Unit-level environment template (REF5b)

Institution: Durham University

Unit of assessment: 7 Earth Systems and Environmental Sciences

Section 1. Unit context and structure, research and impact strategy

1.1 Introduction

UoA7 at Durham is the Department of Earth Sciences: an integrated community whose research combines fundamental and applied approaches to solve important Earth and environmental challenges. We provide an open, collaborative, and equitable workplace in which researchers at all career stages are supported to pursue ambitious and rigorous research, and to deliver impact. We encourage and value individual excellence, applied within a collective framework, across the full spectrum of our activities.

Developments and achievements over the REF period reflect these underpinning values. For example, we have:

- Appointed 9.5 new academic staff (including 3 staff appointed in the REF period, but with post-census start dates) to reposition our research towards environmental hazards and change, and data-driven Earth science.
- Grown both our research income (17%) and our PhD completions (21%).
- Undertaken highly collaborative research in a deeply international context, evidenced through our outputs, collaborative projects, and international leadership roles.
- Delivered a significant research impact portfolio in the areas of risk and resource, including a finalist in the 2018 NERC Impact Awards.
- Achieved Athena SWAN Bronze Award and are addressing a historic gender imbalance (5/9.5 academic appointments are female).

1.2 Structure

Earth sciences are inherently interdisciplinary, requiring combined excellence in aspects of geology, physics, maths, chemistry, biology, and, increasingly, social science. In recent years, there has been a rapid evolution in the discipline's focus – towards finding solutions to issues around environmental change and risk, towards sustainable use of natural resources, and towards realisation of social and economic impact. These contextual factors drive and inform our research structure and our strategy for research and impact.

The expertise and disciplinary specialism of our academics falls within one or more of (i) Observation, e.g. seismology, geodetics, remote sensing, field mapping and sampling, social survey; (ii) Experimentation, e.g. geochemistry, fluid dynamics, rock mechanics, experimental petrology; and (iii) Computation, e.g. innovative seismic processing, geodynamics, hydrological flow simulation, big-data analysis. Academic staff are supported to design and implement their own research operations and to develop the necessary collaborations within the Department, across Durham University, and beyond. Collaborations extend beyond academia, to engagement with industry and policy makers, with funders and the broader disciplinary community, and with stakeholders in ODA countries.

Individual expertise is collectively applied and supported within three cross-cutting Themes. They provide the framework to combine specialist skills and knowledge to address broader research questions that are both curiosity-driven and relevant to society. No individual is bound to a single Theme and many operate across several projects aligned with multiple Themes.

1.2.1 Theme 1: Earth Surface Processes and Hazards

Theme 1 addresses processes that form and modify the Earth's surface, and that transport material and energy to and across the surface, including many hazardous processes. We collaborate with practitioners and stakeholders to support management and mitigation of these hazards.

REF Period Highlights:

Research in this Theme has yielded new insights into the accumulation of fault strain (**McCaffrey**, **Walters**) and subsequent rupture (**De Paola**, **Holdsworth, Nielsen**), drivers of volcanic eruptions (**Humphreys**, **Llewellin**, **Wadsworth**) and their impacts (**Brown**, **Horwell**), and the structure and emplacement mechanisms of gravity currents (**McElwaine**, **Talling**). An Impact Case Study (ICS) addresses health impacts of volcanic eruptions (**Horwell**). The joint appointment of **Talling** further enhanced strong interdisciplinary links with the Hazards and Surface Change research group in Durham's Department of Geography, with further new appointments enhancing Earth observation, experimentation, and computation in remote sensing of earthquakes (**Walters**), and volcanic and magmatic processes (**Wadsworth**). A laboratory for Volcanological Fluid Dynamics (**Llewellin**) was established with NERC support in 2018.

1.2.2. Theme 2: Climate, Environment and Resources

Theme 2 investigates the causes and consequences of changes to Earth environments on multiple timescales, seeking solutions to environmental and resource-related issues of industrial and societal importance, including decarbonisation, energy security, air pollution, and de-risking extractive industries. Since REF2014, we have consolidated relevant expertise into a single Theme, reflecting a shift away from petroleum exploration towards a more diverse portfolio of research to support an integrated and sustainable approach to geo-resources.

REF Period Highlights:

Research in this Theme has uncovered the causes of environmental change over months, millennia, and millions of years using isotopic records (**Baldini**, **Gröcke**, **Macpherson**, **Selby**), explored the consequences of environmental change in deep time through the fossil record (**Harper**, **Smith**), and advanced understanding of biogeochemical cycles in modern environments (**Burton**, **Gröcke**, **Worrall**). Resource-related research has addressed decarbonisation of energy (**Gluyas**, **Mathias**) and the flow, storage, leakage, and retention of fluids in the subsurface (**Aplin**, **Greenwell**, **Jones**). Research in this Theme has delivered an ICS for provision of absolute geological age data for the mineral industry (**Selby**) and for the assessment of reservoir potential of fractured basements (**Holdsworth**, **McCaffrey**), the latter a finalist for the 2018 NERC Impact Awards. The appointment of **Smith** has brought novel quantitative techniques to reconstruct the origins of modern animal groups, and **Knapp** (in-period appointment with post-census start) will bring new strength in catchment hydrology and biogeochemistry.

1.2.3. Theme 3: Physics and Chemistry of Earth and Planetary Processes

Theme 3 explores the fundamental physical and chemical processes that have shaped the Earth and other bodies, from formation to the present-day, and on length scales ranging from molecular to stellar. Blue-skies, curiosity-driven research in Theme 3 also provides a rigorous and quantitative foundation that underpins research in Themes 1 and 2.

REF Period Highlights:

Research in this Theme has explored the causes and consequences of tectonic processes through field studies, petrology, geochemistry, and numerical modelling (**Allen, Niu, Phillips, van Hunen**), and used cutting-edge geophysical techniques to image the structure and dynamics of the Earth's crust and upper mantle (**Hobbs, Peirce**). Magmatic processes on Earth and other rocky bodies have been constrained through geochemical analysis in our world-leading laboratories (**Burton**, **Iveson**, **Macpherson**, **Niu**, **Nowell, Prytulak**). Physical processes on the surface of Mars, and interior of stars have been modelled numerically (**McElwaine**). New appointments have strengthened research in mantle geochemistry (**Prytulak**) and fault dynamics and subduction processes (**Menzies**); new appointments (in-period, with post-census starts) are bringing new expertise in deep-Earth seismology (**Jenkins**), and cross-disciplinary expertise in data analysis and advanced computational techniques (**Valentine**).

1.2.4. Interdisciplinarity

Departmental research is built on collaboration among researchers with diverse technical expertise, within and across Themes, and exploits the interdisciplinary opportunities afforded by Durham's Research Institutes. The Institutes are hubs to connect researchers internally, and foci for liaison with external practitioners and policy makers, nationally and internationally. The Department engages extensively with, and takes leadership roles in, the Durham Energy Institute (**DEI**), the Institute of Hazard, Risk and Resilience (**IHRR)**, and the Institute of Advanced Studies (**IAS**):

- DEI (**Gluyas** Executive Director 2017-present) addresses national and global energy challenges and is a key part of the Department's strategy to move away from conventional hydrocarbon research, towards research that supports a healthy and sustainable future environment. DEI engages over 100 research staff in 12 departments, covering social sciences, geoenergy, renewables, and fusion materials for energy and energy conversion.
- IHRR (**Horwell** co-Director 2012-2016) links hazard and risk researchers across the University with one another, and with external stakeholders. Department engagement is primarily through geohazards research, including through the cross-Faculty Action on Natural Disasters Doctoral Training Initiative (**Llewellin** Director 2016-present), and the research that underpins the 'Preparing for volcanic eruptions' ICS.
- IAS (**Greenwell** co-Director 2017-2020) incubates and funds cross-disciplinary projects connecting Durham researchers with influential disciplinary leaders around the world. IAS has supported 12 senior Fellows (academics, policy-makers and practitioners) for extended research visits (usually three months) into the Department during the REF period.

