

Institutions: UCL (University College London) and Birkbeck, University of London (joint submission)
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Unit of Assessment: 7 Earth Systems and Environmental Sciences

1. Unit context and structure, research and impact strategy
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1.1 Structure and Context*1.1a. Strategic vision*

Our ethos is to carry out world-leading interdisciplinary research that enhances our understanding of the Earth system, life, and planetary evolution, using quantitative science combining theoretical and methodological advances with data collected via field, laboratory and remote sensing observations. A key goal is to transform our findings into societally beneficial outcomes, especially regarding prediction and mitigation of natural hazards, safeguarding Earth resources, working with industry to develop new materials, and bringing science to bear on policy. Our research strategy and wider ambitions look beyond the UoA to leverage collaborative opportunities at the Faculty, University, National, and International levels, and to provide the fundamental data and scientific interpretation required by the public, governments and industry to make informed decisions. We take full advantage of the wider strengths of our host Universities through engagement with interdisciplinary research centres, including the Institute for Origins via our leadership of the Centre for Planetary Science, and the UCL Grand Challenges in Global Health and Sustainable Cities.

1.1b. Structure

This submission returns 37 staff from the Dept. Earth Sciences, UCL (ESUCL), nine from Dept. Earth and Planetary Sciences, Birkbeck (ESBBK) and eight from elsewhere in UCL (Institute for Risk and Disaster Reduction [IRDR], Dept. Science and Technology Studies [STS], and Mullard Space Science Laboratory [MSSL]) (Fig.1). ESUCL and ESBBK form the Institute for Earth and Planetary Science (IEPS), a joint Research School integrated at all levels by: a management group comprising the two HoDs and their deputies; shared PhD students and labs (e.g., the London Geochronology Centre managed by Carter [ESBBK] and Vermeesch [ESUCL]); joint appointments; and abundant collaboration. A Strategic Planning Group determines future research priorities, composition and trajectory of research clusters, and infrastructure investments and appointments. Staff and student surveys also inform our working practice and strategic planning. The IEPS has close links with the IRDR (e.g., joint appointments, shared teaching, and the IRDR Governing Board includes the ESUCL HoD). The close working relationships across the UoA are illustrated by the >70 papers co-authored by members from at least two Departments, two jointly organised conferences, and three joint major grants (Leverhulme, NERC Facilities, ERC), since 2014.

ESUCL staff were spread across four separate buildings during the previous REF, but have been co-located (with key ESBBK staff) in the Kathleen Lonsdale Building (KLB) since 2018. The KLB received a £28M refurbishment, and has state-of-the-art facilities (5b.3). ESBBK has also received investment in new labs. New IEPS teaching labs accommodate 160 students, and include workstations linked to a microprobe/SEM, enabling real-time demonstration of research techniques and data interpretation. The IRDR became a separate department in 2020 after a £580K refurbishment (5b.3). The UoA collectively houses 45 postdoctoral researchers and >60 PhD students. In 2019/20 the UoA had a turnover of £11.92m with a research-grant expenditure of £3.29M.

