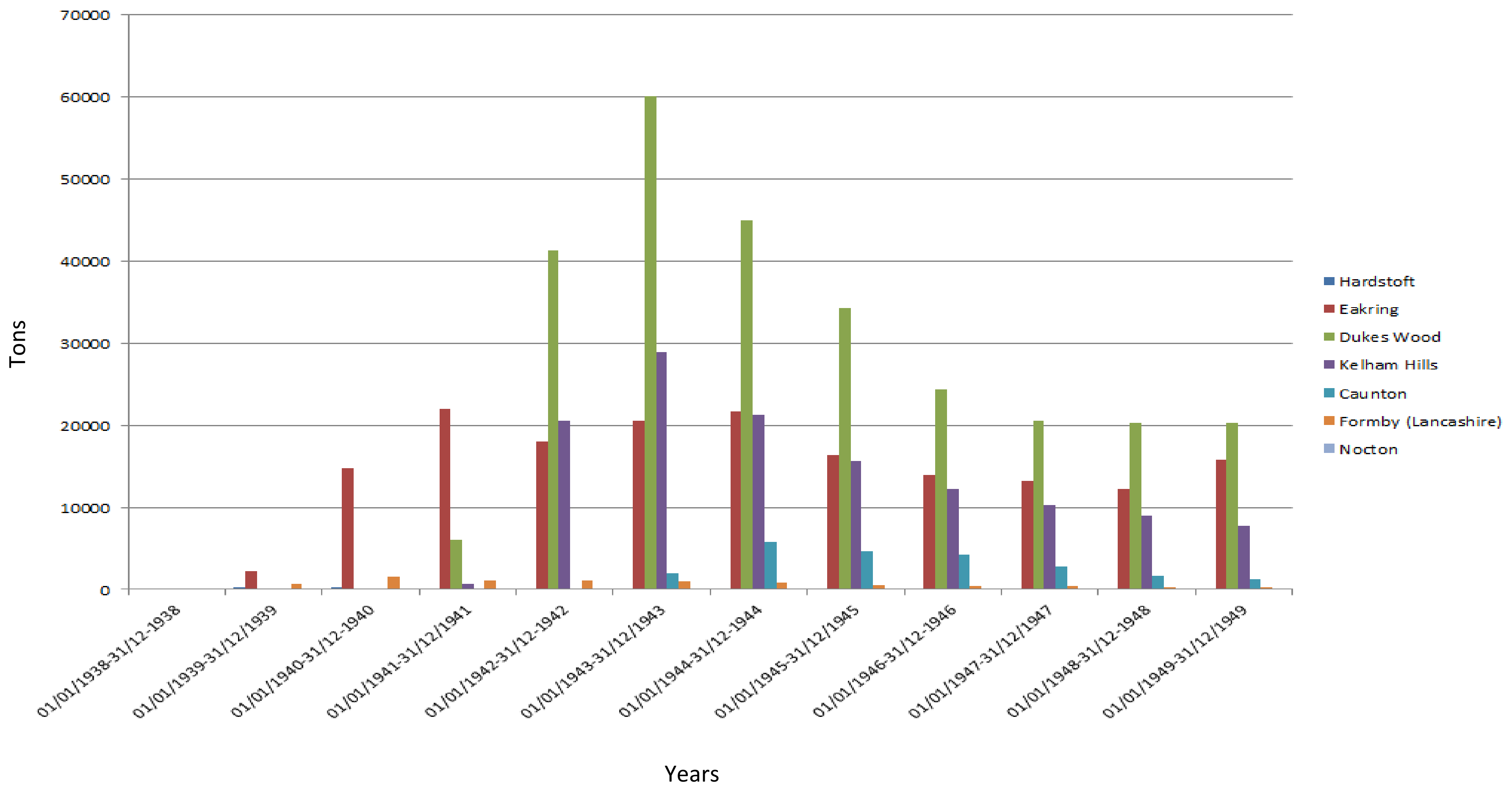
During the summer of 1943 D'Arcy wrote to the Minister of Fuel and Power to ask permission to begin "shooting" some of the wells in order to increase oil output. Well shooting involved placing a "time bomb" at the bottom of the Rough Rock and setting off the charge to fracture the strata. As an example, Eakring Well No. 10 was shot on 4th August 1943 from 1,954 to 1,985 feet with 400 lbs of "polar blasting gelatine", resulting in an increase in production from 2.3 tons to 8-9 tons per day.[62] Well No. 11 was shot on 27th October 1943 from 1,983 to 2,016 feet with 400lb of blasting gelatine, ejecting 350 cubic meters of mud into the air when the shot was fired.[63]

The following production figures show that in 1938, British oil production had stood at only 100 tons, derived solely from Hardstoft No. 1. Formby, in Lancashire, averaged approximately 1,000 tons in each year of the war (DWOM, 2013b, np). With the discovery of Eakring in 1939 British annual oil production increased to 3,145 tons. By 1940 extraction had risen sharply at Eakring, from 2,252 tons in 1939 to 14,855 tons by the end of 1940. Kelham Hills, discovered in 1941, gave a yield of 693 tons by the end of the year. By the end of 1942 annual British oil extraction stood at 81,298 tons – 609,735 US barrels (DWOM, 2013a, np). With the discovery of Caunton and the help of American expertise annual British oil extraction increased to 112,760 tons – 845,700 US barrels in 1943 (DWOM, 2013b, np). Up to 31st

[60] Douthit is buried in the American Military Cemetery, Cambridge, being one of only 33 civilians buried alongside 3780 military dead.
[61] Interview with Mr and Mrs Wallace. Interview conducted at the couple's home in Eakring on 6th February 2011.
[62] Letter dated 8th November 1943 from D'Arcy Exploration Company Ltd to The Secretary for the Ministry of Fuel and Power. TNA: POWE 33/1738.
[63] Letter dated 4th November 1943 from D'Arcy Exploration Company Ltd to The Secretary for the Ministry of Fuel and Power. TNA: POWE 33/1738.

December 1949 the seven British oilfields had cumulatively produced 601,553 tons – 4,511,647.5 US barrels of oil (see figure 6.5).

Figure 6.5: Breakdown of British onshore oil production from January 1st 1938 to 31st December 1949.



Source: *DWOM (2013b, np).*

The Nottinghamshire oilfields had developed amidst some secrecy during World War Two; however, on 19th September 1944 *The Daily Telegraph* stated "to-day Britain has an oilfield in full operation. For security reasons [they] could not give even a hint either of its location of output, [however they could say] the development of the field has reached a point at which production is sufficient to keep a sizeable bomber fleet in the air".[64] The reporter explained how he had spent two days being shown around the oilfields, seeing the "broad steel arms of pumps…dipping and bending over the wells sunk on what was, until 1939, rich farmland".[65]

On 23rd September 1944 *The Times* reported that the oilfield was still a closely guarded secret. However, it revealed 100,000 tons, or 26 million gallons of oil had been produced from 238 wells during the year, compared with only 238 tons of oil during September 1939.[66] Over the course of the war, the oilfield, manned by over 1,000 men travelling from neighbouring towns, had been provided with hot meals day and night to enable them to extract 78,000,000 gallons of oil. *The Times* acknowledged that the production was small when compared to the 568,000,000 gallons of oil imported during 1938, and less still given wartime demand, "nonetheless it deserves celebration as one…example of thoroughness and decision in the pursuit of victory".[67] Today, the wartime efforts of the British and American workforce is recognised by a statue named the "Oil Patch Warrior", which stands close to Dukes Wood Oil Museum, and within meters of an original nodding donkey (see figure 6.6).

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[64] The *Daily Telegraph*, 19th September 1944 entitled "Britain has 300 oil wells in production". TNA: POWE 33/1738.

[65] The *Daily Telegraph*, 19th September 1944 entitled "Britain has 300 oil wells in production". TNA: POWE 33/1738.

[66] *The Times*, 23rd September 1944. "English oil: 100 tons a year from 238 wells". TNA: POWE 33/1738.

[67] *The Times*, 23rd September 1944. "English oil: 100 tons a year from 238 wells". TNA: POWE 33/1738.

Figure 6.6: Standing in front of the "Oil Patch Warrior" with Kevin Topham (left) and Doug Wallace (right). The statue was erected in honour of the 44 American rough necks (listed on plaque), who significantly increased oil production in the Nottinghamshire oilfields during World War Two.

Source: Takumi Sekiguchi Sloan, June 2010.

Closer to the oilfields, The *Sheffield Telegraph* argued that the secret of Britain's oilfield had been so well kept that few people were aware of the interesting developments on the borders of the city's area of influence. It stated, "The field has supplied our home-based bombers with all the "juice" needed for major raids in Germany".[68]

Geoffrey Lloyd and AIOC Chairman Sir William Fraser (later Lord Strahalmond) invited Fleet Street journalists to inspect the fields (see figure 6.7). Geoffrey Lloyd announced "This oilfield, like Britain, is small but of the highest quality. It yields the whole range of refinery petroleum products" (DWOM, 2013b, np). The company slogan for the Midlands oilfields "Milk and oil from the same field" reflected the rurality of the region (see figure 6.8). Geoffrey Lloyd stated "This secret oilfield came into operation just when we needed every ton of oil to carry us through the crisis of the war. These were supplies which the U-boats could never sink!"[69] The *Sheffield Telegraph* stated there were, "over a stretch of farmland two miles

[68] *The Sheffield Telegraph*, 11th November 1944 "Notts. oil fuels big RAF raids". TNA: POWE 33/1738.
[69] *The Times*, 23rd September 1944. "English oil: 100 tons a year from 238 wells". TNA: POWE 33/1738.

long by half-a-mile broad, scores of pumps, standing about seven feet high and operated by silent electric motors, working at intervals of every few hundred yards. From a distance they look like animated donkeys. There is no forest of unsightly derricks to disfigure the countryside, and cattle graze among the wells".[70]

Southwell was interviewed by a reporter for the *Derby Daily Telegraph* (9th December 1944, p. 1) and stated that over 750,000 feet of drilling (140 miles) had taken place at Eakring, spread across 390 wells, with 250 yielding oil, giving rise to a cumulative total of 325,000 tons (2.25 million barrels) during the war years. The *Nottingham Evening Post* (11th November 1944, p. 1) added that the fields were the largest ever found in Britain, asserting "scientists are trying to find the central oil reservoir – believed to be 50 square miles – from which the Eakring "tapping" is derived".

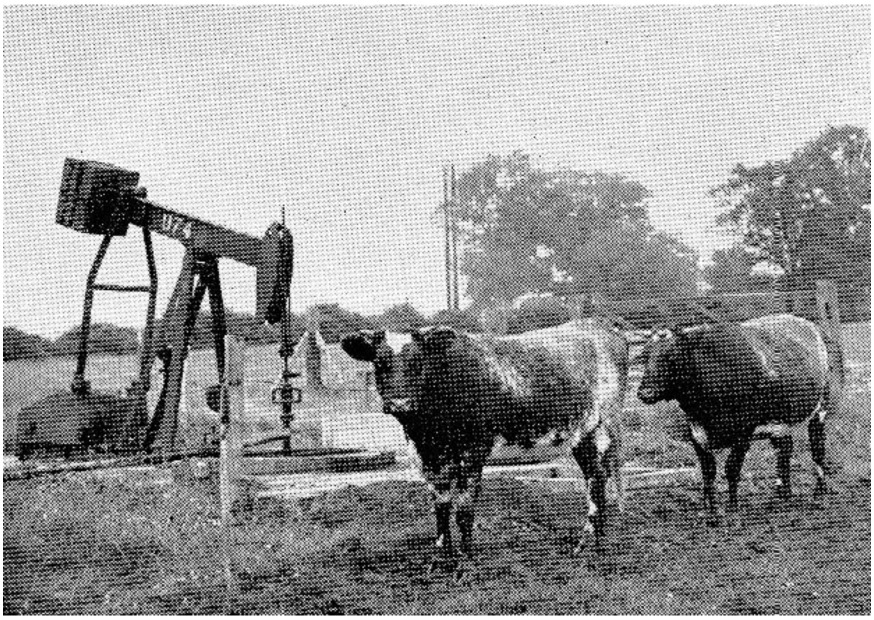
Although the Nottinghamshire oilfields were an extremely significant wartime measure, which helped avert oil castration, this was very much a commercial venture. For example, MAPs increased year on year as oil output rose across the four fields. From 22nd April 1939 to 21st April 1940 D'Arcy paid £846.9.5 on 4,494.8 tons of domestic oil, charged at 4d per ton of oil. In the period 1st January 1944 to 1st January 1945 the company paid £12,795.17.8 in royalties across the four fields.[71] In the year commencing 1st January 1946 D'Arcy also paid an advanced fifth year MAP of £984.10.3.[72]

[70] The *Sheffield Telegraph*, 11th November 1944 "Notts. oil fuels big RAF raids". TNA: POWE 33/1738.
[71] Letter dated 18th March 1946 from D'Arcy Exploration Company Ltd. TNA: POWE 33/1738.
[72] Letter dated 5th March 1946. TNA: POWE 33/1738.