Examples of large research projects that have a strong interdisciplinary basis include:

1. Research underpinning the 'Preparing for volcanic eruptions' ICS arose from **Horwell**'s Health Interventions in Volcanic Eruptions consortium (Wellcome/DfID), which contributed to her award of the EGU's Plinius Medal for interdisciplinary research in natural hazards in 2020. The consortium involved anthropologists, behavioural psychologists, clinical pulmonologists, exposure scientists and PPE experts, at research organizations in the UK, Indonesia, Mexico and Japan, and humanitarian organizations, including WHO, the Red Cross and Save the Children.

2. The ReFINE consortium (2013-present) was developed through the DEI and investigates the environmental impacts of fracking. Departmental expertise in geophysics (**Foulger**, now emeritus) and environmental biogeochemistry (**Worrall**) combines with expertise in engineering, transport, biological modelling, and policy across seven national and international academic institutions (including Newcastle, Stanford, Cambridge, IIT Bombay) to inform and drive global policy on fracking.

Interdisciplinary research is also supported through co-supervision of students in CDTs and DTPs that straddle Departments, Faculties, and Institutions (Section 2.4).

1.3 Supporting research and its impact

A core principle is to provide an enjoyable working environment in which to engender a dynamic and enthusiastic research culture. Given the sometimes serendipitous and opportunistic nature of research, our formal structures and processes are there to provide overall direction and a supportive framework that will enable our staff and students to maximize the quality and impact of their research, whilst minimizing administrative burden. Oversight of structures and processes comes from a Departmental Research Committee comprising members of staff drawn from across the three research Themes and representing all career stages, with support from a Senior Research Administrator.

1.3.1. Supporting the Research Pipeline

Many research projects originate from informal conversations. The Departmental research community interacts through a bustling coffee room, a weekly postgraduate-run social gathering, weekly seminars, and various informal meetings of disciplinary research groups – for example, weekly 'Volc-Coffee' and 'Fault-Tea' meetings each attract 15-20 researchers, across all career stages. Annual 'Research Away Days' facilitate wider research discussions, and a Department Conference every June showcases research from the whole Department, including UG research projects. External research engagement is further supported by the International Office and the University Research Institutes – particularly IHRR, IAS, and DEI.

All academic staff receive £1000 research funds per annum. Additionally, 10% of overheads on external income is returned directly to staff to spend on research-related activities, and a further 10% is returned to the Department. The latter budget is overseen by the Research Committee, and used to support broader research initiatives, including incoming and outgoing research visits, workshops, and pilot work (annual budget ~£50k).

The development of research ideas into research proposals and projects is supported at the Department level by several initiatives, including:

a) A 'grant buddy' scheme pairs staff bidding for funds with an experienced colleague who has a strong funding track record, to act as sounding board and 'critical friend' throughout bid development. This scheme is augmented by wider peer-reading of grant proposals, including cross-Theme reading to identify and cultivate opportunities for broader impact.

b) A 'Fellowship Development Fund' brings promising Fellowship candidates to Durham for periods of 1–3 weeks to scope ideas and undertake pilot work with staff mentors. The scheme has supported 21 visits over the REF period, leading directly to 6 successful applications for independent research Fellowships (including Marie Curie, NERC Independent Research Fellowship, Royal Society Newton International).

c) 2–4 week periods of ‘mini research leave’ enable PIs to relinquish non-essential activities (to be ‘out-of-office’) to develop a proposal for short time-frame funding calls or undertake other time-sensitive research and impact activities.

At University level, support comes from dedicated funder Liaison Committees, and Research & Innovation Services (Section 4.4, REF5a). Translation of research into high-quality outputs is supported through one-to-one mentoring at all career stages, disciplinary discussion groups, and Department-wide activities at Research Away Days.

1.3.2. Supporting the Impact Pipeline

Our Impact Case Studies (ICS) are underpinned by research excellence drawn from all three Themes. They exemplify research-related interactions and collaborations with industry partners, international NGOs, and communities, to address issues of mutual interest. All three case studies emerged through providing specialist expertise, and applying new techniques and approaches designed to address problems initially of academic focus: use of onshore-offshore analogues; Re-Os geochronology; toxicity of volcanic emissions. The Fractured Basement Reservoirs case study also involves close research partnerships with a Durham-based spin-out company (Geospatial Research Ltd).

The impact potential of individual projects is monitored by the Research Committee via an Impact Co-ordinator (**Holdsworth**). This “Impact Nursery” provides resources to support projects delivering impact, and to nurture projects with the potential to do so in the future. The structures outlined below have been implemented over the last two REF cycles to maximise opportunities to create impact, to promote a more outward-facing research portfolio, and to translate research outcomes into changes in policy and practice among stakeholders.

i) Strategic academic posts:
Strategic appointment of academic staff has been used to support impact and knowledge exchange (see also Section 2.2.1). **Gluyas** (appointed 2009) has continued to deliver impact in the geoenergy sector, leveraging his experience drawn from a distinguished career in the commercial sector, before moving to academia. **Talling** (appointed 2016) has delivered impact in geohazards, mitigating submarine flow hazards to international cable networks. **Brown** (appointed 2011) and **Aplin** (appointed 2013) have led impactful engagement with petroleum exploration companies via the Volcanic Margins Research and GeoPOP Consortia.

ii) Durham Earth Sciences Advisory Board (DESAB):
DESAB comprises individuals from the energy, mineral, geotechnical and finance sectors, governmental bodies (e.g. Environment Agency, BGS), NGOs and leading universities. Biannual meetings help drive and define our impact agenda, broaden the knowledge base of our staff, and provide a sounding board for new ideas and initiatives in research and research-led teaching. For example, recent advice has helped shape the Departmental response to the energy transition.

iii) Consultancy and partnerships with spin-out companies:
Departmental expertise and infrastructure provide significant impact to external organisations, and staff are encouraged to undertake consultancy contracts to broaden research impact. Since 2013, staff have undertaken consultancy with international and national end-users in industry and beyond, including: BP, Shell, Chevron, Hurricane, ConocoPhillips, Equinor, and OMV. The Department has launched three successful spin-out companies – Ikon GeoPressure (1998), Geospatial Research Ltd (2004), Geoenergy

Durham Ltd (2010) – with whom we continue to partner to engage more effectively with external public/private sector organisations, and obtain both data and funding.

1.4 Review of 2014-2021 Strategic Objectives

Goal 1: Diversify research income

Outcome: We continued to win funds from a diverse portfolio of agencies: over the REF period, projects each with fEC value >£100k have been won from more than 20 different funding bodies and organisations. We have replaced historically high income from the extractive industries with other funding sources (Goal 2).

Goal 2: Build industry partnerships and investment

Outcome: During the REF period, dialogue with DESAB has helped us to identify future industrial and societal activities that are likely to depend on academic geoscience research. This has supported a broader Departmental strategic move towards partnership with stakeholders that are embracing environmental solutions and the transition towards a low carbon economy. This approach is exemplified by the major projects CESI and Muography (Table 1, Section 3).