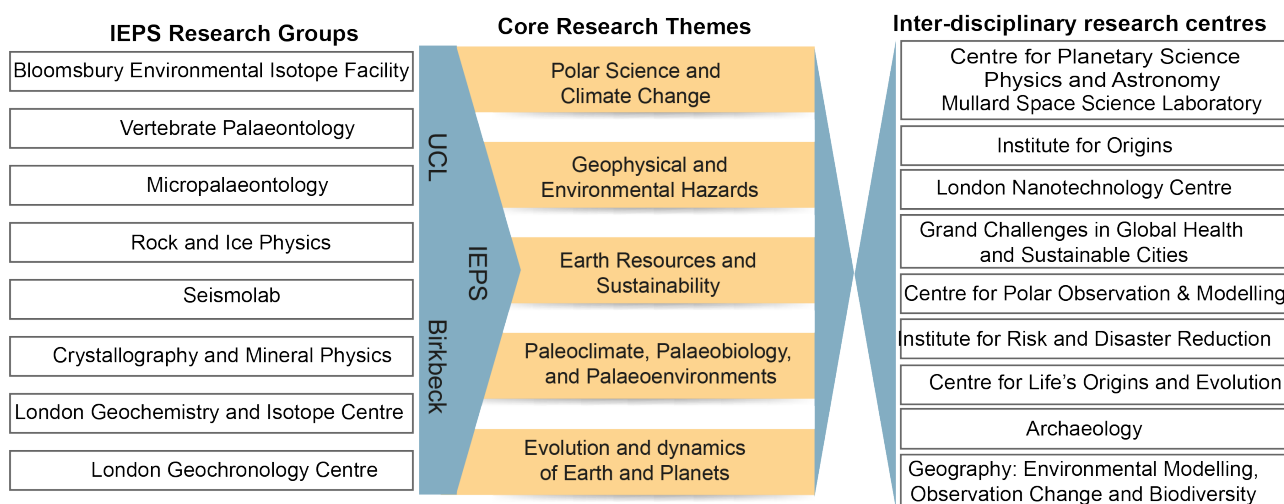


Figure 1. Structure of the IEPS and its relationships with other units and cross-departmental centres.

1.1c. Research interests and themes

Research is carried out via three inter-dependent routes:

- Fieldwork and remote sensing, ranging from geological field-based techniques, ground truthing model predictions to drone and satellite monitoring of sea ice and volcanic emissions.
- Laboratory measurements and experimentation, such as thin-section studies, isotopic analyses, and rock and ice physics experiments that mimic earthquakes and other Earth processes.
- Modelling, statistical and other numerical approaches, ranging from mineral interactions and processes in the deep Earth to new methods for assessing sampling failure in the fossil record.

Our diverse research interests (geology, climate, geochemistry, geophysics, mineral physics, materials science, modelling, palaeobiology, policy) are grouped into five broad themes:

Earth Resources and Sustainability (*Burgess, Edwards, Irvine, Jones, McArthur, Meredith, Mitchell, Oelkers, Osborn, Pogge Von Strandmann*)—This encompasses environmental processes governing resources and development constraints, including climate implications, mitigation and geo-engineering, groundwater, sub-surface energy, and minerals.

Polar Science and Climate Change (*Irvine, Osborne, Rapley, Sammonds, Stroeve, Tsamados*)—This includes the Centre for Polar Observation and Modelling (CPOM), using satellite-based observation (e.g., Cryosat-2) and climate models to monitor and understand the effects of climate change at high latitude.

Paleoclimate, Palaeobiology, and Palaeoenvironments (*Bown, Boudagher-Fadel, Bristow, Carter, Hopley, Homann, Mannion, McArthur, Oelkers, Papineau, Pickering, Pogge von Strandmann, Shields, Underwood, Upchurch, Wade*)—This reconstructs past environments and biological evolution from the Quaternary to the Archean

Geophysical and Environmental Hazards (*Ahmed, Brantut, Bristow, Burgess, Carter, Edwards, Faure Walker, Fearnley, Ferreira, Fox, Hammond, Kilburn, Liu, McArthur, Meredith, Mitchell,*

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Oelkers, Roberts, Sammonds, Saunders, Stavrianaki, Song, Vermeesch)—This encompasses the origins and impacts of earthquakes, volcanoes, landscape change, environmental pollution, and tropical storms. There are particularly strong links between this theme and ‘Polar Science and Climate Change’ and ‘Earth Resources and Sustainability’.

Evolution and Dynamics of Earth and Planets (*Alfè, Ballmer, Brantut, Brodholt, Crawford, Dobson, Downes, El Maarry, Ferreira, Fox, Hammond, Jennings, Jones, Meredith, Mitchell, Price, Song, Thomson, Vočadlo, Wood*)—This combines experimental and theoretical mineral and rock physics, seismology, geodynamics, and observations of extra-terrestrial material to understand the evolution of Earth, planets and meteorites.