Figure 6.7: BP Chairman Sir William Fraser (right) and Geoffrey Lloyd (left) inspect a nodding donkey in the Eakring oilfield.

Source: *BP (1944, p. 3).*

Figure 6.8: Depicting the BP slogan "Milk and oil from the same field!"

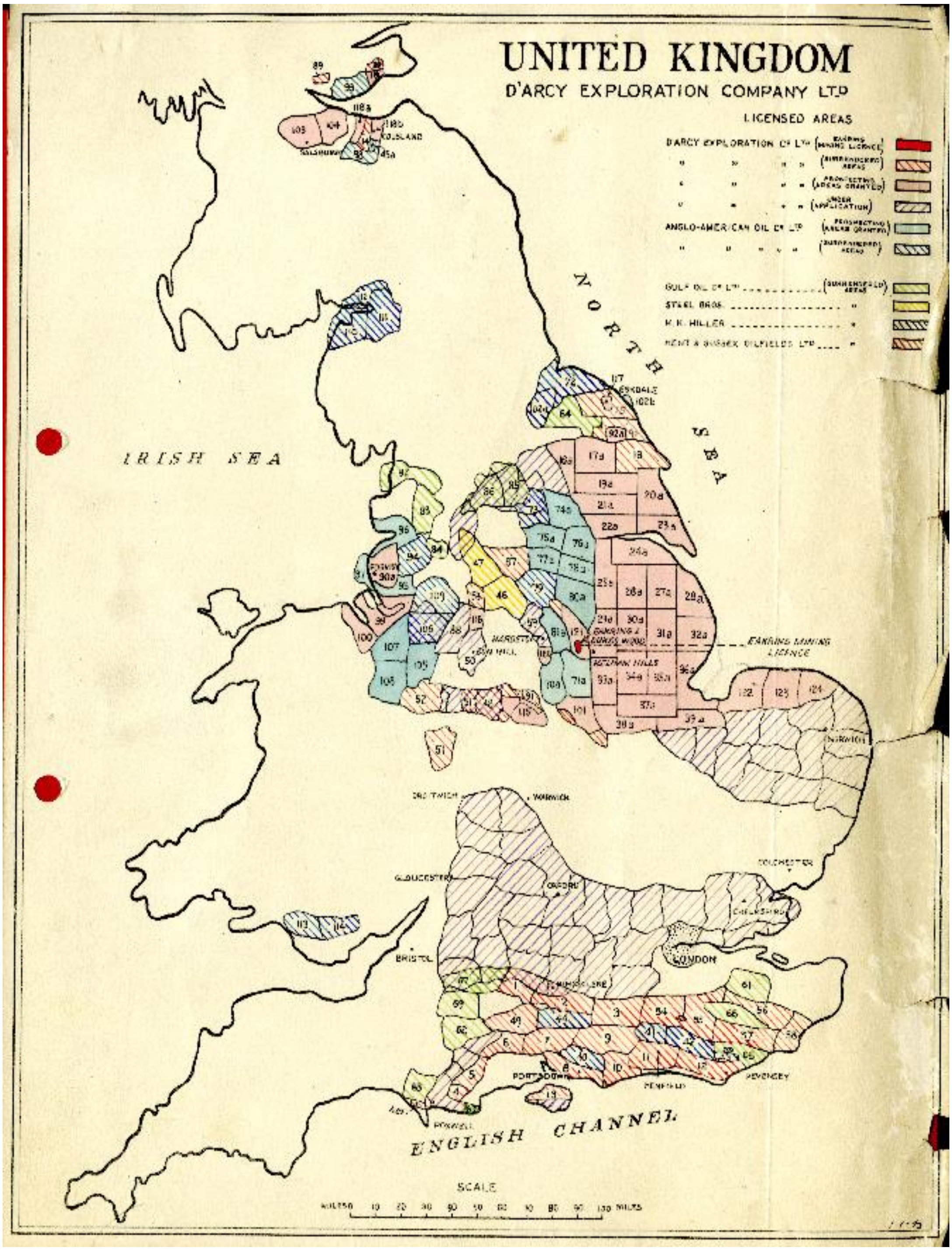


Source: *Southwell (1944, p. 11).*

By January 1st 1945 the surface of Britain had been divided into a patchwork mosaic of prospecting agreements and the single Eakring mining licence (see figure 6.9). The four principle companies, D'Arcy, AAOC, Gulf and Steel Bros, and two smaller concerns - H. K. Hiller and the Kent and Sussex Oilfields Ltd - had delineated the surface of the UK into two large blocks and three smaller units, each thought to have petroliferous potential. Such was the rate of development that by 1945 a number of licences had been surrendered on the grounds the areas they covered offered no potential for oil or gas.[73] Conversely, several new areas were under application for prospecting licences on the grounds that new technologies and freshly interpreted geographical and geological data was giving rise to new potentialities.[74] Drilling activities had produced a heavily punctuated subsurface geography, yielding geological data that added a third dimension to the Britain's territories.

[73] Report entitled "Memorandum to the finance committee D'Arcy Exploration Company Ltd – estimates 1940 23rd September 1940" written by J. A. Jameson BPA: ArcRef 44199.
[74] Report entitled "Memorandum to the finance committee D'Arcy Exploration Company Ltd – estimates 1940 23rd September 1940" written by J. A. Jameson BPA: ArcRef 44199.

Figure 6.9: Britain's hydrocarbon cartographies as of January 1st 1945. Note single mining licence – Eakring Area A. 60.



Source: *Andrew Naylor, April 2012. From: BPA: ArcRef 44191.*

6.5 Post-war Eakring: scientific innovation in oilfield development

Across the four Nottinghamshire oilfields, reservoir pressure initially averaged 1,000 psi. However, following a prolonged period of extraction, pressures fell to 360 psi at Eakring and 100 psi at Kelham, leading to edge-water encroachment (BP, 1956). As a result D'Arcy investigated secondary recovery techniques to sustain production, including water injection and intensive well shooting. These systems were pioneered in America and were leading to marked increases in oil output.

In 1947 a pilot water flooding scheme was undertaken at Eakring. This involved injecting 10,000 gallons of water beneath the oil-water level into the low permeability Rough Rock (sandstone) strata. At the edges of the oilfield the anticlines thinned dramatically, meaning oil would be forced towards the central extraction zones under hydrostatic pressure. Two wells were drilled; one in the oil-producing zone and one 800 feet away on the periphery, acting as an observation well (Dickie and Adcock, 1954). The volume of water was too small to have a noticeable impact on oil production levels. However, the test proved the injected water would migrate laterally, despite the heavily fractured local geology (Dickie and Adcock, 1954). The pilot scheme was viewed as a success and D'Arcy subsequently designed the UK's first large scale water injection scheme.

Water accounted for 75% of the overall fluid production levels at Eakring and occupied 50% of the total pore space (BP, 1956). Not all of the water could be extracted from the oil before it entered the royalty tanks, giving rise to a mixed fluid volume. The Petroleum (Production) Act 1934 defined crude oil as "oil in its natural state before the same has been refined or otherwise treated but excluding water and foreign substances". Oil was clearly divorced from water as a separate liquid, therefore should not have been subjected to royalty payments. However, oil from the four Nottinghamshire oilfields often contained a fraction of water in suspension, which settled to the bottom of the storage tanks and was periodically drawn off.

In tests conducted earlier in 1940 it was found that 1.5% (360 tons) of the fluid volume from Eakring was water, which equated to £70 in royalties.[75] D'Arcy chose not to question the additional charges, though on 22nd May 1941 Maurice Richard Bridgeman[76], the Under Secretary for Petroleum raised the issue arguing it was "unreasonable to expect the Licensee (D'Arcy) to pay royalty on water [especially] when we are urging the company to produce oil

[75] Letter dated 22nd May 1941 from M. R. Bridgeman entitled "Petroleum (Production) Act 1934. Measurement of Crude Oil for Royalty. Deduction of water present in Crude. TNA: POWE 33/538.

[76] Bridgeman was petroleum advisor to the Minister of Economic Warfare from 1939 and Principal Assistant Secretary to the Minister of Fuel and Power from 1944-1946. He became chairman of BP from 1960-1969. He was honoured as Commander of the Order of the British Empire in 1946 and as a knight Commander in 1964 (Slinn, 2004).

as quickly as possible".[77] Bridgeman put it to the Secretary for Petroleum that, despite a possible lack in clarity in the definition of crude oil, water be excluded from royalty payments. The Petroleum Department subsequently informed D'Arcy that no royalty would be paid on the "combined water" fraction of the total fluid volume in the future. As reservoir pressure fell, so too did oil production. For example well No. 151 fell to 0% oil, 100% water production by November 1945.[78]

Dickie and Adcock (1954), argued that by November 1945 a "closed system" pumped recycled water separated from the oil during the extraction phase back into the producing field. Fresh water "back up" wells were then drilled into the Bunter sandstone to a depth of 500, providing an additional supply of water. The system utilised four pumps (two at Eakring, two at Dukes wood) formerly used to pump oil under the channel from Britain to France during World War Two. The PLUTO pumps were not considered wholly suitable as they utilised dated World War Two technology. However, they enabled the scheme to advance one year ahead of schedule. Water flooding commenced at Eakring in 1948, Dukes Wood in 1949 and at Kelham Hills towards the end of 1951 (Dickie and Adcock, 1954).

In the summer of 1947 D'Arcy also began an intensive well shooting programme. Using time delay bombs loaded with up to 400 lbs of explosives, they fractured the Rough Rock sandstone to allow the oil to flow more freely (BP, 1956). Well shooting aimed to increase the commercial viability of the oilfields and avoid having to abandon wells when infrastructure was already in place. D'Arcy contacted the Ministry of Munitions in June 1947 with a list of wells earmarked for well shooting. By November 1947 it had set off time bombs in wells 70, 75, 76 and 122 and requested permission to shoot wells 71, 73, 115, 116, 133 and 136 from January 1947 to December 1948.[79] The scheme doubled oil production and conferred a secondary benefit insofar as it increased the capacity of water injection wells. By 1953 water injection accounted for an additional 91,000 tons of oil across the three fields.

At Kelham Hills, production increased three fold, giving an overall yield of 27,000 tons. Dickie and Adcock (1954, p. 182), argued that "using only primary recovery techniques oil production would have fallen from ten tons per day per well to 0.5 tons per day per well by 1953". The economic advantages were justified on the basis that fifteen injection wells, costing the equivalent of twenty four production wells gave a yield of 91,000 tons, compared with 4,000 tons using primary recovery techniques for the equivalent twenty four wells. By 1953 the AIOC had injected 365,000,000 gallons of water into the Nottinghamshire oilfields at an average rate

[77] Letter dated 22nd May 1941 from M. R. Bridgeman entitled "Petroleum (Production) Act 1934. Measurement of Crude Oil for Royalty. Deduction of water present in Crude. TNA: POWE 33/538.
[78] Letter dated 12th November 1945 from G. W. Lepper to A. H. Taitt. TNA: POWE 33/1738.
[79] Letter dated 28th November 1947 from W. Woodcock, Manager, U.K. drilling and production for D'Arcy Exploration Company Ltd to The Secretary of the Ministry of Munitions. TNA: POWE 33/1738.

of 283,000 gallons per day.[80] Overall, the secondary recovery systems were deemed a success, with economic returns offsetting the initial investment and running costs.

Successes in the East Midlands created a temporary feeling of elation for the AIOC. Lees and Taitt (1945, p. 279), remarked "the discovery of these four oilfields encouraged the belief that the extensive area to the east, north-east and south-east might contain other oil accumulations governed by similar structural and stratigraphical conditions". They stated that following further exploration, D'Arcy staff found that oil conducive structures extended in a 35 mile radius of Eakring, leading many to believe the success of Eakring could be repeated (Lees and Taitt, 1945). Despite drilling 37 wells on 20 anticlines or other potentially viable trap structures, and revising geophysical methods, only one well, Nocton No. 2, six miles south-east of Lincoln produced a small quantity of oil (Lees and Taitt, 1945).