Goal 3: Attract PGR students and postdoctoral and academic researchers from around the world

Outcome: Staff played a central role in winning funding for a suite of doctoral training programmes, including 5 EU ITNs (Section 2.4). More than half of PhD students who started over the REF period are EU or International students, and all 25 students in the GCRF CDT cohort (4 of whom are in the Department) are citizens of DAC-listed nations. A major innovation has been the development of MSc(Res) thematic programmes in Volcanology, in Geoenergy, and in Computational Geoscience (Section 2.4). As a result of these efforts, PGR student numbers increased substantially over the REF period (e.g. PhD awards up 21%, normalised per annum). Efforts to attract more international postdoctoral researchers and academic visitors have also been very successful (Sections 2.2 and 4.1).

Goal 4: Enhance international profile and collaboration

Outcome: Staff have collaborated very widely over the REF period – 87% of REF outputs include international co-authors – and hold a range of international leadership roles, as evidenced in Sections 3 and 4. Ten academic staff hold visiting professorships/fellowships at international institutions, and, over the REF period, the Department has hosted more than 40 visiting academics for research visits longer than one week.

Goal 5: Strengthen involvement with University Research Institutes (URIs) and Centres

Outcome: Over the REF period, UoA staff have had leadership roles in URIs (Section 1.2.4) and the Durham Centre for Soft Matter (**Wadsworth**, committee member). Staff engaged strongly with IAS through three major projects, and by hosting seven IAS Fellows and five COFUND Fellows. 15% of successful research grant proposals identified direct involvement of an institute.

Goal 6: Diversify areas of impact

Outcome: All Impact Case Studies returned for REF2014 related to Geoenergy. The initiatives in Section 1.3.2 have successfully broadened impact into other areas for REF2021: health impacts of volcanic eruptions; and reducing the cost and impact of mineral exploration.

1.5 Vision and Strategy beyond 2021

Informing society's response to challenges posed by the natural environment motivates research across the University. Research in the Department is central to this effort, particularly through fundamental research into the physics and chemistry of Earth and environmental processes. Over the next five years we will seek to capitalise on this local context, through enhancing capacity in three main areas (recent appointments are **underlined**):

1. Natural Hazards and Risk

Hazard and risk are areas of leadership and broad interdisciplinary activity at Durham, to which the Department contributes fundamental research in solid Earth and Earth surface processes, and solutions-based research on the impacts of hazards, facilitated, in part, through engagement with IHRR. **Talling**'s joint appointment provides an opportunity to develop research into geophysical density flows (with the Department of Geography) while augmenting Departmental expertise in this area (**McElwaine**, **Brown**). Volcanic hazards will be addressed through experimental approaches (augmented by appointment of **Wadsworth**) in the new Volcanological Fluid Dynamics laboratory, and petrological and geochemical approaches (**Humphreys**) to understand the mobilisation of magma mushes. We will seek intersection and augmentation of these approaches with ongoing research in rock mechanics (**De Paola**, **Nielsen**), seismology, and fault reactivation, bolstered by the recent appointments of **Walters** and **Jenkins**, and with landslide and surface deformation monitoring in the Department of Geography. Geochemical approaches to monitoring surface movements and fault dynamics will also be developed through the appointment of **Menzies.** Advances and impact achieved in understanding the health hazards of volcanic eruptions, and community protection, will be expanded to address factors affecting childhood exposures to urban particulates (**Horwell**). Such work will increasingly develop interdisciplinary links with social, health, and exposure sciences, at Durham and beyond, to inform approaches and disseminate effective practice. Advances in socially-informed approaches to the solution of Earth and environmental problems will bridge into the second of the main objectives of the coming period.

2. Energy and the Environment

We will build further capacity to address the industrial and environmental challenges posed by development of a low-carbon economy, cementing our transition away from hydrocarbon funding. Decarbonisation is a long-term commitment for society and the Department will enhance work with DEI to understand the most efficient management of necessary, existing hydrocarbon resources, and their replacements. This will include work to improve understanding of the retention and leakage of fluids in the subsurface (**Aplin, De Paola**, **Holdsworth**, **Jones**, **McCaffrey**, **Worrall**); investigation of carbon sequestration in sandstone reservoirs (**Worrall**); and extraction of geothermal heat from abandoned mines (**Gluyas**, **van Hunen**). **Knapp**'s recruitment will enhance the Department's capacity to understand hydrological and environmental challenges, and we will seek solutions to natural and industrial pollution in the UK (**Worrall**) and abroad (**Greenwell**), many of which may be exacerbated by climate change (**Baldini**). A new undergraduate degree programme in Climate Science, starting 21/22, underlines commitment to expansion in this area.

3. Quantitative Approaches to Earth and Environmental Research

The use of large data sets and numerical simulation are essential to modern geoscience research. Durham has made substantial institutional commitment in this area, launching an Institute for Data Science (IDAS; in 2019) along with both postgraduate and undergraduate degrees. These initiatives will provide an interdisciplinary framework within which the

Department will exploit significant recent enhancement of infrastructure and personnel to model a range of natural processes. **Jenkins** and **Valentine** will augment Departmental expertise in deep Earth observation with new expertise in seismic observation, pattern recognition and data mining. **Walters** will apply large remote-sensing datasets to investigate surface movement and its subsurface drivers. **Smith** will develop novel mathematical techniques to improve stratigraphic correlation and reconstruct the origins of modern animal groups. Quantitative experimentation, instrumentation, and analysis are also growth areas for the Department. The quality and impact of the Department's geochemical facilities are widely acknowledged, and recruitment of **Prytulak** will ensure continued leadership in this field, as we expand into novel applications in archaeology and bioscience (**Gröcke**; **Nowell**). Substantial UKRI investment has augmented capacity in ocean bottom geophysics instrumentation (**Peirce**) and terrestrial scanning (**McCaffrey**), with direct observation of submarine sedimentation (**Talling**), which we aim to transfer to subaerial work in volcanic settings (**McElwaine**, **Talling**, **Brown**). UKRI and ERC investment is transforming our capacity for experimental investigation in rock mechanics (**De Paola**), fluid dynamics and rheometry (**Llewellin**, **Wadsworth**), and experimental petrology (**Humphreys**).

1.6 Research Integrity

The Department is strongly committed to ensuring the highest standards of personal and professional behaviour in research.

1.6.1 Ethics and Transparency

Durham University's ethics policies provide a framework for reviewing all research projects, which is facilitated through Departmental and Faculty ethics panels. Routine peer-reading of proposals and outputs supports ethical practice throughout the research cycle. All research collaborations with industry and other HE institutes, either in the UK or abroad, require a legal agreement that is developed in conjunction with Legal Services. Funding in 'cautionary areas', which includes extractive industries, also requires ethical approval. On an individual level, all staff have been trained in the consequences and operation of new data protection laws (GDPR), and in unconscious bias.

1.6.2 Open Research

The Department is strongly committed to the principle of open access to publications and data. During the REF period 87% of publications that have a Departmental author are available through open access. The Department has also been involved in novel schemes to promote open access to research outputs and datasets:

- Volcanica (http://www.jvolcanica.org) is the first 'diamond' open access journal in the Earth Sciences – i.e. it is free for authors, and free for readers. This community-led, not-for-profit journal covers all aspects of volcanology and was co-founded by **Wadsworth** in 2018. It has published 36 articles, and includes dual-language abstracts to broaden access.
- The 'mantleplumes' portal (http://www.mantleplumes.org/), created and maintained by **Foulger** since 2003, has made research on the origin of anomalous volcanism "hot spots" accessible to cross-disciplinary researchers, the media, and the public. Over 900 scientists have contributed, and its newsletter has a distribution of 6000.
- The HiQuake database of anthropogenically-induced earthquakes was created by **Foulger** and **Gluyas** and is freely available to all stakeholders, including industry,

government and the general public (https://inducedearthquakes.org). It has received around 250,000 visitors since its inception in 2018.