1.2. Research Objectives and Strategy

1.2a. Meeting REF2014 objectives

We aim to maintain a balance between our various strengths and to promote an open and collaborative research environment. This is underpinned by recent major investments in our infrastructure and new hires.

Key REF2014 strategic objectives were:

Breadth—While acknowledging that the ‘centre of gravity’ of our work would remain in the ‘solid Earth’ (where we have strength in depth e.g., 192 papers by 10 staff since 2014), a key goal was to maintain the breadth of our research. We emphasised the intimate inter-connectivity between the atmosphere, cryosphere, hydrosphere, biosphere and solid earth, which combine to shape environments over human and geological time scales. Engagement with all components of the Earth system, and with other planets was viewed as essential for addressing the challenges of understanding Earth’s origins and habitability.

Bridges—Our REF2014 strategy recognised the importance of leveraging ‘breadth’; by building programs in areas that naturally forge links among existing strengths, specifically:

- Seismology, linking Earth’s interior, crustal dynamics, and natural hazards.
- Environmental isotope geochemistry, linking palaeoenvironments, modern environmental change, and hazard.
- Polar observation and modelling, linking rock and ice physics, meteorology, palaeoenvironments, and other planets (e.g., via leadership in space missions).
- IRDR, linking natural hazards, climate and sustainable resources to the causes of conflict, humanitarian relief and policy.

Benefit—Our REF2014 submission emphasised our commitment to fields that directly address key societal needs in the areas of resources (e.g., groundwater), environmental hazards, and climate change.

Building on the 5 new hires made prior to 2014, the IEPS and IRDR have made a further 14 new hires in: Earth’s interior and crustal dynamics (Ballmer, Fox, Thomson, Jennings), hazards (Ahmed, Hammond, Liu, Stavrianaki, plus increased FTE for Edwards), isotope geochemistry (Little), climates/Earth observation (Irvine, Tsamados), planetary evolution (El Maarry) and

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Palaeobiology (Homann, Mannion). Aside from maintaining our strengths, this has enabled expansion into new fields (e.g., Liu's use of drones for geophysical hazards monitoring, Irvine's solar engineering work, and Mannion's links with conservation palaeobiology). Our Breadth and Benefit agendas mesh well with UKRI strategic themes in Adapting to Environmental Change, Resilience to Hazards, and Securing Natural Resources, all areas in which the UoA has growing strength. Moreover, the expansion of the IRDR in terms of new staff, an enlarged and refurbished accommodation, the creation of a BSc in Humanitarian Studies, and transformation into a full Department, provide a major new avenue for enhancing the reach of current impact and forging links with new stakeholders.

A key problem for ESUCL, in 2014, was that its staff were spread across four separate buildings, hampering efficient working and collaborations. Teaching rooms and several labs were also outdated. However, the £28M refurbishment of the KLB, formally reopened by Sir David Attenborough in 2018, has revitalised the Department. This has enabled the co-location of all ESUCL staff and key ESBBK collaborators/joint appointments, expansion and renovation of labs (including new equipment), new teaching rooms seating 97 students, social hub spaces to enhance interactions, and increased office space to house our growth in PDRAs and Research Fellows.

These strategies and investments have led to a highly productive environment, resulting in world-leading research outputs. Since 2014, the UoA has grown substantially (e.g., +26% total FTE, +39% in research income, +41% in research outputs). We have produced 1175 research outputs, with 3.4% being in the top 1% for citations. Our REF output submission includes 45 papers in *Nature* Group journals and *Science* (+55% compared to REF2014).