Peter Kent stated that following World War Two the Eakring Geological Department was managed by M. W. Strong, "a mathematician, who became obsessed with the adverse success ratio of exploration and felt progressively unable to make any recommendations for drilling".[81] As a consequence, "under this incubus the exploration programme came to a complete halt…it was only after he left that we were able to…restore normal activity".[82]

Developments in geophysical surveying techniques revived the search for domestic onshore oil in the 1950s, resulting in a flurry of drilling activity and the discoveries of Plungar (1953), Egmanton (1955), Bothamsall and Corringham (1958), Beckingham and Gainsborough (1959) (at Gainsborough slant drilling techniques were employed to access oil situated directly underneath the village) Apleyhead and South Leverton (1960), Torskey (1962), and small finds at Langar, Trumfleet and Tuxford (Huxley, 1983). These discoveries added to a growing literature on deep regional subsurface geographies, in particular pre-Mesozoic geology and the Jurassic (Lees and Taitt, 1945; Falcon and Kent, 1960; Kent, 1966).

Post-war, the AIOC adapted the Nottinghamshire oilfields to become research and development sites, attracting large numbers of oilfield workers, who had a significant impact on the social development of Eakring and the surrounding towns and villages. Vital infrastructure, for example, altered the rural fabric of the landscape. Mr Doug Wallace recalled how D'Arcy:

"[changed the village of Eakring] entirely, I mean, when I was a child of six or seven...there was no electricity in this village, there was no mains water. All the water that you had was drawn up from wells, these artesian wells...I can remember electricity being laid on; I

[80] Under Section 6 of the Water Act, 15th June 1945 (Abstraction Regulations 2342/47) D'Arcy had to provide records of any well capable of yielding over 50,000 gallons of water per day, including details on quantity and quality to the Geological Survey and Museum.
[81] Deep exploration in Eastern England. HLUNMSC: 43.5.93/A.10 1950s. p. 4.
[82] Deep exploration in Eastern England. HLUNMSC: 43.5.93/A.10 1950s. p. 4.

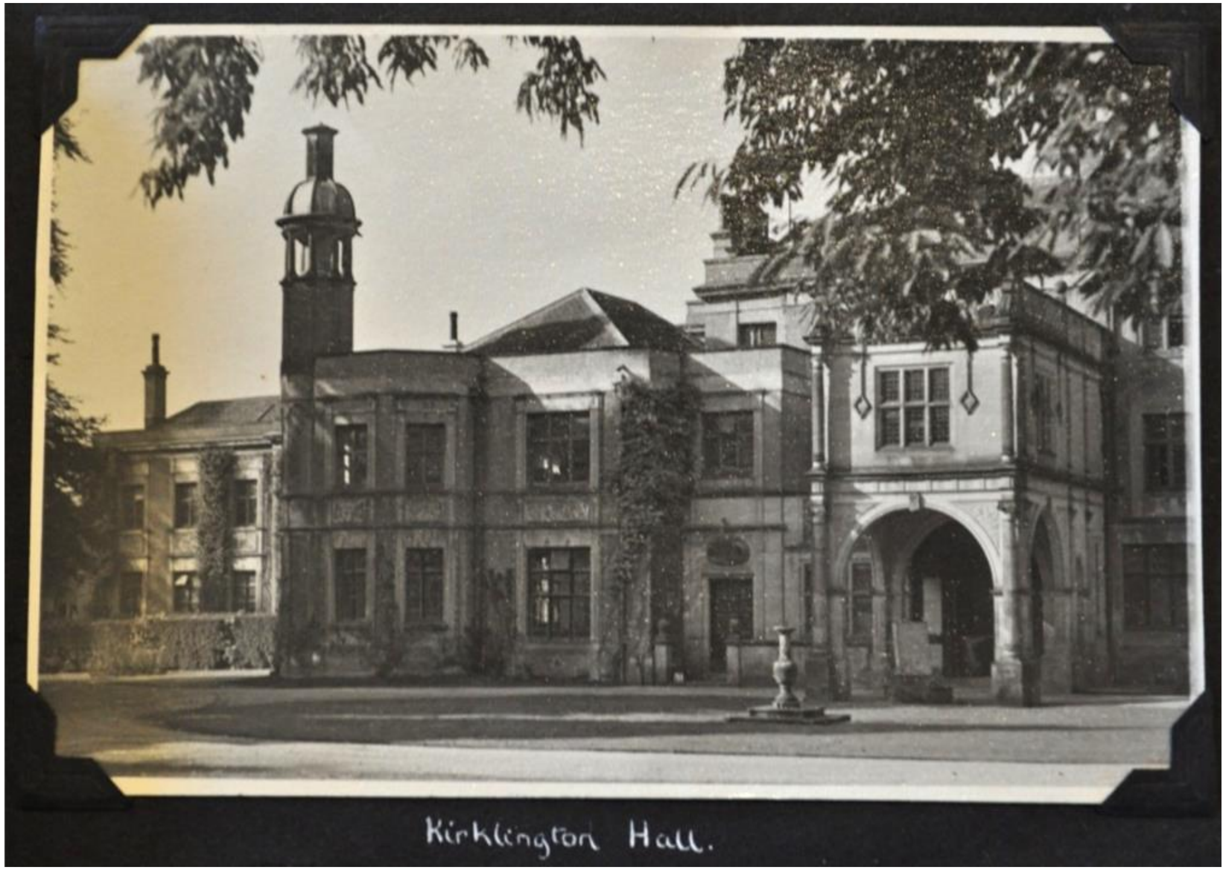
can remember water being laid on. All these things came fairly quickly after they found the oil".[83]

D'Arcy's modernisation was swift as they began to install an extensive infrastructure network. The development of the fields also had a wider benefit for British manufacturing, which took over the production of oilfield machinery. Back in 1942 D'Arcy purchased Kirklington Hall (see figure 6.10) 17 miles north west of Nottingham, following the death of its former owner Lady Robinson[84], whose family had resided in the hall for centuries (Kempson, 2006). AIOC reconfigured the former residence into its UK Research Station, serving as a global centre of calculation for hydrocarbon exploration.

Jack Birks, a geophysicist employed at Kirklington Hall spoke to *The Telegraph* (2001, online) and revealed that in 1948 "petrol was two shillings a gallon and the company was restoring its fortunes after the damage inflicted by the war". In Iran and Iraq, exploration and production efforts were increasing, while Kuwait had come on stream in 1946. A decision had been made by the Anglo-Iranian Oil Company to transfer the science and technology which had been developed over the past 30 years, from Masjid-i-Suleiman in Iran to a base in the UK, as it was anticipated that a political crisis would develop in Iran. This crisis was, according to Kinzer, largely due to a feeling of ill treatment by the Iranians (Kinzer, 2008). Iran felt exploited by the unequal distribution of profits, as well as "anti-Iranian discrimination in the AIOC's employment policies" (Abdelrehim, *et al*., 2009, p. 2). Consequently the Iranian Parliament (the Majlis) voted to nationalise the AIOC in 1951 (Kinzer, 2008) Following its withdrawal from Iran, the AIOC dispersed the majority of its staff to oilfields in the Persian Gulf. However, some returned to Britain and were channelled into Kirklington Hall Research Station, where they formed a specialised global oilfield development unit. By the late 1950s the workforce had grown to approximately 1,200.[85]

[83] Interview with Mr and Mrs Wallace. Interview conducted at the couple's home in Eakring on 6th February 2011.
[84] Lady Robinson reared Aberdeen Angus cattle at Kirklington Hall, and was related to Jesse Boot, who established the British high street brand "Boots".
[85] Interview with Mr Mitchell. Interview undertaken at Mr Mitchell's home in Mansfield on 14th February 2011.

Figure 6.10: Kirklington Hall Research Station in 1953.



Source: *Kindly reproduced from a private collection owned by Sivyl Wallace.*

Doug Wallace joined the AIOC in 1948, working in the D'Arcy production section. His first job was collecting waxed up pipes in the Nottinghamshire oilfields, which was "quite a menial task – to go and fetch these pipes on lorries and bring them back to BP (D'Arcy Exploration Company Ltd) where they were dewaxed…that just meant super-heated steam. They were put in a huge long oven and dewaxed. [Following this] they could go back to the well they came from. And this was all on what they called production. There was production...carpentry...drilling and estates, they were the majors".[86] Wallace was frequently asked to visit well sites, elucidating "now at one time I knew where every number (well number) was between Eakring, Dukes Wood, Kelham and Caunton...Somebody would say I want you to go to No. 39s or No. 49s...and I could go straight there no problem...I got all that experience in my head from working in production".[87]

Mr Ivan Mitchell, who now lives in Mansfield, Nottinghamshire, began working in Eakring and the surrounding oilfields in 1944. Before D'Arcy he worked at Meadow Foundry, Mansfield, Nottinghamshire, turning valve seatings for motor torpedo boats. His employment ceased on medical grounds when he was recommended to seek outdoor work. Mr Mitchell explained that at Mansfield job centre he was told "they want some rig men at Eakring".[88] At the age of 17 he worked in the geological laboratory washing samples. At 18 he moved to de-waxing oil pipes. He remarked:

"Well the Yanks had done these wells 18 months before that and they were getting waxed up as they had a high concentration of wax. We would go over and clean everything out…I did Eakring, Dukes Wood [and] Kelham. [At Eakring] there were dozens of lorries and banter…Yanks flying about on winch trucks and tanks flying about – thousand gallon tanks wafting about!"[89]

Mr Mitchell was posted to Sawley on the Yorkshire Moors, six miles south west of Ripon in 1945. No oil was found in the locality and he was subsequently sent to Weymouth near Lulworth Cove.[90] Following military service he continued to undertake numerous postings throughout the UK, including Plungar and Egmanton. Next he supervised a drilling team at

[86] Interview with Mr and Mrs Wallace. Interview conducted at the couple's home in Eakring on 6th February 2011.
[87] Interview with Mr and Mrs Wallace. Interview conducted at the couple's home in Eakring on 6th February 2011.
[88] Interview with Mr Mitchell. Interview conducted at Mr Mitchell's home in Mansfield on 14th February 2011.
[89] Interview with Mr Mitchell. Interview conducted at Mr Mitchell's home in Mansfield on 14th February 2011.
[90] Interview with Mr Mitchell. Interview conducted at Mr Mitchell's home in Mansfield on 14th February 2011.

Bathgate in Scotland and subsequently Bothomsell, Winchester[91] and Whitby, where the drilling team encountered gas.

In Eakring, the D'Arcy workforce was having a marked effect on the social fabric of the village as people of all nationalities found temporary accommodation with local residents. Many rented accommodation, generating revenue for the village. Mr Wallace's wife, Sivyl, who he met in Eakring as a child, recalled how her mother had seven lodgers at one point; "they didn't mind what kind of accommodation it was so they were sleeping in attics and this sort of thing. Nearly every house in the village had some kind of income from lodgers or tenants. Our front room where I lived...was occupied by a young couple...he worked in the offices. Of course, he bought his wife with him and they just lived in the one front room and can you imagine it! To get to their accommodation they had to walk through our kitchen. We didn't think anything about it".[92]

One oilfield worker, Tool pusher Ivan Priest, named the local workforce the "Mansfield Mafia", in recognition of the diverse array of characters and their sometimes unruly ways.[93] Mr Wallace stated:

"There were lots of settings on and sackings...it just went on daily I think… [there were] a hell of a lot of people - they employed people from Egmanton, Caunton and all the villages around. It was surprising the number of people that came out of the mining industry. On my crew I had about three that had already been in the mining industry. They were just the right people for the industry...they have no airs or graces...they were there to do a job".[94]

Following the war oilfield workers undertook eight hour shifts. Free transport was provided by 17 reserved double decker buses which would take them to and from the D'Arcy production headquarters at Eakring. Mr Mitchell recalled "down at Mansfield at St Peter's Church…20 or 30 blokes [would] be waiting down there to get picked up and taken to Eakring. There were pipe work labourers, erection gang - people who erected rigs".[95]

Mr Kevin Topham, born in 1926, worked at the Eakring Research Station during the 1950s and 1960s. He joined the AIOC at Kirklington Hall in the early 1950s following six years in the RAF. He was employed initially as a fitter mechanic at the D'Arcy workshops before transferring to drilling, where he became a "derrick man", which saw him and his crew drill in 28 UK counties, 26 in England and two in Scotland. He worked alongside numerous eminent

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[91] The drilling was to examine the possibility of gas in the green sand found there. Five wells were drilled here on behalf of the gas council.

[92] Interview with Mr and Mrs Wallace. Interview conducted at the couple's home in Eakring on 6th February 2011.

[93] Interview with Mr and Mrs Wallace. Interview conducted at the couple's home in Eakring on 6th February 2011.

[94] Interview with Mr and Mrs Wallace. Interview conducted at the couple's home in Eakring on 6th February 2011.