- The International Volcanic Health Hazard Network (https://www.ivhhn.org), founded and directed by **Horwell**, is a global umbrella organisaation which provides evidence-based informational products (some endorsed by the World Health Organization) for distribution during eruptions, and advises governments on public health response. Products have been translated into ten languages.

Section 2. People

2.1 Overview

The UoA REF return includes 34.86 FTE Category A staff. Over the period we have hosted 18 Category A fixed-term independent Research Fellows (total: 33 person-years), 65 fixed-term postdoctoral research assistants (total: 118 person-years), and 132 Research Students have matriculated (87 PhD, 45 MSc(Res)/MPhil).

We seek to recruit and retain Earth and environmental scientists who are, or who have the potential to be, world-leaders in their disciplines. This strategy underpinned a period of significant expansion over the 15 years preceding the current review period. Growth prior to 2014, coupled to the success of our staff development programme, resulted in an increasing profile of senior, promoted Category A staff. In the current REF period, we have therefore targeted new academic appointments at Assistant Professor level. Over the REF period **Armstrong**, **Foulger**, and **Goulty** retired, **Davidson** passed away, **Davies** and **Williams** moved to other Institutions, **Imber** left academia, and **Mathias** moved to the Engineering Department (though remains in UoA7). Appointments of **Humphreys** (who moved from a Fellowship onto a permanent academic contract), **Menzies**, **Prytulak**, **Smith**, **Talling**, **Walters**, and **Wadsworth** (and **Jenkins**, **Knapp**, and **Valentine** with post-census start dates) strengthen and invigorate all three research Themes (outlined in Section 1).

2.2 Staff Recruitment and Development

2.2.1 Recruitment

Recruitment strategy is determined by the Board of Studies and Senior Management Group, aligned with the broader Departmental strategy outlined in Section 1. Department strategy links with University level policy and strategy via an annual planning round – this looks ahead over a two-year period and proposes new appointments in response to likely retirements, projected changes in student numbers and grant income, and identification of priority research areas.

These considerations have informed a mix of discipline-specific and more general advertisements during the review period, underpinned by the intention to: 1) recruit the very strongest researchers; and 2) support our goal of increasing diversity. All staff are recruited by gender-balanced panels using carefully worded job descriptions and adverts, following strict University protocols to ensure transparency and compliance with diversity and equality policies. The balance of protected characteristics of the applicant pool for any vacancy (which are all conducted under the two-tick scheme) is monitored, with every effort to ensure shortlists that reflect applicant diversity. The effectiveness of our approach is illustrated by recruitment rounds in 2015, 2017 and 2020, in which seven Assistant Professors were recruited. Each call attracted >200 applicants, with 25% female applicants and 43% female hires.

2.2.2 Staff Development

New staff receive a bespoke start-up package and are assigned reduced teaching and citizenship workloads, allowing them rapidly to become established within the Department. Regular discussions with the Head of Department (HoD) and mentors define specific research and impact goals, direct new hires to sources of support and opportunities for collaboration within the Department and University, and align new hires with our core EDI principles. A shortening of the statutory probationary period to one year, in 2015, reflects our commitment to rapid integration of new hires into their roles.

Staff engage with peer-support throughout their careers and all have at least one mentor from the Department (some also have an external mentor from another department) with whom they meet regularly to discuss professional development outside formal management processes. Both Department and University support continuing professional development of researchers, and incubation of research projects, collaborations, and impact. These include competitively awarded Research Seedcorn and Research Impact funds to support pump-priming and proof-of-concept activities, and courses and workshops run by the Durham Centre for Academic Development (DCAD). The Department runs regular internal workshops on, for example, grant-writing and paper-writing, and has a 'grant buddy' scheme to support development of competitive funding applications (Section 1.3.1). Staff are also encouraged to share pre-submission manuscript drafts with colleagues to maximize the quality and impact of outputs. Many groups of staff, postdocs, and students meet regularly via informal and supportive disciplinary groupings (e.g. volcanology, geochemistry, structural geology/tectonics, geodynamics).

Research leave is accrued by all academic staff, regardless of FTE weighting, as a nominal allowance of one term of leave for every six terms worked. Staff are expected (but not required) to apply for their full entitlement of research leave. The Department uses the annual round of staff development and progression discussions to support staff in planning optimal times for leave. Leave is awarded for applications that demonstrate clear plans for scholarship or research, assessed by the Department Research Committee.

The University overhauled its promotion and progression processes in 2015 to be more transparent and robust against unconscious bias. Since then, all staff submit a standard CV, annually, to the Departmental Progression and Promotions Committee (DPPC) chaired by HoD, and including a member from outside Durham University, which assesses CVs against transparent benchmark criteria, and recommends staff for consideration by the Faculty Promotions Committee. The HoD then meets each staff member to provide tailored feedback, discuss career development goals, and agree objectives for the coming year.

All academic staff are ex-officio members of the Board of Studies, which is the Department's decision-making body. Independent Research Fellows are invited members, and there are PDRA and PhD student delegates to ensure full representation and participation in decision-making.

2.2.3 Independent Research Fellows (IRFs)

The Department hosted 18 IRFs over the REF period (NERC, Royal Society, Newton International, Leverhulme, Marie Curie). Research Fellows are energetic contributors to research vitality, and we have invested in expanding the number of Fellows in the Department by establishing a dedicated 'Fellowship Development Fund', managed by Research Committee (Section 1.3.1). This scheme has directly resulted in Fellowship awards to Stevenson, Dobson, Topper, Zhitova, Heron, and Soldati, and one permanent appointment (**Wadsworth**). We treat

each IRF as an academic staff member, with all the same mentoring and career development opportunities (Section 2.2.2) including the same level of access to facilities and services. IRFs are encouraged and supported to obtain research funds, and to supervise postgraduate students and MSci research projects, in order to build a research group. IRFs are not required to undertake teaching, but receive Departmental and University support if they wish to gain teaching experience. Likewise, IRFs have access to the same impact, engagement and development opportunities as academic staff. The DPPC handles promotion and progression of IRFs following University procedures for Research Track staff.

2.2.4 Postdoctoral Research Assistants (PDRAs)

Over the REF period, the Department has employed 65 PDRAs, averaging 17 at any given time. Using the same approach as for academic staff recruitment, we receive strong applicant pools, resulting in a PDRA body that is highly international (almost 50% non-UK nationals), significantly enriching the diversity of the research environment and raising the Department's international profile. Several PDRAs have gone on to permanent academic posts at other Universities, including Utrecht, Nancy, Glasgow, and Hull.

The University has adopted the Concordat for Researcher Development and the Department seeks to meet all its expectations. Each PDRA is assigned a mentor on arrival, and has regular meetings with the Postdoctoral Liaison Officer, a member of academic staff responsible for supporting the postdoctoral community. To support their integration into the Department's research environment, each PDRA is invited to present their research to the Department soon after arrival and is assigned to research offices with mixed-discipline groupings. PDRAs participate in Departmental research activities, such as Research Away Days, and are expected to attend informal disciplinary discussion groups, in addition to their own formal project meetings.