1.2b. Research highlights

Shrinking sea ice and polar oceanography—Satellite data produced the iconic documentation of shrinking Arctic sea ice with a growing melt season (Stroeve et al., *GRL*, 2014; *ERL*, 2018), increasing melt pond cover (Schroeder et al., *Nature CC*, 2014), younger and smoother ice cover (Petty et al., *JGR*, 2017), and accelerating sea ice drift (Tsamados et al., *JPO*, 2014). Satellite observations revealed the spinning-up of the Beaufort (Armitage et al., *Cryosphere*, 2017), and Ross and Weddell (Dotto et al., *GRL*, 2018; Naveiro Garabato et al., *GRL*, 2019) Gyres. Together with 'Atlantification' (Hwang et al., *MCCIP Sci. Rev.*, 2019), such responses to climate change couple with warming of the polar regions and sea ice retreat, accelerate polar glacier, ice cap and ice shelf instabilities (Dotto et al., *JPO*, 2019).

Past life and environments—New isotopic data and geochemical modelling highlighted the role of the sulphur cycle in oxygenation events and related biological radiations (He et al., *Nature Geo.*, 2019; Shields et al., *Nature Geo.*, 2019). Carter et al. (*EPSL*, 2017) provided new insights into the early glaciation of the Antarctic continent by detecting widespread glacier calving in eastern Antarctica at least 2.5 Myrs before the prominent oxygen isotope event at 34–33.5 Ma. Dodd et al. (*Nature*, 2017) announced the discovery of the Earth's oldest fossils (4.2-3.7Gyr) (Altmetric =3763, >99 centile for 2017 articles, >95 centile for all articles published).

Hazards—We showed that bends in faults are vital for earthquake triggering (Mildon et al., *Nature Comms*, 2019). Schellenberg and Liu (*J. Field Robotics*, 2019) developed new inter-disciplinary drone-based strategies for quantifying volcanic gas emissions and monitoring high-risk volcanic

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systems, and revealed previously unrecognised periodicity in volcanic outgassing with applications in forecasting (Liu, *G-Cubed*, 2019).

Solid Earth—Ballmer et al. (*Nature Geo.*, 2017) showed that early crystallisation of bridgmanite in a magma ocean can result in rheologically strong mantle domains which remain unmixed for more than the age of the Earth, potentially explaining many geochemical observations of the mantle. We showed that the Earth's outer core almost certainly has some oxygen to explain its properties (Badro et al., *PNAS*, 2014). Moreover, the properties of the inner core cannot be explained by a single light element but must contain a cocktail of elements (Li et al., *EPSL*, 2018).

1.2c. Future strategic goals

- Strengthen and expand our interdisciplinary research, especially fields of key importance to society (e.g., climate change, sustainable resource exploitation, hydrology, hazard monitoring and mitigation). We will be hiring three new lecturers in these areas during 2021-2022.
- Continue to promote a working environment that meets the highest standards for Equity, Diversity and Inclusion, via our hiring strategy and procedures, rewards for excellence, staff training, and transparent and fair working practices (5b.2).
- Continue to foster collaborations and strengthen the research environment to grow and extend interdisciplinary collaborations both within the UK and elsewhere. We encourage and support research seminars and journal clubs, networks, joint appointments and studentships, cross-HEI Centres/institutes, and multi-institutional grant bids.
- Ensure a healthy research environment by maintaining a diverse portfolio of grant funding (NERC, EPSRC, STFC, ERC, charities, and industry). The IEPS won three ERC grants worth euro5.4M (Brantut, Ferreira, Pogge Von Strandmann). Since 2014, EU funding more than tripled, and EPSRC and STFC funding increased. We support staff to take advantage of strategic research calls, and also set and lead the agenda of such calls by proposing their remits. We have a strong track record of 'agenda setting' such as the NERC's Biosphere, Evolution, Transitions and Resilience thematic call (Shields), and Deep Volatiles Programme (Brodholt). The number and range of available funding opportunities has been substantially increased by the expansion of the IRDR, which has already won major grants (5b.3).
- A key driver of our research strategy is the ongoing transformation of the field by discoveries made possible by the impact of technology. Our new hires and refurbished facilities mean we are well placed to take advantage of technological developments. Examples include:
 - Our leadership in the exploitation of high-performance computing to simulate complex interactions at the atomic and continuum scales, with wide application to understanding thermodynamic and dynamic processes.
 - We have ensured a position at the forefront of Earth and planetary observation, via new hires active in the design of space missions and use of satellite data (El-Maarry, Irvine, Jennings, Tsamados).
 - We play a key role in enhancing the impact of powerful particle sources (including synchrotrons) on laboratory-based investigations of Earth processes. The IEPS is the second-largest UCL user of the ISIS neutron facility, and is in an excellent position to maintain leadership at ISIS as well as in the development of new capabilities at Diamond with new hires (Thomson) and promotion (Wood).