[95] Interview with Mr Mitchell. Interview conducted at Mr Mitchell's home in Mansfield on 14th February 2011.

scientists including marine biologist/deep sea-oceanographer Dr Tom "Tommy" Gaskell, Jack Birks and Chief Geophysicist Dr Donald Thomas Germain-Jones who worked in D'Arcy's laboratories. He returned to drill in the Midlands oilfields from 1964 to 1965, after which he was transferred to North Sea exploration, which was driven by geophysicists like Dr Germain Jones. According to Topham, following the war:

"A number of personnel came from Bletchley Park to Kirklington Hall....when Bletchley finished, there you see there was nothing really for the clever professors and that to do, so they came here, and joined the petroleum industry, and they did very well. There was Jack Birks who I worked under – he ended up as supremo for BP in New York...In the oil industry you have got physicists and geologists and you have the same personnel at Bletchley probably doing a different job but the same principle".[96]

D'Arcy's Eakring headquarters grew into a thriving community. Sivyl Wallace worked at Kirklington Hall from 1948 to 1962, acting as seismic expert Dr Germaine-Jones' secretary. She recalled "it was a lovely setting down there, it was like a family".[97] Sivyl was one of a number of secretaries responsible for typing up draft field reports. She also worked under geophysicists Dr Veovech and Dr Tomaschek, preparing reports as they poured in from all over the world. Ironically, as a secretary to the AIOC's field scientists Sivyl often typed reports (see figure 6.11) for areas her husband Doug would later drill. She recounted "I'd never heard of a lot of the places as these reports came in....and then [they] became sort of familiar then because you were sort of dealing with new things coming in".[98]

Sivyl's familiarisation with emerging fields mimicked a societal understanding of global oil exploration and world economics in Britain as the sites became economically viable. Interestingly, despite the sensitive nature of the reports she was not asked to sign any confidentiality clauses. Sivyl recalled how two employees, Dr Pip Threadgold and Dr Ben Noble were frequently seconded to Schlumberger headquarters in France, collaborating on new techniques and technologies for oilfield exploration, some of which were tested in the Nottinghamshire oilfields.

In one study, scientists attempted to apply geochemical prospecting methods to investigate how the structure of the subsurface and associated discontinuities affected the migration of oil through the caprocks (Evans, *et al.,* 1962). From Kirklington Hall D'Arcy developed the echo meter, which was field trialled at Eakring. This lorry-mounted apparatus measured well depletion by generating sound waves which reflected off the underlying fluids

[96] Interview with Mr Kevin Topham. Interview conducted at Dukes Wood Oil Museum on 26th February 2011.
[97] Interview with Mr and Mrs Wallace. Interview conducted at the couple's home in Eakring on 6th February 2011.
[98] Interview with Mr and Mrs Wallace. Interview conducted at the couple's home in Eakring on 6th February 2011.

(BP, 1956). Visiting scientists were housed at Saracen's Hotel, King Street Southwell, five miles south east of Kirklington Research Station. One such scientist/engineer was Sir Frank Whittle, who developed a novel drilling system using his turbo principle.

Figure 6.11: Sivyl Wallace (left) typing one of many field reports which flooded into Kirklington Hall affirming its pivotal role in global oil exploration.

Source: *Kindly reproduced from Mrs Sivyl Wallace's private photograph collection.*

6.6 Frank Whittle's turbo-drill: attempting to revolutionise oilfield development

Frank Whittle, famed as the inventor of the jet engine, was appointed as Specialist in Mechanical Engineering with N.V. de Bataafsche Petroleum Maatschappij (BPM), one of the principal operating companies in the Royal Dutch/Shell Group in August 1953.[99] Here he would act as a "catalyst" or "spark-plug", bringing fresh ideas to the Engineering Department.[100] His principal duty became work on his novel concept, the W.1 turbo-drill; a self-propelled contra-rotating downhole motor inserted between the gear box and drill bit driven directly by the drilling mud pumped down into the advancing borehole, which avoided the need to rotate the drill pipe at the surface.[101]

[99] The previous year Whittle completed his book "Jet: The Story of a Pioneer".
[100] Letter dated 21st April 1960 to C. C. Williams. CACCC: WHTL 338-B. 1959-1964.
[101] Author unknown. Report entitled "Note on a proposed turbo-drill for oil well drilling". Dated 14th September 1959. CACCC: WHTL 339-B. 1959-1964.

Conceived in 1924 by a Russian named Kapeluchnikoff, by the 1950s Russia was claiming to use turbo-drills for 85% of their drilling using multi-stage direct drive turbines.[102] Turbo-drills offered a number of advantages over conventional methods, including increased bit and greater rotational speeds (combined facilitating higher Rate Of Penetration (ROP)), reduction in wear on drill pipes and casings (which in turn reduced the propensity for twist offs and thus costly fishing jobs) and a greater level of control at the surface. The disadvantages included high capital expenditure in their development, high unit costs against a relatively short life span, an inability to control the speed of the drill from the surface and a lack of drill bits capable of withstanding the wear brought about by high operational speeds.

Under project name W.1, Whittle's small team developed a "multiple ram" (British Patent No. 755,207) which responded to pressure and turbine speed differentials, increasing the weight on the bit if the turbine speed increased and decreasing bit weight as speed decreased. The turbo-drill had two rotors – one low speed (500 rpm), the second high speed (3,000 rpm).[103] As a result of its novel design, it was possible to carefully monitor the effects at the bottom of the borehole from the surface. The overall effects included reduced wear on casings, drill string joints, reduced fuel consumption, greater direct power and greater control–which in turn meant the ability to deviate the drill string.[104]

In September 1959 Sir Arnold Hall, Managing Director of Bristol Siddeley Engines Limited (BSEL) and Dr S. G. Hooker, Technical Director (Aero) of Bristol Siddeley Aero Limited (BSAL) took an active interest in Whittle's project and entered into a formal agreement with him in November 1962.[105] According to Whittle the group subsequently formed Bristol Siddeley Whittle Tools (BSWT) which would act as the commercial front end of the project, reserving the sole right to lease Whittle's drill to contractors/operators.[106] Whittle became Director and Deputy Chairman of BSEL, assigning licence rights so that it was able to design, develop and manufacture the drill. Whittle was also the Director of a third company, Chagford Investments Limited which had a 30% stake in BSWT.[107] A prototype turbo-drill was built at the BSEL plant for laboratory testing to verify whether the gearbox mechanism could transfer the necessary power to the bit.

[102] Author unknown. Report entitled "Turbo-drilling – Manufacture and exploitation: A tentative assessment of the potential business in the event of successful development (Revised)". Dated 22nd April 1961. CACCC: WHTL 341-B 1959-1968.
[103] Conventional rotary methods typically operated at around 60-120 rpm. Pamphlet produced by Bristol Siddeley entitled "The turbo-drill". Date unknown. CACCC: WHTL 341-B. 1959-1968.
[104] Author unknown. Report entitled "Note on a proposed turbo-drill for oil well drilling". Dated 14th September 1959. CACCC: WHTL 339-B. 1959-1964.
[105] Author unknown. Report entitled "Turbo-drill – Bristol Siddeley". Dated 15th March 1961. CACCC: WHTL 340-B.
[106] Author unknown. Report entitled "Turbo-drill: A general review – October, 1969". CACCC: WHTL 378-B. 1969-1972.
[107] Report entitled "Turbo-drill: A resume of drilling trials to July 1964 by Air Commodore Sir Frank Whittle, K. B. E. , C. B., F.R.S". Dated 28th August 1964. CACCC: WHTL 482-B. 1951-1988.

Aware of BP's Research Station in Eakring, Nottinghamshire, Sir A. Hall selected Egmanton, Nottinghamshire (six miles north east of Eakring) to be the first test site for Whittle's turbo-drill. Using BP's T.20 drilling rig the first test was undertaken at well No. 66 on 13th March 1963.[108] Only one hour of turbo-drilling was achieved due to a coupling bolt failure, however, it was sufficient to verify the concept had potential. Field trials were subsequently moved to Eakring, with Whittle based at Kirklington Hall Research Station. However, being an active, pressurised oilfield, drilling was limited to a depth of 1,500 feet. Torque levels only became sufficient to operate the drill's turbo at 200 feet; therefore Whittle only had 1,300 feet in which to test the drill's operational capabilities in the field.[109] The Eakring trials were undertaken from 2nd August 1963 to 16th July 1964 and cost approximately $86,000.[110] Eight boreholes were drilled, giving a cumulative depth of 10,500 feet in a total drilling time of 106 hours.[111]

Whittle's turbo-drill attracted the attention of scientists at Kirklington Research Station who could see its practical application in deep drilling. Oceanographer Dr T. F. Gaskell alerted the Brown and Root Company who had been appointed the main contractor for Project Mohole. The project involved drilling several shallow and intermediate wells before proceeding to pierce the earth's crust to extract samples from the boundary between the earth's crust and the mantle, named the Mohorovičić discontinuity (located at a depth of 20-90 kilometres beneath most continents and 5-10 kilometres beneath the ocean floor averaged 35 kilometres globally) after Croatian seismologist Andrija Mohorovičić who identified the zone in 1909 under the Balkan mountains (Hekinian, 2014, p. 31).

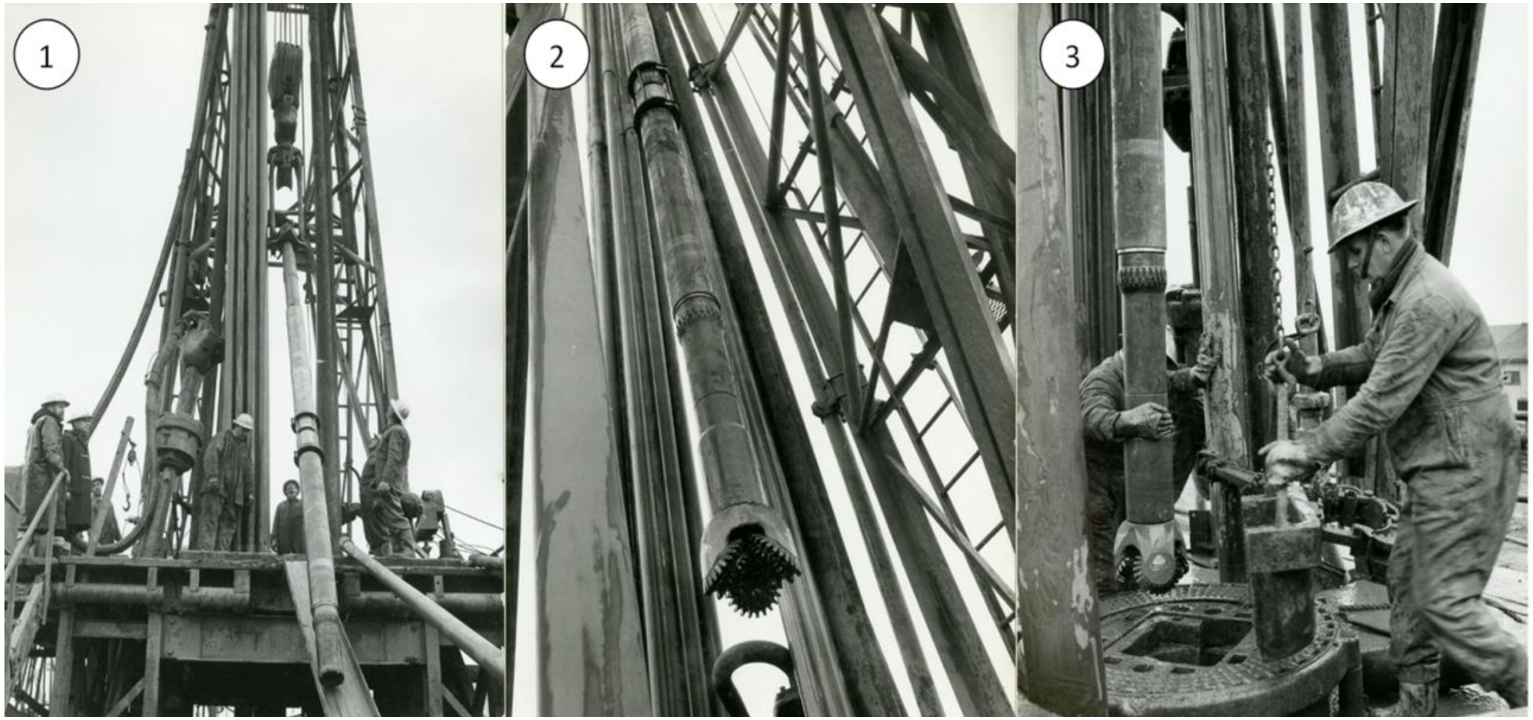
Mr William E. Benson, Head of Earth Sciences Section Mathematical and Physical Sciences Division wrote to S. W. Mansell of Bristol Siddeley stating he was very interested in perusing the turbo-drill for its use in Project Mohole, asserting the company had "made excellent progress in developing [the] equipment into a serviceable and practicable tool".[112] According to the Toye (2000, p. 105) "Project Mohole dominated [National Science Foundation] management councils from its inception in 1957 to its demise in 1967". Notwithstanding the failure of Project Mohole, Brown and Root's interest in Whittle's turbo-drill highlighted the tool's potential as an instrument to gain physical access to previously inaccessible areas within the earth's interior.