2.3 Equality, Diversity and Inclusivity (EDI)

EDI is a core principle in all aspects of our work and is fundamental to an enabling and supportive research culture. The Department obtained the Athena SWAN Bronze Award in 2016 and will submit a Silver Award application in 2021. The Bronze Award was underpinned by a broad consultation of staff and students via a survey developed with the University HR department (which attracted > 70% participation), followed up by focus group meetings. This allowed us to develop a plan informed by experiences of colleagues and students, and by sector best practice. The team of staff, ECR, PGR and UG that developed the Athena SWAN plan evolved into a permanent Equality, Diversity, and Inclusivity (EDI) Committee, tasked with developing and implementing inclusive policies and actions, including and beyond the protected characteristics, to embed equitable treatment for all in an accepting and diverse environment. The Department runs termly social meetings as part of the University's First Generation Scholars Network, which aims to create an inclusive environment for students and staff for whom University study and research were not part of their background. The EDI Chair (**Greenwell**) sits on the Department's Senior Management Group.

Compulsory training in unconscious bias is undertaken by all staff, and training in awareness of sexual violence and misconduct is undertaken by all staff and postgraduate students (Durham's Colleges lead in this area for undergraduates). A wide range of actions have been implemented to encourage a more supportive and equitable Departmental culture. These include family-friendly facilities (including baby-changing, cot, milk fridge, microwave) and working practices, such as scheduling meeting and social activities between 10am and 3pm. We have introduced gender neutral toilets, run multicultural pot-luck lunches for staff and

postgraduates, and ensured online and printed materials celebrate diversity in the Department and the discipline. The Committee produces monthly bulletins that communicate opportunities for staff and students to increase their awareness and engagement with EDI issues, and highlight good and questionable practice from across the sector.

Departmental responsibilities are overseen by the HoD and the Senior Management Team (currently 30% female) to balance workloads in terms of colleagues' FTE weighting, experience and interest. Over the REF period, all requests for flexible working patterns have been agreed. Opportunities to engage in Departmental management roles are made through open calls and are discussed with HoD as part of both career progression and work-life balance at annual reviews. The Department has also benefitted from the University's revamp of the promotion process to use objective and externally-scrutinised review of all academic progression (see Section 2.2.2): all eligible Category A female staff have secured promotion at least once in the REF period.

Outputs for REF were selected through peer-reading by at least two members of staff, calibrated against external benchmarks, on the basis of scientific significance, originality, and rigour, and without regard to the status or other characteristics of the authors.

2.4 Research Students

60 PhD students and 29 MSc(Res) students are currently under supervised study or examination and a total of 132 graduate students have begun their studies during the REF period, with 64:68 Female:Male split. Doctoral graduates have increased by 21%, normalised per annum, compared with REF2014. Using a gender-balanced panel, we conduct interviews for all studentships to ensure equitable recruitment of strong candidates. All research students have a supervisory team that includes at least two Departmental academic staff, and external staff as appropriate. The supervisory team is responsible for guiding the student through their research, providing training (directly or by sourcing support) in all technical and academic matters. The supervisors also facilitate access to opportunities for outreach or impact development through Departmental and University resources. Research students are accommodated in open-plan clusters that cut across year groups and disciplines, facilitating peer-support and exchange of ideas.

All research students have a review team comprising two members of staff who are not involved in the project, and who conduct yearly progress reviews. Students submit written work and undergo an interview with the team. Progress reviews also serve to identify additional support and training needs for students, and the review team is available to offer general academic advice and support throughout their study. The Department's support measures contribute to its 90% on-time completion rate, which is the best of all departments at Durham University. PhD graduates have gone on to a wide range of careers in research (e.g. British Antarctic Survey, United States Geological Survey, Japan Agency for Marine-Earth Science and Technology), academia (e.g. Johns Hopkins, Baghdad, McMaster, Liverpool, Derby), and the commercial sector (e.g. Nature Communications, BP, Chemostrat, Shell, Nestle, Northumbrian Water).

The needs and opinions of postgraduate students inform Departmental action through a Postgraduate Education Committee, which includes student representatives from each PhD and MSc(Res) year group. The Director of Postgraduate Research also chairs regular open fora to allow informal discussion. The PG Director is part of the Department's Senior Management Team and a PG student representative also sits on the Board of Studies. Initiatives arising from these processes include the provision of dedicated quiet space for

writing-up (from 2014) and development of several dedicated student training initiatives, including two NERC-funded Advanced Training Short Courses (in numerical modelling, and in design of laboratory experiments). Our research students appreciate this involvement: scores from the 2019 national Postgraduate Research Experience Survey were in the top quartile for Russell Group Universities in 7 out of the 8 categories, including 'supervision', 'research culture', 'wellbeing', and professional development'. All 35 respondents agreed with the statement: 'Overall, I am satisfied with the experience of my research degree programme'.

Postgraduate students make prominent contributions to the Department's research culture. They organise a weekly social gathering for the whole Department, regular cultural events and social fieldtrips, and a series of Research Forums throughout the year in which all PG students present their research to the Department.

A range of strategic actions have contributed to the increase in PGR numbers over the REF period:

1) Encouraging staff to seek funding for studentships and DTCs

Staff are supported to develop applications for studentship funding programmes via the same mechanisms as for other funding opportunities, and are encouraged to participate in multi-institution doctoral training programmes. Applications are enhanced by a University DTC framework that provides a blueprint for creating programmatic doctoral training centres regardless of funding source. The Department is a key partner in the NERC-funded IAPETUS DTP (2013-2018), IAPETUS2 DTP (2019-2024), Oil & Gas CDT (2014-2020), GeoNetZero CDT (2020-2024), the EPSRC-funded Aura CDT (2019-2024), the GCRF CDT (2019-2021), the donor-funded Action on Natural Disasters DTC (2016-2021), and 5 EU ITNs (SUBITOP, METTRANS, CREEP, VERTIGO, and TOPOMOD). All of these programmes involve interdisciplinary research and training, and provide cohort support for the participating students.

2) Devising innovative routes into graduate research

In AY 17/18 we launched a new thematic MSc(Res) programme in Volcanology. We proactively recruit yearly cohorts of students to this 12-month MSc by Research programme, which includes cohort training in disciplinary and transferable skills. The number of students has increased each year, totalling 12 to-date, with 5 graduates, so far, going on to doctoral studies in Durham and elsewhere. The model is now being rolled out for similar programmes in Computational Geoscience and in Geoenergy.

Section 3. Income, infrastructure and facilities

3.1. Research Income

The Department generated research income of £25.3M over the REF2021 period, representing a 17% increase compared with the REF2014 period (normalised per annum) driven primarily by a 50% increase in Research Council income (Figure 1).