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- New hires and facilities place the IEPS at the forefront of discoveries generated by increasingly powerful means of characterizing natural samples, including advances in mass spectrometry and nano-scale imaging. This has included nano-characterization of the earliest fossil evidence for life (Papineau), and the use of non-traditional stable isotopes to characterize palaeoenvironmental change (Oelkers, Pogge von Strandmann). Our state-of-the-art clean labs, refurbished BEIF lab and investments in new equipment (5b.3) mean that we can respond rapidly to changing research needs in isotopic studies and Geochemistry.

1.3. Impact Strategy

1.3a. Supporting impact and developing new streams

Our impact enhancement strategy involves multiple mutually reinforcing strands: research-led teaching; hiring policy; staff support; and knowledge exchange and engagement.

Research-led teaching—Our UG, PGT and PhD teaching are fully aligned to UCL’s Connected Curriculum (5a). This places cutting-edge research and impact at the heart of our syllabus, with a strong emphasis on independent projects (ranging across field mapping, lab experiments, and computational modelling), internships, and industrial placements. For example, Geophysics field courses have collected Ground Penetrating Radar data used by English Heritage. Collaborative PhD studentships (e.g., CASE, and ‘Impact studentships’ funded 50-50 by Departments and industry) generate productive relationships within and beyond industry. These approaches mean that our students enter academia, industry or other workplaces (e.g., the media) with a full appreciation of the ways the Earth sciences produce impact, and with the skills to engage with non-academic stakeholders and develop their own impact-related activities.

Hiring and staff development—We have introduced ‘Impact’ as one of the selection criteria when hiring. Annual staff appraisals, and Promotion criteria, also list ‘Enterprise and Engagement’ as a key indicator of achievement, in order to recognise such activities and reward appropriately.

Support for impact—The time required for impact-related activities is included in Workload Models (WLMs). We have a reward scheme that means that staff receive a payment into their discretionary accounts for their impact-related activities (see 2.1f).

Engagement and communications—We engage with governments, policy-makers, industry, business and the public at all levels (5b.4). Activities include; press releases and social media; public lectures; consultancy for policy and commercial products; formulating protocols for predicting and mitigating natural disasters; working with researchers, NGOs and governments to monitor and mitigate environmental hazards; and building publicly accessible datasets used in education and industry (e.g., the Nanotax database in the Bown/Wade Impact Case Study). UoA staff gave >300 public lectures and were involved with >100 consultancies during the REF period (5b.4). Much of this work is supported by grants (e.g., NERC Knowledge Exchange), industrial grants, PhD projects part-funded by industry (5b.4). IEPS and IRDR seminar series provide weekly opportunities for staff and students to engage with academics, people from industry, policy bodies, NGOs and alumni. We also promote impact by hosting meetings that connect academics and non-academic organisations. For example, in order to facilitate knowledge exchange and develop impact relating to our work on groundwater quality, Burgess co-convened meetings in Bangladesh in 2014, 2017 and 2020, and the IEPS hosted a workshop in 2019. These were attended by

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academics, government engineers and policy makers, from the UK, Bangladesh, India and Vietnam.

1.3b. Impact highlights

Sustainable groundwater—Models of groundwater fluctuation in south Asian aquifers provided a new basis for sustainable management, adopted by Bangladesh government (Burgess ICS). A new understanding of arsenic groundwater pollution, affecting tens of millions of consumers in Pakistan/northern India (Ghosal et al., *Groundwater*, 2015; MacDonald et al., *Nature Geo.*, 2018), have provided a sound scientific basis for aquifer development and remediation.