108 Author unknown. Report entitled "Turbo-drill – Bristol Siddeley". Dated 15th March 1961. CACCC: WHTL 340-B. 1959-1964.
109 "Turbo-drill: A resume of drilling trials to July 1964 by Air Commodore Sir Frank Whittle, K. B. E. , C. B., F.R.S". Dated 28th August 1964. CACCC: WHTL 482-B. 1951-1988.
110 Report entitled "Turbo-drill: A resume of drilling trials to July 1964 by Air Commodore Sir Frank Whittle, K. B. E. , C. B., F.R.S". Dated 28th August 1964. CACCC: WHTL 482-B. 1951-1988.
111 Report entitled "Turbo-drill: A resume of drilling trials to July 1964 by Air Commodore Sir Frank Whittle, K. B. E. , C. B., F.R.S". Dated 28th August 1964. CACCC: WHTL 482-B. 1951-1988.
112 Letter dated 6th August 1960 to S. W. Mansell from W. E. Benson. CACCC: WHTL 338-B. 1959-1964.

With depth restrictions in place at Eakring, Whittle moved tests to Plungar, Leicestershire – an oilfield discovered by D'Arcy in 1953. Only one well was drilled (hole 8A completed at 4,650 feet), for the purpose of verifying the tool's long term durability in the field (see figure 6.12). Testing was subsequently moved to Severnside, close to Bristol Siddeley's headquarters. Operations took place from January 1966 to August 1968, during which Rolls Royce took over BSEL and established a "Turbo-Drill Division", giving the project the code RB211. Three separate wells were spudded for the purpose of assessing speed, endurance and well deviation capabilities. According to Whittle, at Severnside "the very old Carboniferous, Devonian and perhaps older rocks…proved a severe test both on turbo-drill" leading to severe vibration and heavy loading on the drill string.[113] However, in hole No. 3 Whittle successfully deviated the well in eight different directions from vertical, marking a landmark in the history of deviated drilling. Whittle celebrated his achievement proclaiming "this operation of drilling 8 holes without moving the rig is probably unique in the history of drilling".[114]

[113] Author unknown. Report entitled "Turbo-drill: A general review – October, 1969". CACCC: WHTL 378-B. 1969-1972.
[114] Author Unknown. Report entitled "Turbo-drill: A general review – October, 1969". CACCC: WHTL 378-B. 1969-1972.

Figure 6.12: Hoisting Whittle's turbo-drill up the "catwalk" into the derrick (1); raising turbo-drill inside derrick (2) and lowering into position ready for drilling (3). Exact location and date unknown.



Source: *Andrew Naylor, April 2012. BPA: ArcRef 113250.*

Despite early successes, during field testing Whittle found it very difficult to isolate problems occurring at the bottom of the well, as surface indications were small and troublesome to observe. Turbo-drilling often destroyed the evidence required to make diagnostic assumptions. Bearing failures resulted from drilling mud blockages which caused ingress of drilling fluids on the gearing assembly.[115] A recurring problem was sand entering the turbo. De-sanding equipment was often ineffective, filling the drill to the point of failure.[116] Overall, technical failings and budget overruns resulted in the abandonment of Whittle's turbo-drill project. The turbo-drill concept would not be seen again in Britain until the 1980s.

As discussed by Beswick and Forrest (1982), in 1981 a new type of downhole motor, developed in Russia, became available in Aberdeen. It was primarily designed to be used for onshore operations in Western Europe and for deep North Sea drilling. However, examples were also used by the Camborne School of Mines, Cornwall, to drill two wells for a deep geothermal project in the early 1980s. In the early 1990s turbo-drills were combined with continuous coiled pipe to allow uninterrupted drilling at any angle (Webb, nd). These technologies are increasingly being applied to 21st century unconventional hydrocarbon exploration, for example by companies now looking to explore for and exploit Britain's vast shale gas deposits using horizontal, rather than vertical drilling methods (Hadley, *et al*., 2015). Deviated drilling today forms a significant part of drilling companies' total workload as they exploit increasingly marginal oil/metal ore/coal/shale gas deposits. At Wytch Farm in Dorset, BP's well M16 was for many years the world's longest producing oil well (BDF, 2009, np). The well is sited onshore on the Goathorn Peninsula and extends under Bournemouth Bay with a horizontal displacement of 10,728m, total length of 11,278m and depth of 1,638m (BP, 2003). This "extended reach drilling" allows the company to control drill trajectories at huge distances, removing the need for costly offshore drilling platforms or artificial islands, and minimising the ecological impact of oil exploration.

Although there are numerous, social, economic and environmental advantages of directional drilling, the process does open the door to land ownership controversies concerning infringement and trespass. A notable case involves former Harrods owner, Mohammed Al Fayed, who won damages against energy company Star Energy for drilling diagonally beneath his Oxted Estate, Surrey, in order to extract oil worth £10 million from the Palmers Wood oilfield (BBC, 2010).

Deviated drilling involves passing physical capital through subsurface territory which, in itself, may be considered an infringement on another's privacy, resulting in a loss of amenity.

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[115] Report entitled "Turbo-drill: A resume of drilling trials to July 1964 by Air Commodore Sir Frank Whittle, K. B. E. , C. B., F.R.S". Dated 28th August 1964. CACCC: WHTL 482-B. 1951-1988.
[116] Report entitled "Turbo-drill: A resume of drilling trials to July 1964 by Air Commodore Sir Frank Whittle, K. B. E. , C. B., F.R.S". Dated 28th August 1964. CACCC: WHTL 482-B. 1951-1988.

With all oil in the UK being vested in the Crown since the Petroleum (Production) Act 1934, Al Fayed was unable to claim a share of the oil that Star Energy extracted. However, the principal of extracting, or indeed injecting capital in the case of carbon sequestration may lead to an explosion of litigation cases as individual privacy and property rights are infringed from below. Sir Frank Whittle's turbo-drill represented a revolution in well drilling in the 20th century. Its implications, however, are perhaps only just beginning to be seen in the 21st century as the ability to exploit subsurface territory becomes a central focus of geopolitical debate.

6.7 Conclusion

This chapter, which has covered the period from 1939 to 1964, has identified Eakring, Nottinghamshire as a centre of calculation for global oilfield development. Between 1941 and 1961 D'Arcy drilled 543 onshore oil wells, most during World War Two, the most prolific period of onshore drilling to date (Davies *et al*., 2014, p. 244). Many of these wells have been sunk in the thirty-three fields located within Carboniferous rocks (Harvey and Gray, 2013, p. 49). Like the Hardstoft field, Eakring (and the surrounding oilfields) and Kirklington Hall Research Station assumed the quality of a technological zone - a bounded space in which common forms of measurement, infrastructure (connection) and qualification (assessment) are established (Barry, 2006). Following a frantic period of exploration and initial exploitation, the process of oilfield development, which includes a combination of operational and administrative practices, was reduced down to common standards making it easier to govern the oilfields. Following geological and geophysical qualification (assessment) a standardised layout (measurement) was applied to well spacing. Portable Drilling Outfits and drilling procedures, i.e. oilfield infrastructure was standardised and all production wells were connected to a pumping system that delivered oil to a siding at Bilsthorpe.

Interviews with former employees have revealed that D'Arcy Exploration Company's entry had significant social implications for the sleepy rural village of Eakring. The influx of an American workforce affected each and every household in the village, with many offering lodgings to families. The needs of the industry resulted in electrification, as well as a central water distribution system, largely replacing artesian wells. The surrounding towns and villages also benefited in terms of increased revenue and job opportunities. Socio-economic implications were, however, secondary to the scientific and technical advances that emerged from the laboratories and field sites - in particular Kirklington Hall Research Station. From the development and implementation of secondary recovery systems to novel drilling techniques, Eakring became a thriving research hub which attracted scientists and engineers from around the world. The flow of intellectual capital connected private companies with research institutions, and the state to the governance of physical territories.

As with Chapters 4 and 5, Chapter 6 continued to trace the lives of petroleum geoscientists. From 1914 onwards, when he became the Duke of Devonshire's consulting scientist, John Cadman occupied a central position within Britain's new oil industry. His working life was devoted to the science and art of hydrocarbon exploration and exploitation. Sadly, his life ended before the full potential of the four Nottinghamshire oilfields was realised. As one of his geological emissaries, Birmingham Petroleum Mining graduate Phillip Southwell rose to the challenge of continuing his mentor's vision. Cadman guided Southwell, assigning him to several international projects, many of which were problematic. During his international travels, which took him to Persia, Australia, Papua, and New Guinea amongst other places, Southwell negotiated oil terms, oversaw development programmes, ensured sustainable oil production using the paradigm of unit development, designed and implemented secondary recovery systems and maximised oil production.

These actions required tact, diplomacy, self-assurance and steadfast dedication to the cause. Of particular significance was his involvement in the recruitment of drillers from America. The team of 44 oilfield workers, equipped with the latest drilling technologies revolutionised drilling in Britain and significantly increasing oil output. Southwell's geobiography, pieced together via archival shows the importance of place when examining spatial networks. Each country or site he visited exposed him to a new set of material circumstances, equipping him with the skills and experiences required to tackle the complex challenge of onshore oilfield development.

Interviews with Mr Kevin Topham, Mr Doug Wallace and his wife Mrs Syvil Wallace revealed the names of a number of prominent petroleum geoscientists operating within BP's Research Station at Kirklington Hall, which existed for 15 years from 1942 to 1957, when BP decided to move its research operations to Sunbury-on-Thames. Jack Birks, for example, became vice-president of exploration for BP North America, which was charged with locating oil in Alaska (*The Telegraph*, 2001). In 1970 he was appointed Director and General Manager for the Iranian Oil Exploration and Producing Company at Masjid-i-Sueiman, which had a major influence on the company's fortunes (*The Telegraph*, 2001). In 1978 he was appointed Managing Director of British Petroleum, following in the footsteps of John Cadman.

Threadgold, Tomaschek, Germain-Jones and Gaskell were also key actors involved in pioneering research at Kirklington Hall Research Station. Pip Threadgold, a seismologist, would later become the President of the London Petrophysical Society in 1973 (Whyte, 2014). Experimental physicist and German pioneer in gravimetry Rudolf Tomascheck was employed at Kirklington Research Station from 1948 to 1954, when he left to become president of the Permanent Tidal Commission in Germany. During his time at Kirklington, Tomasheck published scientific reports on earth tilting (see Tomasheck, 1953; 1955a) (which involved locating sensitive geophysical equipment in the former gun-room at Kirklington Hall), the sensitivity of flat spiral springs (see Tomasheck, 1955b) and tidal gravity in the Shetlands, (see Tomasheck, 1955c; 1957), which resulted in the earliest tidal gravity record in history and was used to inform debate during the International Geophysical Year (1957-58).

Donald Thomas Germain-Jones joined the AIOC in 1927. In 1953, whilst based at Kirklington Research Station he was appointed BP's Chief Geophysicist and also President of the European Association of Exploration Geophysicists, establishing BP's Geophysical Research Station at Kirklington Hall (Malone, 1960). He expanded BP's global geophysical exploration programme and was ever conscious of the importance of knowledge exchange between academics and practical geophysicists through the medium of publications such as *The Geophysical Journal*. From 1953 to his retirement in 1959 "he travelled far in both hemispheres for the purpose of gaining first-hand knowledge of the working conditions and technical problems of his parties in the field" (Malone, 1960, p. 239). International travel, therefore, continued to be at the centre of oilfield developments, with Kirklington Hall Research Station serving as the epicentre of BP's global expansion programme during the 1950s.

Another of Kirklington Hall's resident scientists, identified during semi-structured interviews was Thomas Frohock Gaskell. As stated by Bates, *et al*., (1982, pp. 491-492), Gaskell received his PhD in terrestrial and seismic studies from Cambridge University in 1940. During the early part of World War Two he assisted Dr (later Sir) Edward Bullard in geophysical warfare, which included the design of mines, anti-submarine devices and minesweeping. From 1946 to 1949 he served as AIOC's Chief Petroleum Physicist in Iran. From 1950 to 1952 he served at the Chief Scientist on-board HMS Challenger, which surveyed 120,000km of Ocean floor (see Gaskell, *et al*., 1953; Gaskell, 1954). On his return he worked in research at Kirklington Hall Research Station before later becoming Scientific Adviser to the Information Department. This role involved several television and radio appearances, during which he discussed various earth science topics.[117]

The aforementioned examples of earth science specialists located at Kirklington Hall Research Station, Eakring, Nottinghamshire demonstrate that the accumulated knowledge extended far beyond Eakring. Knowledge was exchanged throughout BP's global network, with former employees going on to take up high level jobs throughout the world. Research and development involved various institutions across the earth scientists, with specialists at Eakring keen to ensure research married academia with practical field science. Through the likes of Gaskell, the work carried out within Kirklington Research Station was communicated to the general public via popular science books, radio and television, highlighting the importance of Eakring as a centre for the dissemination of scientific truth.