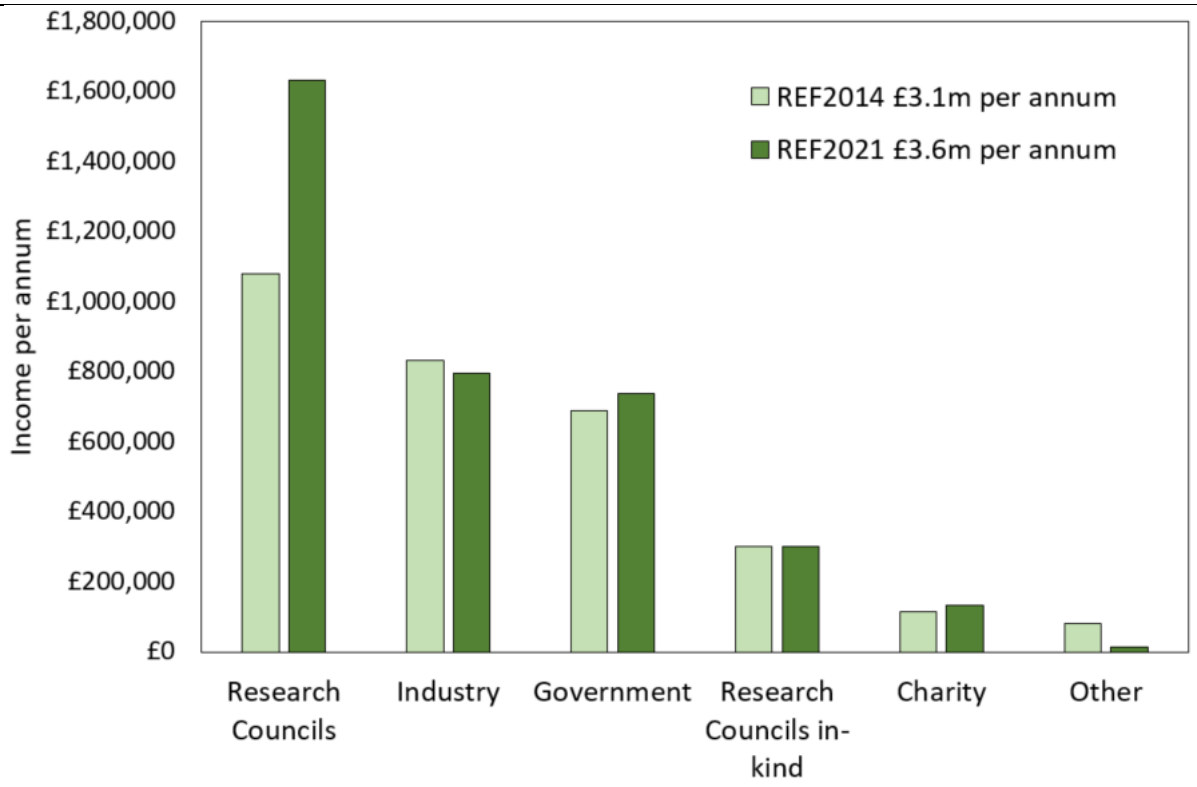

Figure 1: Income comparison REF2014/REF2021

3.1.1. Support for Income Generation

Our increased income generation reflects the introduction of new support measures, ranging from mentoring of individuals to institutional support from the University's significantly expanded Research & Innovation Services (RIS).

In addition to the bespoke Departmental support detailed in Section 1.3.1, University-level Liaison Committees for Research Councils and other major funders, such as GCRF, sharpen proposals through peer review and mock panels and interviews, and provide a hub for sharing best practice. Together, Liaison Committees and RIS support the development of interdisciplinary research programmes via cross-departmental and cross-Faculty scoping meetings and workshops. The success of these initiatives is evidenced by the 50% increase in our Research Council funding over the REF period.

Mindful of continuing uncertainty over research funding in the next REF cycle, and the changing nature of the research landscape, our aim is to continue to develop and diversify income streams. We are working to expand our engagement with other funders, such as: EPSRC through engagement with Physics and Chemistry Departments via expertise in the physics and chemistry of high temperature materials; ESRC and GCRF through geohazard and geohealth initiatives; and industry and agencies to build more sustainable geoenergy solutions. We will also build on our existing successes in capturing large research consortia, mentoring less-experienced staff, and giving them the confidence to apply to large grant programmes. We will continue to prioritise doctoral training centres and partnerships, building on the considerable successes that we have achieved with NERC, GCRF, ITN, and industry, remaining alert to emerging opportunities.

3.1.2. Major Awards During REF2021 Period

We respect the fact that not all the research in our portfolio requires substantial funding and that some areas of research are more fundable than others. In that context, over the REF period, 89% of Cat A staff have been PI on at least one successful funding award. Department PIs have secured >30 'standard grants' (NERC, Leverhulme Trust, UK Government, Industry) with a fEC value over £100k, and three Durham-led major projects: ERC Consolidator Grant – Storage and Eruption of Mushy Magma Systems (**Humphreys**, £2.3M fEC); UKRI/GCRF Consortium Grant – Factors Affecting Childhood Exposure to Urban Particulates (**Horwell**, £2M fEC); Wellcome/DfID Consortium Grant – Health Interventions in Volcanic Eruptions (**Horwell**, £0.6M). Members of the Department have also made major contributions to a number of externally-led major research projects. Significant collaborative funding awards are listed in Table 1, totalling £3.85M to the Department.

Table 1: Major collaborative research projects funded during the REF period

Project	**UoA PI/CoIs**	**Funding**	**Key partners**	**Topic/Title**
CESI	**Gluyas**	EPSRC/Siemens £900k to DU £20M total	Newcastle, Sussex, Heriot Watt, Edinburgh	National Centre for Energy Systems Integration: Sustainability and affordability of energy supply
OSCAR	**Hobbs** **Peirc**e	NERC-NSF £601k to DU £1.7M total	NOC, UCL, Newcastle, Virginia Tech	Oceanic and seismic characterization at an axial ridge
ReFINE	**Worrall** **Foulger**	NERC/Environment Agency/Industry £597k to DU £1.7M total	Newcastle, Stanford, Cambridge	Researching fracking in Europe
DisEqm	**Llewellin**	NERC-NSF £454k to DU £3.0M total	Manchester, Bristol, UCL, Arizona, Cambridge	Quantifying disequilibrium processes in basaltic volcanism
Muography	**Gluyas**	DECC/Industry £450k to DU £1.6M total	Sheffield, Bath, RAL, NASA	Developing prototype muography tool and protocols for monitoring geo-stored CO2
VoiLA	**Davidson** **Macpherson** **van Hunen**	NERC £322k to DU £2.0M total	Bristol, Soton, Liverpool, U West Indies	Volatiles in the Lesser Antilles, and consequences for seismicity and volcanism
Deep Volatiles Consortium	**van Hunen**	NERC £273k to DU £3.4M total	UCL, Liverpool,	Feedback between volatiles and mantle dynamics

			Leeds, Manchester	
SHAPE-UK	**Aplin** **De Paola** **Worrall**	NERC £255k to DU £1.7M total	Bristol, Newcastle, Leeds, Liverpool, BGS	Impact of hydraulic fracturing in the overburden of shale resource plays

Staff have also made major contributions to securing funds for regional, national, and international doctoral training centres and partnerships (Section 2.4).

3.2. Infrastructure

The Department houses extensive analytical and experimental infrastructure that is complemented by University-level facilities.

3.2.1. Physical and Operational Infrastructure

The Department is housed in the Arthur Holmes Building. Purpose-built in 2004, this co-locates the majority of academic staff, research staff, and research students on a single floor, contributing to a strong sense of unity and identity, and facilitating collaboration across all research activities.

Laboratory facilities are managed and operated by a Senior Research Officer, a Senior Experimental Officer, a Departmental Superintendent, and four permanent Technicians. Additional technical support is funded through grants, and two apprentice technicians have been hosted and mentored in the Department. The laboratories are a major engine for generating research and for providing training to Durham staff and research students, as well as many collaborators and visitors.

The Durham Geochemistry Centre (DGC), hosted in the Department and directed by **Burton**, has world-leading laboratory facilities that develop and apply innovative techniques for isotope and elemental tracing across the Earth, environmental, physical, archaeological, biological and biomedical sciences. DGC lab analyses underpinned 295 publications over the REF outputs period, and three ERC Grants (**Humphreys** in Earth Sciences, and one each in the Geography and Archaeology Departments). The Rock Mechanics Lab (RML), directed by **De Paola** and **Nielsen**, is equipped with a rotary shear apparatus, triaxial rig, and high-frequency data logging. The RML underpins a Marie-Curie Fellowship (Tesei) and an EU ITN studentship. Recently established laboratories include the Volcanological Fluid Dynamics Lab (analogue experiments) and Hot Lab (including high-pressure-high-temperature (HPHT) petrology, HPHT rheometry), which were fundamental to the award of a Newton International, and a Leverhulme Fellowship, respectively. Researchers across the Department also benefit from in-house microscopy facilities (including desktop SEM) and thin section and rock preparation facilities.