[117] For example, Gaskell appeared on the BBC's "Signpost" on 31st May 1962. Entitled "Working Under the Sea" it focused on new developments in oceanography.

After the 1940s BP entered into an agreement with the National Coal Board (NCB), whereby the NCB provided BP with the coal exploration data in return for the deepening and appraisal of coal exploration boreholes (Harvey and Gray, 2013, p. 49-50). However, this was not sufficient to avoid the temporary demise of the onshore oil industry. In 1964 the British government added a duty to domestic oil, making it uneconomic against Middle Eastern imports. This, according to Kent (1985, p. 63), meant that "oil exploration on land in the UK virtually ceased" with staff being dispersed". Also in 1964 the British government passed the UK Continental Shelf Act, (1964), which enabled exploration around the coast of Britain and resulted in the discovery of a number of massive offshore oilfields. In an interview with BBC Nottingham, Mr Kevin Topham discussed how the "trained up drilling crews from Eakring were transferred to the North Sea project" following the passing of the UK Continental Shelf Act 1964 (BBC Nottingham, 2009, np). During this transition, staff at Eakring built a 200 foot derrick, which would become the Sea Gem jack up barge. A demand for onshore acreage following the 1973 oil crisis led to a revival in the industry and the subsequent discovery of Wytch Farm in Dorset, as well as other discoveries around the UK (Hine, 1985; Huxley, 1983).

Exploration and exploitation across the Nottinghamshire oilfields revealed a great deal about the subsurface of the vicinity. Physical samples provided geologists with important rock characteristics data, while geophysics provided earth scientists with a subsurface hologram of the oil deposit and surrounding structures. A plethora of other important 20th century developments emerged from the Nottinghamshire oilfields, including ways to significantly increase drilling speeds (American influence), separate oil from water and establish sustainable well spacing programmes. Secondary recovery systems, geochemical prospecting methods (see Cooper, 1959) and the development of the echo meter amongst others were also developed. Additionally, Frank Whittle's turbo-drill, despite suffering operational deficiencies in the field, was found to have the potential to increase drilling speeds and allow drillers to navigate the drill string at great depths. The unification of directional drilling with secondary recovery systems would have significant ramifications for the future of oilfield development, including, significantly, in offshore drilling in the 21st century.

Chapter 7 – Conclusion

7.1 Introduction

This thesis has uncovered the complex and forgotten historical geography of onshore oil exploration in the British East Midlands between 1908 and 1964. This research has traced how a small but contentious industry based in the British East Midlands exemplified Britain's move from a coal based energy regime to one centred on oil. By considering this previously unexamined initial phase in Britain's 20th century love-affair with oil, this project has provided necessary historical perspectives which will contribute to on-going debates about the nation's energy supplies in the future.

This thesis has identified the British East Midlands as having been a nationally and internationally significant region for scientific innovation and government rationality – a place in which domestic oil was secured on a commercial scale during three distinct episodes of political negotiation within the first half of the 20th century. It has disentangled the onshore oil industry from within two specific sites of knowledge production; Hardstoft in Derbyshire and Eakring in Nottinghamshire, showing how the process of oil exploration and exploitation improved with cycles of accumulated knowledge over the three episodes examined. It has considered the webs of relations existing between people, places, techniques and technologies, structured institutions and companies through space and time.

This project has generated new collaborative, interdisciplinary research, based on nine archive collections from around the United Kingdom, as well as some oral testimonies with former oilfield workers. Examining both the physical and the human spheres of the early British onshore oil industry through correspondence and discourses; it has revealed a complex, porous oil assemblage, which was determined by the space-time dynamics of the early to mid-20th century political economy. Having remained hidden from view in the various archive collections, this thesis has revealed the oil biographies of the Hardstoft and Eakring oilfields. The physical qualities of the oil, its liquid state and physical location several thousands of feet below the ground, resulted in new forms of governance and geological interpretation in Britain, undertaken by a cadre of geological experts who engineered "political relations out of the flows of energy" within the British East Midlands (Mitchell, 2011, p. 5).

Oil exploration in the 20th century involved the use of cutting edge technology and skilled human operators, who mobilised infrastructure to explore unchartered territories across spatial networks. This thesis has focused on vertical exploration, and importantly, the subsurface. During the period examined, the oil enclaves beneath the villages of Hardstoft and Eakring became governable spaces, commandeered by the state during World War One under DORA and ultimately nationalised under the Petroleum (Production Act) 1934 during protracted three-dimensional geopolitical struggles. These complex new frontiers brought the state into contact with its vertical territories, in particular during the interwar period when the many boreholes, geological and geophysical surveys recreated holographic representations of boundary layers within the earth's crust.

By investigating the practice of geological science, the thesis has unearthed an important period of geological, geophysical, and geographical surveying, which focussed on the anticlines of the British East Midlands and drew together disparate fields including geology, engineering and, importantly, geography. The places in which oil exploration occurred were not randomly selected, but chosen based on the scientific rationality of geological experts with significant international experience in finding oil. A geologist's reputation was extremely important to landowners and the state, given a lack of understanding on both sides at this time. The geological qualities of the Carboniferous rocks of Pennsylvania (A. C. Veatch on behalf of Cowdray in Chapter 4), and the Zagros mountain range of Iran (George Martin Lees on behalf of D'Arcy in Chapter 5) were thought analogues to Hardstoft and Eakring respectively. In the period examined, geologists were vital to Britain's oil strategy. Oil was essential to war, and warfare essential to oil exploration. Precise applied geology, stemming from the geophone, meant geologists could penetrate deeper into the subsurface, improving the likelihood of finding oil. The need to secure domestic oil during World War One revealed its liquidity. Britain's established coal industry, with its abundant reserves, established distribution and governance systems was a solid, robust industry. Oil, conversely, was liquid, physically and metaphorically. Located thousands of miles from Britain where it was governed and distributed by international markets, oil was an uncertain, dynamic and high risk energy source.

In the early 20th century, tensions existed between oil companies, host countries and the Western industrialised states; to an extent, this reflected in the British East Midlands. The geopolitical controversies played out in relation to Hardstoft and later Eakring involved oil companies, the state, and, importantly, the British landowner, who was analogous to Middle Eastern host nations prior to the nationalisation of oil in 1934. Like the oil-producing companies of the Middle East, landowners in turn feared the economic and political exploitation of their oil, which was under threat of subjugation by the likes of Cowdray, who, it was believed, was attempting to monopolise the British onshore oil industry. Operating at a smaller scale, the power of long-established British traditions was such that landowners were able to manipulate agreements and licence terms, hampering oilfield development at the worst possible time – when energy increasingly became a necessity for warfare.

The landowner was reliant on the oil companies to provide financial backing and technical expertise, resulting in a complex web of conflicting relationships, at the centre of which was John Cadman, who acted as a mediator between the various parties. Ultimately, the unwillingness of landowners to cooperate with the government threatened national security. In the interests of strategic national interests, the government, via a democratic process, nationalised oil, taking responsibility and control of its subsurface territories in much the same way that Iran nationalised its hydrocarbon resources in 1951, which gave impetus to the establishment of Kirklington Hall Research Station.

The empirical chapters of this thesis have revealed a number of geographical dynamics, notably with respect to scale, spatialities (in particular three-dimensional territories) and oil assemblages. Overall, the thesis has critically evaluated the processes and practices - social, technical and geopolitical - that resulted in the British East Midlands becoming the country's first oil frontier. By considering the people, places, techniques and technologies, institutions and companies involved in oil exploration, a rich, diverse historical narrative has emerged.

7.2 Uncovering hidden oil histories: reflections on the conceptual framework

This research has drawn on a number of conceptual ideas, from Science and Technology Studies, geobiographies and vertical geographies. The main conceptual driver, however, has been Actor Network Theory. Together, these organising concepts have guided the overall approach and analysis of empirical chapters, focusing the research on the roles of human and non-human actors enrolled within the "actor-network" (Law, 2009). Earlier versions of this thesis drew on prosopography (Manchester School of thought, founded by anthropologist Max Gluckman) as a conceptual idea, however, it was decided that as the research focused on individuals rather than a clearly delineated grouping, ANT and prosopography were in fact competing conceptual ideas and the decision was made to remove prosopography from the thesis. As a conceptual approach, ANT provided the scope to link disparate human and non-human actors across the East Midlands oil assemblage.

As discussed by Müller (2015, p. 27), "actor-network theory… (has) been at the forefront of a paradigm shift that sees space and agency as the result of associating humans and non-humans to form precarious wholes". This approach has "far-reaching implications (for) geography – the notion of space and distance, the relationship of humans with technology and the environment, (and) the exercise of power across distance" (Müller and Schurr, 2016, p. 218). However, strict adherence to ANT alone may not have allowed the socio-material relationships existing within this thesis to have been fully explored. Concerned with the creation of relationships, the association of human and non-human actors across networks and the "ordering of entities beyond one universal principle" (Müller, 2015, p. 30), this research utilised geobiographies to demonstrate how power, place, politics and space were guided by the emotions and spatial life histories of key human actors. Cadman, Lees and Kent all had strong motivations for securing domestic oil. So too did the oilfield workers interviewed in chapter 6.

By combining complementary conceptual ideas, this research has offered new insights into how power, politics and space, particularly beneath the land surface, was negotiated within the East Midlands oilfields.

The methodological approaches used in this thesis have resulted in the production of an historical narrative, rendered with human stories from both the living and the dead communities. Rich in primary empirical data, archival material has created new interpretations and explored the "rhetorical actions… [of] a particular group of people (Gaillet and Elbe, 2016, p. 4). Inter-textual analysis has revealed the key figures involved in the development of the British onshore oil industry in the first half of the 20th century, facilitated the critical evaluation of scientific and technical advances during the interwar period, and revealed the international significance of Kirklington Hall Research Station. As stated by Ogborn (2010), different sources answer different questions. The use of varied sources has revealed the factors that shaped the geography of onshore oil exploration and ensured that this research "is original and contributes to ongoing conversations" within cultural and historical geography (Gaillet and Elbe, 2016, p. 6). Private letters, diaries, notebooks, parliamentary debates and photographs have shown the tensions between groups of people at different scales (above and below the ground) and demonstrated how teaching and research in universities responded to the commercialisation of geology post World War One, as new techniques in mineralogical exploration were discovered. Secondary published sources have allowed this research to trace the political roles of geologists associated with oil companies and the state and helped to reveal the rationale underpinning why it was necessary to secure a domestic sources of oil in Britain during the early 20th century.

Both methodological approaches have limitations. Archival research often produces only a partial record due to fragmentation and loss. However, gaps in the historical narrative encouraged me to investigate new lines of enquiry and consider the dispersed geographies of archival remnants (McGeachen, 2012). No archive is completely neutral in its portrayal of past events. The Chatsworth Estate Archive, for example, represented a single landowner in a period involving multiple stakeholders. Censorship surrounding commercial sensitivities is also a potential issue, as demonstrated within the BP archive. Material approved for consultation by company archivists could be part of a larger body of material deemed unsuitable for public consumption, potentially making it hard to establish causality.

Oral testimonies too have limitations. The semi-structured interviews serve only as "snap-shots" in the lives of a few former employees of D'Arcy and new research hypotheses and new lines of enquiry have emerged since 2011 when the interviews were undertaken. A fascinating strand, for example, is the link between Bletchley Park and Kirklington Hall Research Station, which, according to one interviewee, supplied scientists who possessed the necessary scientific and technical expertise to work on the complex maths and physics integral to D'Arcy's oilfield operations, both in Britain as well as overseas. Given the small number of living respondents, interview data was limited and it was sometimes difficult to identify key themes and make connections between each transcript (Kitchin and Tate, 2000). Following this research I hope to utilise social media to raise the profile of the East Midlands oilfields and to potentially undertake further interviews with oilfield workers or their families. Interviewing Lady (Lorna) Kent, Peter Kent's wife, who lives in West Bridgford, for example, could reveal insights beyond the archival material held by Hallward Library, University of Nottingham, Manuscripts and Special Collections.

This thesis shows that oil exploration is an "empirical and experimental multiplicity" (Appel, *et al*., 2015, p. 17). The three objectives set at the beginning of this thesis, which have resulted in the overall aim of the thesis having been met, moves away from examining oil in either political or economic terms, representing an alternative way of writing about the history of oil. By tracing the flow of oil back to the key protagonists, significant pieces of oilfield technology and the institutional spaces (truth spots, or centres of calculation to use Latourian language) involved in the exploration process the thesis examines the ways that knowledge was produced, consumed and mobilised within the British East Midlands and beyond. These hidden constituents were never discrete, but rather co-constitutive – no single actor or agent was more, or less significant within the regional production network. However, as the network underwent political, economic and social changes over the course of the period examined a particular actor or agent, or indeed group of actors was thrust into the spotlight at a given moment in time. The Eötvös gravimeter, for example, was enrolled at a moment in history (1928 onwards) when scientific rationality was at the centre of the future of the onshore oil industry.

John Cadman, Norman Falcon, Philip Southwell and Peter Kent can all be explicitly linked to one chapter (in the case of Cadman, two – Chapters 5 and 6), though again, they rose to eminence at specific points in space and time within a hybridised oil assemblage that included non-human agents. As well as individuals, the thesis has shown that groups of human actors were important to the development of the British onshore oil industry at different times. The part played by the drilling crews operating during the Hardstoft episode (Chapter 4) was, for example, overshadowed by the landowners, who were attempting to shape and control the industry from 1915 until oil nationalisation in 1934. In Chapter 6, however, American drilling crews significantly increased oil production at Eakring due to technological improvements in drilling during the early 1940s. The role played by the drilling crews at Hardstoft were no less important to those operating at Eakring, however, as the context changed with time, so did the significance of the role of certain groups. This phenomenon can also be applied to Chapter 5, when a group of geophysicists influenced political decision making, higher education institutions (Imperial College's School of Geophysics), precision engineering and ultimately the process of professionalization, specialisation and the commercialisation of geological science in the interwar period.

By examining the materiality of oil the thesis has shown how, during the first half of the 20th century, Hardstoft and Eakring shaped geopolitical governance by expediting the passing of two Petroleum Acts (1918/1934) based on the qualities of oil, notably the depth at which it was found in the subsoil. Chapters 4, 5 and 6 of this thesis are held together materially by the physical, hard rock qualities of the British East Midlands, in particular the Carboniferous, Mill stone Grit and Coal Measures which were found to exhibit the geological prerequisites for petroleum systems, including; source rock, migration route, porosity permeability and impermeable seal. Oil has numerous physical qualities, for example its viscosity, sulphur content, flash point and so forth. These petrochemical qualities take on "broader social and cultural significance [which] varies tremendously with time and place and with the scale of the analysis" (Rogers, 2015, p. 61).

The refinement of exploration processes and philosophies materially influenced the spatialities of onshore oil exploration, particularly in the interwar period. Geological and geophysical interpretation resulted in flurries of activity at particular field sites, connected to which was administrative and organisational arrangements between the oil companies, service companies (geophysics), landowners and the state. Failings resulted in the rapid mobilisation of oil infrastructure to new sites, whereas successes resulted in an influx of actors and agents as the extent of the fields was established and developed. Following a period of exploitation, Hardstoft, Eakring and the surrounding fields were deemed "matured" as oil levels fell below what was deemed economically viable given available technologies. Boom and bust cycles are common in the oil industry, given that oilfields are a finite natural resource. However, their life-cycles can be extended as new technologies become available. In June 2014, for example, onshore operator IGas announced it was seeking planning permission to frack at two sites, one on either side of the Pennines in an attempt to extract shale gas. Chief Executive Andrew Austin stated "It is our intention to have permits in place such that we can drill and flow test wells at two sites – one in the North West and one in the East Midlands – in 2015" (*The Telegraph*, 2014, np).

Fundamentally, the structure of the British onshore oil industry depended on the negotiation of power across space: firstly, in relation to property rights, secondly, the extent of the oil territories – which themselves exist at various scales, from oil zones in the strata to petroleum systems and finally, at the national scale in relation to state control over natural resources. Permeating between scales and across space and time, John Cadman was the architect of the British onshore oil industry during the first half of the 20th century. He represented the British landowner in an attempt to negotiate equitable financial terms (Chapter 4), influencing the direction of national policy objectives and materially influenced technological advancement by promoting geophysics within higher education institutions (Chapters 4 and 5). The careers of Falcon, Lees, Southwell and Kent can all be traced back to Cadman through institutional spaces, commercial organisations and the field sites within the British East Midlands. By tracing the geobiographies of prominent actors the thesis has revealed the relationships that determined how the oil assemblage was arranged, constructed and maintained.

The development of the East Midlands oilfields was fraught with financial risk, geological uncertainty and applied state pressure during war and depression. Ultimately, however, exploration resulted in the discovery of Britain's first oil province – a physical, three-dimensional volume sharing a common geological history. The discovery of Britain's first petroleum system initiated a process of nationwide appraisal and development. Drilling and subsequent petrophysical analysis confirmed the existence of multiple oil-bearing structures within the East Midlands, which, significantly, became an oil supply zone during World War Two (Watts, 2014). Subsequent exploration campaigns (extending beyond the period examined within this thesis) meant that by the end of October 2009, British onshore oil output (since 1919) has contributed 69.2 million tons (approximately 519 million barrels) to UK demand (Evans, *et al.*, 2011, p. 3). Notwithstanding Wytch Farm, the East Midlands has been the most productive province in the UK, having produced 8.6 million tons of oil since 1919 (Evans, *et al.*, 2011, p. 9).

7.3 Contribution to geographical and geological scholarship

Chapter 4 of the thesis examined the World War One exploration campaign undertaken by a group of American experts. It spanned the period 1908 to 1927. This was a period in which Britain was scrambling to secure a stable, global oil supply network as coal was being surpassed by oil modernity. The establishment of commissions, councils, and the Petroleum Executive signalled Britain's increasing acceptance of, indeed need for oil, in Britain's energy regime in the early 20th century. This diversification was predominantly outward facing, targeting the Persian Gulf. This thesis has focused on British territories, while considering how domestic oil exploration co-existed with international oil exploration. The commercial success of Hardstoft 1 provided geologists with a tantalising, enigmatic insight into Britain's hydrocarbon prospectivity. The drilling episode was time critical, with World War One necessitating a mobile, flexible, liquid energy source. The physiochemical qualities of oil became an essential component of naval warfare in particular, thus the agency of oil, i.e. its physical and chemical properties, became central to the impetus behind exploration, as well as determining the techniques and technologies used to extract it.

From the outset, John Cadman assumed a central position. By tracing his geobiography, the chapter explored how his contribution to the professionalisation of geological science in the early 20th century, as well as his role in the Persian Commission, helped to define him as a world leading authority in petroleum geoscience. His Birmingham University degree in petroleum geoscience, established in 1912, had revolutionary effects, supplying graduates to all corners of the global oil assemblage. Cadman acted as a consulting scientist to the Duke of Devonshire, a government official, and Technical Advisor to the APOC. Following this he became Director of the D'Arcy Exploration Company and ultimately Chairman of APOC. Notwithstanding his government role during World War One, Cadman continued to act as a scientific advisor to the Duke of Devonshire. He had an understanding of the many spheres of petroleum geoscience, including politics, exploration geoscience and fieldwork. A skilled geologist with wide ranging and embodied practical experiences, his role as consulting scientist meant he was aware of the conflicts of interest between landowners and the state. Cadman permeated boundaries and crossed scales, enabling him to link up institutions as well as global field sites – as demonstrated in Chapter 5 when he organised a field trip to Persia for two members of the BGS. This would lead him to drive forward onshore oil exploration in Britain, with the backing of the APOC during the interwar period. Cadman brought oilfield sciences to the attention of scientists, landowners, politicians and the British public. By tracing the life of Cadman the thesis attends to a significant issue within the history of geology. This is summarised by Torrens (2002), who argues that perhaps the least studied aspect of geological science is its practice, which serves to detract from the intellectual provenance of knowing the fuller story, created 'in the field'.

The World War One campaign was politically charged and extremely protracted, owing to the unwillingness of British landowners to allow exploration without equitable fiscal and legal terms. Nationalisation, monopolisation, royalty payments and the unknown location of an oil pool all acted as barriers to exploration. Despite his experience, Cadman was unable to draw up licence terms which suited all parties. Even after the passing of the Petroleum (Production) Act 1918, landowners contested licence terms, as indicated by the ongoing work by the Association of Rural Landowners, which was seeking to add amendments to the legislation. It was difficult to see how oil exploration could fit into Britain's established mineral exploitation regime. Successive drilling failures, high water production and spiralling costs made commercial onshore oil exploration a dismal prospect.

Despite this the process of exploration resulted in a number of positive outcomes. Firstly, the discovery of oil supported scientific hypotheses that Britain's land mass contained oil. In the process petroleum geoscientists had drawn the first maps in Britain to target oil, which became immutable mobiles to be discussed and disseminated within structured institutions. By triangulating the results of drilling at Hardstoft No. 1, 2 and 3, petroleum geologists could also build a three-dimensional model of the subsurface, positively identifying the presence of anticlines similar to those found elsewhere around the world.

Although significant advances were made in terms of geological theories, technological developments were largely absent from the chapter. Percussive drilling, widely used up until the 1930s was extremely slow and the destructive nature of the technique meant it was difficult to retain representative samples. Non-standardised equipment, designed to drill at greater depths in Persia was large and cumbersome, with replacement parts only available in America. Prior to electrification (steam powered boilers powered the rigs) drilling operated in isolation within the landscape. Despite these technical deficiencies, the drilling process established a regime for specimen collection, which enrolled institutions such as the BGS. This was a robust system, with samples from all of the wells drilled during the Hardstoft episode being readily available for examination today. At the site scale, Hardstoft necessitated all of the infrastructural elements of a much larger oilfield, including upstream and downstream processing. Drilling rigs, pipelines, storage tanks, rail links and refineries formed a distribution network which transcended the site scale and began to link, albeit at a very modest level, the British East Midlands to a global oil network.

The episode resulted in a clearly defined, though contested, piece of legislation, as well as the assignment of oil-related roles to British government departments, for example the BGS, which retained drilling samples/logs for future reference. Typified by multiple drilling failures and substantial financial losses, the period added considerably to geologists' understanding of deep subsurface structures, as well as to the issues inherent to negotiating a path towards domestic oil security. Albeit small in volume, the successes at Hardstoft induced an influx of private companies to investigate Britain's hydrocarbon potential. The episodes that followed advanced the oil production assemblage, connecting the British East Midlands to the global oil network. In particular, it identified the problems of access to and ownership of mineral oil, which continued until the nationalisation of oil. Importantly, the period established a "regime of accumulation and regulation" – a key theme which would extend into Chapter 5 (Appel, 2015, p. 18). Hardstoft represented the first cycle of accumulation examined during the thesis.

Chapter 5 covered the period from 1922 to 1939. Following on from the Hardstoft episode it examined three interconnected strands: firstly, the role of several revolutionary technologies, including geophysical survey techniques and isopachyte methods, which enabled geologists to visualise the subsurface, secondly it examined the debates before, during and immediately after the passing of the Petroleum (Production) 1934 Act, finally it examined D'Arcy Exploration Company's systematic search for oil across the United Kingdom. The chapter revealed the inadequacies of the Petroleum (Production) 1918 Act, which would only be addressed by resolving longstanding ownership laws and being able to accurately, quantifiably locate oil in the subsurface. Differentiating the boundaries between solids and liquids at depth was central to revising legislation, which was imposing spatial restrictions and deterring specialist oil exploration companies from pursuing domestic oil.

At the beginning of the period (1922), only three licences were held by non-oil specialist licensees. By 1939, the D'Arcy Exploration Company, Anglo America Oil Company, Gulf and Steel Brothers companies all held blocks of British territory, in turn being investigated by specialist seismic companies established in Europe during the interwar period following the formation of the IUGG. The rise of specialist oil exploration companies, the production of high tech scientific instrumentation and the introduction of geophysics into Imperial College, London marked a process of commercialisation within the geological sciences during the 1920s and 1930s. The potentialities of these techniques were quickly recognised by Cadman who, as Chairman of the APOC, supported BGS staff to undertake field studies in Persia in 1925. This act signified a high level of openness and transparency between the APOC and a British government institution. This transparency spilled over into the media, whose reports during the 1930s closely aligned to the material accessed within the BP Archive.

The interwar period was spearheaded by D'Arcy, who, during their multiple topographic and subsurface surveys created a vast number of inscription devices, including maps and scientific reports. This process of validation and fact-finding was disseminated through committee meetings and lectures. This served to convince other scientific experts of the likelihood of finding commercial quantities of oil, and in doing so "[making] claims spread out in time and space" (Latour, 1987, p. 131). For example, upon returning from their field studies, the two BGS staff sent to Persia to study emerging geophysical survey methods disseminated their immutable mobiles (scientific reports) to British scientists, who debated the most suitable location for British deployment. Field tested over the Swynnerton-Butteron Dyke near Keele, Staffordshire, the Eötvös Torsion Balance successfully detected gravity anomalies, marking the inception of a new method of graphically representing places and spaces beneath Britain's landmass. Such was the importance of geophysical surveying, that Imperial College London quickly became established as a centre of calculation for this new arm of economic geology. The successful implementation of geophysical surveying methods in Britain provided a political catalyst. It enabled, for the first time, geologists to state with some certainty where oil pools were in the subsurface. The process of attempting to locate hydrocarbons in the subsurface involved "epistemological and material mechanisms through which oil came to establish its contemporary political power" (Knox, 2015, p. 309).