The Department hosts NERC's national Ocean Bottom Instrument Facility, which provides the UK's academic and commercial communities with access to versatile, multi-sensor ocean bottom seismographs to enable sub-surface geophysical imaging at high vertical and lateral resolution. The facility is directed by **Peirce** and supported by four dedicated Experimental Officers.

The University provides research facilities that the Department accesses extensively. Staff make heavy use of the Durham X-ray Centre, which hosts facilities for x-ray tomography and x-

ray diffraction for analysis of geomaterials. We have strengthening links with the Durham Centre for Soft Matter, via research into multiphase flow and the behaviour of geomaterials at high temperature. Many researchers use the cross-departmental GJ Russell Microscopy Facility (SEM, TEM, FIB-SEM).

Research computing facilities are largely managed at University level through Advanced Research Computing (ARC), and include the Hamilton High Performance Computing Service, which is free to use for UKRI-funded projects within the University. The Department is supported locally by a Senior Geoscience Computing Office. Recent investment at University level has significantly enhanced storage capacity for research data, so that all staff and PGR have 5Tb storage.

3.2.2. Use and Development Strategy

The Department's laboratories are shared facilities available to all and are adapted and re-purposed according to the changing landscape of research projects and income, and changes in Department composition. Laboratory use is overseen by the Facilities User Group (FUG). Departmental staff work collaboratively through FUG to identify, finance, and implement development and maintenance of infrastructure, with support from the Faculty and University. Facilities development over the REF period includes the refurbishment and repurposing of laboratory space for a new Volcanological Fluid Dynamics laboratory, associated with the DisEqm NERC Large Grant (Table 1), a new Hot Lab, associated with the ERC Consolidator Grant to **Humphreys** (Section 3.1.2), and other more minor refurbishments to accommodate requirements of new staff.

3.2.3. Investment

The University's Research Equipment Group supports the purchase and replacement of strategic and underpinning research equipment and oversees match-funding of equipment against external income. Investment in the Department over the REF period includes plasma source MC-ICP-MS (£403k), a laser ablation system for ICP-MS (£250k), a particle size analyser (£35k), and a simultaneous thermal analyser (£250k, joint with Chemistry). Bids to NERC Capital Equipment calls have funded a scanning probe microscope and sulphur isotope ratio mass spectrometer (**Greenwell** PI, £360k), a hydrothermal atomic force microscope (**Greenwell** PI, £176k), a facility for HPHT rheometry (**Llewellin** PI, £300k), and an ultra-high frequency data logging system (**Nielsen** PI, £165k). The GJ Russell electron microscope facility has been upgraded with £700k of new microscopes, and the Ocean Bottom Instrument Facility has received £2.9M to deliver NERC's UK seabed instrumentation facility operations over the REF period.

3.2.4 Use of National and International Facilities

Extensive use has been made of NERC's Research Vessels and supporting facilities, through ship-time associated with NERC grants to **Peirce**, **Hobbs**, and **Talling**, accounting for the majority of in-kind income of £2.1M (REF4c). Staff have also used the NERC Ion Microprobe Facility and Isotope Geosciences Facility (**Humphreys, Menzies**). Access to the national HPC facility ARCHER has been awarded to **van Hunen**, and **Walters** was awarded access to JAXA Satellite Data, representing in-kind income of £180k. Five beamtime proposals across the Diamond Light Source and Swiss Light Source, totalling >20 days, have been awarded (Dobson (NERC IRF)**, Llewellin, Humphreys, Wadsworth**) representing in-kind income in excess of £650k.

Section 4. Collaboration and contribution to the research base, economy and society

The Earth and environmental sciences sit at the nexus of physics, chemistry, materials science, engineering, ecology, social science, health, energy, resources and industry. Consequently, collaboration and cooperation with scientists and stakeholders, nationally and internationally, are embedded in our practice. This is reflected in our REF2 outputs – 97% include at least one collaborator from outside the Department.

4.1. Networks and Partnerships

Staff in the Department lead, or take a major role in, many national and international collaborative research projects (Section 3.1.2 and Table 1). The HIVE project and the FACE-UP project – both led by **Horwell** – are exemplars of interdisciplinary collaboration and stakeholder engagement. Between them, these projects secured £2.6M from UKRI, government and UK charities, to partner with the World Health Organization, UNICEF, Save the Children, Red Cross, and many local agencies, as well as academics in the UK, Indonesia, Nepal, Japan and Mexico, who work across the natural, medical, exposure, and social sciences, and with experts in behavioural psychology, public health and air pollution. National partnership is exemplified by the £20M EPSRC/industry-funded National Centre for Energy Systems Integration (CESI), of which **Gluyas** is Associate Director. The Centre partners six UK Universities with more than 30 industrial and government organisations, with the mission to reduce the risks associated with securing an integrated UK energy system. These projects exemplify the Department's strategic vision to inform society's response to the challenges posed by the natural environment (Section 1.5).

Financial and logistical support for national and international networking and pilot projects come from internal sources – University Research Seedcorn Funds and internationalisation grants, and from Research Institutes (Sections 1.2.4) – and external sources. Dedicated mobility funds, including outgoing Fellowships, have been won from the Royal Society (**Llewellin**, **Greenwell**), and the Leverhulme Trust (**Harper**, **Macpherson**). Many staff hold visiting positions overseas, including Switzerland (**Burton**, Visiting Professor, ETH), Iceland (**Burton**, Adjunct Professorship, University of Iceland), China (**Harper**, Distinguished Visiting Professor, China University of Geoscience, Wuhan, and Chinese Academy of Sciences, Nanjing), Netherlands (**Holdsworth**, Visiting Professor, Utrecht), and Austria (**Worrall**, Guest Professor, University of Vienna). Several staff have been involved in major international ocean cruises and drilling campaigns (**Menzies**, **Peirce**, **Hobbs**, **Talling**, **Prytulak**). National and international research collaborations have also been facilitated through co-supervision of PhD students, notably via 5 EU Innovative/Initial Training Networks, and NERC and EPSRC DTP/CDTs (Section 2.4).

Collaboration with commercial enterprises via consultancy contracts over the REF period have included BP, Shell, Chevron, Hurricane, ConocoPhillips, Equinor, and OMV. Some of the most established areas of impact are based on long-term programmes of research carried out in partnership with external stakeholders. The 'Fractured Basement' ICS was initiated in 2000 during a NERC Ocean Margins LINK project with BP and Statoil, triggering a 20-year cascade of collaborative research and impacts, involving the creation of a spin-out company (GRL in 2004), collaboration and funding from NERC, the ITF, Shell, BG, Hurricane and the Clair Joint Venture.

We welcome visiting academic staff from all over the world, for periods ranging from weeks to months. Visitors make a strong contribution to the vitality of the research environment, contributing seminars and workshops, undertaking collaborative research, and enhancing the

Department's international and interdisciplinary reach. The University's Institute for Advanced Studies has supported seven Fellows for three-month Fellowships in the Department through its flagship scheme: Tebo (Oregon), Gardner (Texas), Servais (CNRS), Ruby (Lorraine), Narayanan (Florida), Carteret (Lorraine), Dong (Miami). We have also hosted 5 COFUND Senior Research Fellows (co-funded by Durham University's IAS and the EU): Greathouse (Sandia National Labs), Kheirkhah (Iran Geological Survey), Goddard (UC San Diego), Elias (US Geological Survey), Glatzel (Vienna), McDonald (Queensland) and 2 senior academics via the Royal Society International Exchanges scheme: Houghton (Hawaii), Sahagian (Lehigh). In total, we have hosted more than 40 visiting academics for research visits of more than one week during the REF period.