Though largely technological, Chapter 5 involved three human actors - Cadman, Lees and Kent. Under Cadman, then Chairman of the AIOC, Lees was appointed to investigate oil regions of the world. His many expeditions resulted in geological theories and ultimately a model of exploration in Britain, transposed from the Zagros mountain range of Iran and Iraq. Lees' internal report, submitted in 1933 (see Chapter 5), in which he suggested blocks of territory for exploration, formed the precursor to today's Petroleum Exploration Development Licences (PEDLs). The three human actors, Cadman, Lees and Kent were connected within a hybridised network which included increasingly complex technologies. Their joint efforts operated across scales. Cadman operated primarily at the international and national scales, organising field trips to Persia through the APOC and negotiating with the state over all licensing terms. Lees investigated the oil potential of various landscapes at a regional scale, while Kent operated at the site scale, pinpointing exactly where to locate the drill based on the detailed evaluation of data following geophysical surveying.

The depth at which oil is typically located stimulated a specific type of social and political response and mobilised a particular type of human actor – notably the petroleum geologist. It also fostered a certain type of imagery, conveyed during the interwar period via media reports and radio broadcasts by the likes of John Cadman, for example "*The Romance of Oil: Six Broadcast Lectures*" (Cadman, 1930). The chaotic geographies of onshore oil exploration at this time involved numerous geological and geophysical investigations undertaken by a cadre of individuals and technologies previously unknown to the British public. Sensationalised media reports focused on the costs of drilling, instrumentation, industry collaborations, the geography of oil exploration within Britain, the depth of wells and expected size of oilfields and the scale of the potential new industry.

Such coverage helped to produce a mythology of oil as an imagined substance capable of starting a new industry and offering national hope during economic depression. These reports exposed the British public to the possibilities of an extraordinary 20th century industry, with cartoons and detailed geological illustrations creating imaginative representations of Britain's subsurface territories and a positive attitude towards what could easily have been portrayed as an unwanted energy regime in Britain. Serving to raise public perception of geological sciences, and in particular those related to exploration and extraction, the media reports during the interwar period were high impact, yet present only for a fleeting period of time. With the discovery of oil at Eakring, media reports stopped completely in the interests of national security during World War Two.

Almost all media articles were filled with celebratory hyperbole; hopeful speculation lacking empirical evidence. Celebratory reporting also helped to divert attention away from "harmful or controversial material qualities of oil" (Rogers, 2015, p. 71). Throughout chapters 4, 5 and 6, only fleeting mentions are made of the potential environmental impacts of oil. For example, the Archdeacon of Chesterfield described oil as a poison affecting vegetation (Chapter 4), Cadman writing to Lawrence Chubb to assure him there would be minimal injury to amenities (Chapter 5), and various environmental covenants were issued under D'Arcy's 50 year licence agreement (Chapter 6). The relative disregard for environmental issues reflected the temporality of the episodes examined – the need to secure domestic oil for war overshadowed environmental considerations in periods of conflict and economic depression. The interwar period stimulated popular engagements with oil exploration, encouraging national participation in geopolitical debates surrounding oilfield development. Such engagements enrolled audiences who would have remained otherwise ignorant of the rationale behind the need to secure domestic oil.

In terms of field operations, drilling improved markedly during the interwar period due to the replacement of percussive methods with rotary drilling, which doubled drilling speeds. Due to the nature of the technology, it also helped to locate aquifers and coal seams, identify fault zones, past mining activity (where applicable), the presence of cavities and hazards as well as providing geological data on a range of rocks. A large number of physical samples were taken, including cores which, following detailed analysis, informed various branches of geological science, including micro-palaeontology, hydrogeology and coal science. Geological samples could also be used to determine the physiochemistry of rocks, including their engineering properties and structure. Managing a scheme of such magnitude required the collaboration of several government departments, including the Petroleum Department, BGS, Fuel Research Department and Board of Trade, which indicated the growing network of regulators, acting in their various capacities to achieve a unified objective.

Chapter 6 of the thesis focused on the role of four Nottinghamshire oilfields covering the period from 1939 to 1964. Although they provided a small amount of oil during World War Two, it was the central role of the D'Arcy Exploration Company's production site and research centre, the latter located at Kirklington Hall, Eakring, that was particularly significant. D'Arcy supported a large workforce of highly trained specialists who were engaged in oilfield research and development throughout the world. An influx of oil infrastructure and human actors rendered the area a technological zone, where common standards were drawn up for oilfield development (Barry, 2006). The size of the oilfields was calculated, (albeit wrongly to begin with), nodding donkeys, pipes, cables and transport infrastructure were connected spatially and temporally, and improving methods of subsurface visualisation had further refined geologists' understanding of the geological conditions needed for oil accumulation in Britain.

Attracting engineering specialists such as Frank Whittle, Kirklington Hall played an important role in the advancement of drilling techniques and technologies. During World War Two, American drilling crews introduced several revolutionary conservation strategies, significantly, the introduction of standardised equipment, which served to maximise oil output and reduce drilling times. They also increased the longevity of machinery by repairing worn parts. Pioneering secondary recovery techniques, including gas absorption, water flooding and well shooting (a precursor to modern hydraulic fracturing, or fracking) also contributed to a developing understanding of how best to maximise oil production within Britain.

Having nationalised oil with the Petroleum (Production) Act 1934, the British government had removed many of the ownership/royalty issues hampering oilfield development. However, local controversies surrounding vertical territories proceeded unabated. Despite the prevailing wartime conditions, oilfield development was a capital venture that hinged on the governance of subsurface spaces and the cooperation of multiple stakeholders in two and three-dimensions. Securing oil meant staging discursive and diplomatic meetings across scales, from colliery owners to government officials, leading to democratic agreements between landowners, colliery owners and the state. Advancements in geological surveying did, however, finally provide a relatively accurate representation of subsurface territories, making it easier for coal and oil extraction to co-exist. Ultimately, D'Arcy opted to purchase titles to the land surface, whilst entering into fixed financial arrangements with subsurface protagonists. Only in 2014 were changes made to trespass laws, allowing, against strong opposition during consultations, oil and gas companies to drill and to drill and store materials below 300m without the landowner's permission (Carrington, 2014; DECC, 2014b).

Philip Southwell was the key human actor in Chapter 6, continuing the work of his lifelong supporter, university lecturer and employer John Cadman, who continued to engage the public with regular press updates until his death in 1941. Southwell's life-path traced that of his mentor, which exposed him to technically challenging and geopolitically charged situations. These embodied experiences were vital to his role in the British East Midlands, especially in respect to secondary recovery techniques, labour and infrastructure provision. Chronologically, Frank Whittle was the final human actor examined in the thesis. Whittle's turbo-drill, a novel concept in 20th century drilling, was revolutionary in the manner in which it could explore formerly inaccessible spaces in the subsurface. While based at Kirklington Hall Research Station, Whittle undertook his pioneering research, which, following a period of interruption due to funding shortages was later revised and is today used in offshore drilling and fracking for onshore shale gas deposits.

For over a decade, Kirklington Hall Research Station served as D'Arcy's exploration headquarters – a centre of calculation for oilfield development, which involved international collaboration with service companies such as Schlumberger. Now all but forgotten, the Nottinghamshire oilfields once supported a vibrant community of 1,200 workers, signalling the transition from an agricultural to science-based rural economy, up until its demise in the mid-1960s. Semi-structured interviews revealed that oilfield infrastructure improved the social conditions of local residents and connected the sleepy village of Eakring to a global oil infrastructure. Here, scientific data on potential, new, and existing oilfields from around the world was accumulated, interpreted and disseminated, thus producing "action at distance" (Latour, 1987). With the passing of the UK Continental Shelf Act in 1964, Kirklington Hall Research Station realigned its objectives to offshore oil exploration. Indeed, Peter Kent was responsible for locating many of the early North Sea discoveries, which in turn led to his knighthood in 1973.

7.4 Outcomes and scope for further research

This thesis has undergone a number of substantial revisions, with previous iterations, for example, including an additional empirical chapter. Originally positioned as a Victorian pre-history, it examined the role of Riddings, Derbyshire in the development of the paraffin industry from the 1850s to the first two decades of the 20th century. Using ANT as a guiding approach, it focused on the agency of the oil itself, investigating how oils physio-chemical properties (or materialities) led to its dominance as a form of domestic lighting in the 19th century. The chapter was removed on the grounds that it took the focus away from the 20th century, however, it is hoped that future research will revisit this fascinating episode, resulting in the generation of journal articles.

The year 2018 will mark the centenary of commercial onshore oilfield exploration in Britain. To mark the spudding in of Hardstoft No. 1, the supervision team and I plan to organise a full-day session on ‘Hydrocarbon cultures: geographies of oil exploration and exploitation in the 20th century’, at an appropriate international conference (e.g. the annual meeting of the *Association of American Geographers* or the annual conference of the *Royal Geographical Society with the Institute of British Geographers*. The objective is to foster a network of scholars across the arts and humanities, to create a forum to examine the everyday life-world of oil and to uncover the complexities of a substance and an industry that has, until now, remained hidden from examination. The conference session will add to an emerging body of literature which seeks to overcome the ‘intellectual vertigo’ of the oil assemblage. Hannah Appel, Arthur Mason and Michael Watts (eds) *Subterranean Estates: Life worlds of oil and gas* (2014), which draws together geographers, ethnographers and anthropologists, amongst others, is an exemplar of how the oil industry can be examined through a cultural, symbolic, material and social lens to make the industry more intelligible and to uncover hidden aspects of the industry.

According to DECC (2010), Hardstoft No. 1 led to the discovery of more than 30 oil fields, some of which are located in the East Midlands. Using the same conceptual approach presented in this thesis, future research could target oilfield discoveries such as Plungar, in the Vale of Belvoir, Leicestershire, discovered in 1953 and Egmanton, Nottinghamshire, discovered in 1955. Research undertaken at the BP Archive, University of Warwick has already identified a rich body of archival material relating to both sites. Further research into the fascinating links between Bletchley Park, Buckinghamshire and Kirklington Hall Research Station, Nottinghamshire, revealed during oral testimonies would also be a further exciting opportunity.

A long-term objective of this research is a larger project on the historical and cultural geographies of the 'oil age' in Britain, with particular reference to the exploration and exploitation of the oil and gas resources of the North Sea since the 1960s, though also involving further research on the role of British company geologists in other parts of the world. With this wider objective in mind, the supervisory team and I will investigate the possibility of an exhibition in Nottingham, with input and advice from representatives from the BGS and other interested parties, on the history of British oil exploration in the late 20th century.

This thesis has a chronologically arranged narrative which traces Britain's hesitant attempts to become energy independent in the first decades of the 20th century. It has contributed to a number of extremely topical, hotly debated and on-going themes. Firstly, it has added to contemporary histories (Button, 1983; McBeth, 1985; Woodward and Woodward, 2002; Kemp, 2004a/b; Mackie, 2004; Simmons, 2005; More, 2009) on British energy, identifying the key personalities, different types of technologies, institutions and companies involved in an exploration process which moved from a low key discovery in Derbyshire (Hardstoft) to an internationally recognised industry. Secondly, it has reinforced debates on how regions may be conceptualised as arenas based on their industrial and economic past, as well as by their unique qualities, in this context geological, and in particular by the presence of oil-containing anticlines. Thirdly, it has encouraged historical geographers to consider the hidden world beneath their feet. This conceptual shift beyond the physical-topographical draws the field sciences of geology and geography together, extending two dimensional cartographies into the third dimension. By considering territories as volumes existing beneath the ground, historical geographers, building on the work of Weizman (2002), will be brought into contact with a bewilderingly complex array of boundaries and intersections – physical, political and economic - through space and time. Fourthly, it encourages historians of science, and in particular those critically evaluating the history of geology, to consider how the practice of geology as a field based science changed during the 20th century as a consequence of a global shift in energy sources, from coal to oil. Finally, the historical geography of the onshore oil industry, played out within the East Midlands has revealed the cyclical instability of a small-scale industry, helping scholars to understand how the global energy landscape has changed since the advent of the oil industry. This knowledge will empower humanity to consider a world beyond hydrocarbon dependence, as demand for energy continues to increase.

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