4.2. Impact and Engagement

Our knowledge exchange strategy is founded on the principle that partnership with stakeholders is essential to create impact, and that the earlier partners are involved in the research process, the more impact our research is likely to have. We have therefore developed fora and processes to effectively engage internal and external stakeholders, and maximise impact-generating opportunities. Examples of success in this area include:

i) Use of strategic academic posts: The appointment of **Gluyas** (in 2009) from a distinguished career in the commercial sector, to a Chair in Geoenergy, Carbon Capture and Storage, has continued to deliver impact and engagement in the current REF period. He has led a joint University–Industry programme that discovered commercial helium reserves in the East African Rift. **Talling** was appointed to strengthen our impact in geohazards research, and has held Royal Society and NERC Industry Fellowships, which underpinned engagement with the International Cable Protection Committee (ICPC), the SAT3 and WACS submarine cable teams in the W Africa region, and Angola Cables Ltd, to mitigate submarine flow hazards to international cable networks. As a current member of the UK Natural Hazards Partnership, he leads efforts to add tsunamis and submarine flows to the UK's National Risk Register, engaging with the UK Government Chief Scientist and the Cabinet Office.

ii) Commercially-funded research consortia: The Department led two industry-funded research consortia during the last REF period. The Volcanic Margins Research Consortium, which completed in 2015-2016, provided technical skills training to industry staff from 5 petroleum companies via workshops and fieldtrips to the UK, Iceland and USA, led by **Brown**. Technical training focused on volcanic and igneous geology and the impacts of volcanic and igneous rocks on petroleum systems, to enable industry geoscientists to better understand uncertainties and risks during exploration of volcanic margins worldwide. GeoPOP4 (2019-2023), funded by Petrobras and BP (£300K) and led by **Jones** and **Aplin**, supports a PDRA and PhD student to look at the geological and engineering implications of high fluid pressures in sedimentary basins. The Department also takes a major leadership role in the ReFINE consortium (**Worrall**) with university partners at Newcastle, Cambridge, Strathclyde, Keele and Stanford (USA). ReFINE is funded by NERC, Shell, Chevron, Total, GDF-Suez, Centrica, INEOS the Environment Agency and the EU Horizon 2020 programme to undertake independent research on the impact of fracking (shale gas exploitation) across Europe, with Durham leading on water quality, fugitive emissions, induced seismicity, and well integrity. This includes a national baseline study of anthropogenic earthquakes in the UK prior to shale exploitation, which led to the development of the HiQuake database (http://inducedearthquakes.org/). Recent work with industry partners has included fundamental research to enhance drilling mud technology and the effective recovery of oil

(**Greenwell**), shed new light on the exploration for helium (**Gluyas**) and has investigated the use of abandoned mines as a source of geothermal energy (**Gluyas**).

iii) Provision of expert advice: Through membership of the Office for Nuclear Regulation (ONR) Expert Sub-Panel for Seismic Hazard, **Holdsworth** has provided expert review of materials and co-written technical guidance documents that impact directly on permissioning decisions made by the ONR during the planning and construction of multi-billion pound nuclear facilities of fundamental long term strategic importance to the UK energy supply. He is also leading on the technical review of geological aspects of documents related to the development of a UK Geological Disposal Facility.

4.3. Contribution to Discipline

During the REF period Departmental staff have contributed to their disciplines through leadership roles in national and international academic and professional bodies. **Horwell** was President and founding leader of the AGU GeoHealth Section and AGU Council Member; **Harper** was President of the Palaeontological Association, and is Chair of the International Commission on Stratigraphy, and Council Member of the International Union of Geosciences; **Peirce** was Vice President of the Royal Astronomical Society and **van Hunen** is Deputy President of the EGU Geodynamics Division. For NERC there has been representation on the Marine Facilities Advisory Board and the Geophysical Instrument Steering Committee (**Peirce**), the KE Advisory Board, the Oil & Gas Decommissioning Panel (Chair), and RATE Programme (Chair; **Holdsworth**), and the Isotope Geoscience Steering Committee (Chair; **Macpherson**). More than a third of staff have served on NERC review panels for Standard Grants, Large Grants, International Grants, Independent Research Fellowships, Knowledge Exchange Fellowships, Highlight Topics, and similar. **Brown** served on the National Geographic Committee for Exploration, and **Greenwell** on the MinSoc Council. Internationally, **Harper** sat on the IGCP (UNESCO) Science Panel, **Prytulak** on the IODP Science Evaluation Panel, **Aplin** on the Research Council of Norway, and **Gröcke** worked for the Council of National Science Centre, Poland. A majority of our staff have editorial roles for international journals including Editors-in-Chief (Geological Magazine, Solid Earth, Palaeoworld, Volcanica); Editor (Solid Earth, Lethaia, Geology, Scientific Reports, Science Bulletin); and Associate Editors and Editorial Board Members of 20 journals.

International recognition for the quality of the work done by Departmental staff comes from receipt of AGU Fellowship (**Niu**), Fellowship of the Geological Society of America (**Selby**), EGU Plinius Medal (**Horwell**), European Association of Geochemistry Houtermans Medal (**Prytulak**), IAVCEI Wager Medal (**Humphreys**) and George Walker Medal (**Wadsworth**), and to **Harper** the William King Medal (National University of Ireland), an Einstein Professorship (Chinese Academy of Sciences), and Foreign Member of the Royal Danish Academy of Sciences and Letters and the Royal Swedish Physiographic Society. Nationally our achievements were recognised through the Mineralogical Society's Max Hey Medal (**Greenwell**); the Geological Society of London's Coke Medal (**Peirce**, **Holdsworth**), William Smith Fund (**Walters**), and Murchison Fund (Cooper, PDRA), the Volcanic and Magmatic Studies Group Annual Award and the British Society of Rheology's Annual Award (**Llewellin**), and the Edinburgh Geological Society's Clough Medal (**Holdsworth**). **Horwell** was made an honorary Professor at Public Health England, **Wadsworth** received Fellowship of the Winston Churchill Memorial Trust, and **Harper** and **Macpherson** received Leverhulme Research Fellowships.

4.4. Regional Development

Partnerships with many entities underpin our commitment to supporting social, environmental, and economic development in northeast England through our research; particularly, but not limited to, Theme 2. **Gluyas** serves on the County Durham Economic Partnership and Local Enterprise Partnership, and chairs the county Climate Emergency Strategic Partnership. He has initiated several projects with NE England councils and the Coal Authority to repurpose abandoned mines as low-grade heat sources. He and **van Hunen** have also developed several projects investigating exploitation of geothermal heat in County Durham. **Gröcke**'s work with the Environment Agency and Natural England has sought to constrain nitrogen pollution in coastal waters, while **Wadsworth** is working with Durham County Council on terrestrial costal pollution from former coal workings. **Gluyas** has also transferred muon tomography technology from carbon sequestration and storage monitoring to identify issues with infrastructure integrity in railway tunnels. **Wadsworth** leads our collaboration with the National Glass Centre (Sunderland) and University of Sunderland to explore how comparing the different perspectives of those studying artistic and natural glass production can mutually benefit the work of both.