Carbon Sequestration—We lead, with partners in Iceland, the science and management of the World's only industrial-scale project on CO₂ capture and subsurface storage (CarbFix: Oelkers ICS). Field experiments and isotope geochemistry quantified the long-term carbon cycle, enabling development of new methods to capture and immobilise greenhouse gases in the sub-surface, while maintaining permeability (Matter et al., *Science*, 2016; Pogge Von Strandmann *et al.*, *Nature Comms*, 2019). This led to the first industrial negative emissions scheme by subsurface injection of atmospheric CO₂ (Climeworks collaboration).

Resilience modelling—IRDR research revealed the potential for humanitarian disaster for Rohingya refugees (Ahmed et al., *Lancet Global Health*, 2018). A new approach was developed for increasing resilience in conflict zones (Sammonds, *IJDRR*, 2019). The UCL-Lancet Commission on Migration and Health established impacts on migration of climate change and disasters (Sammonds *Lancet*, 2018). Emergency planning and management for cascading disasters was operationalised (Pescaroli and Alexander *Natural Hazards*, 2016), contributing to the UNSDR 2017 Guidelines on National Risk Assessment and integrating with the UNDRR 2019 Global Assessment Report.

1.4. Interdisciplinary Research Strategy

We support and participate in a wide range of institutes and centres across UCL and BBK (Fig.1), and facilitate links with other HEIs and industry (5b.4). Joint appointments, and the existence of the IEPS itself, play a key role in promoting interdisciplinary activities. The Centre for Planetary Science links the IEPS, UCL's Dept. Physics and Astronomy and MSSL, and is led by us (Director Papineau). A joint appointment also links the IEPS with Physics via the London Centre for Nanotechnology. IRDR grew out of ESUCL, and represents a strategic initiative to bridge the gaps between environmental hazards, disaster resilience, health, and humanitarian relief. Several UoA staff (Crawford, Little, Shields, Wade) participate in the Centre for Life's Origins and Evolution (CLOE, created 2017) and/or have taken a leading role in the London Geochemistry and Isotopic Centre (LOGIC, launched 2015).

1.5. Open Research

The importance of Open Research is emphasised at staff meetings and via email reminders. A member of staff is tasked with monitoring Open Access (OA) compliance. Staff have received training and information regarding how to use online repositories. UCL and BBK provide reports on compliance and distribute funds for OA (5a) with additional financial support from Depts. For the UoA, 97% of all articles and conference papers (accepted from 1 April 2016) have been deposited

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in *UCL Discovery*, are gold OA, or qualify for exceptions; 91% comply with or have exceptions to the REF OA policy.

1.6. Research Integrity

Staff are expected to uphold the highest standards of rigour and integrity in all aspects of research. A Research Ethics Officer sits on institutional Ethics Committees, and both HEIs publish annual statements on research integrity as recommended by the *Concordat to Support Research Integrity*. *The Concordat on Researcher Development* is circulated to staff, and we adhere to its standards. PDRA's and PhD students are provided formal research ethics and integrity training. All researchers are aware of procedures to raise concerns regarding research practices, which would go to HODs initially and be referred to the Research Integrity Unit within the Office for the Vice-Provost Research if necessary. No ethical issues have been identified during the REF period.

2. People**2.1. Staffing Strategy and Development***2.1a. Overview*

Our academic staff has been rejuvenated and strengthened since 2014 by planned strategic growth. A significant increase in HESA2 researchers and 14 new permanent posts (2 IRDR, 3 ESBBK, 9 ESUCL), increase FTE by 26.3%. 13 appointments were at lecturer level (including six ECR). Since 2014, five lecturers have been promoted to Associate Professor, and seven of the latter to full Professor. Consequently, we are well placed to continue building on our accomplishments beyond REF2021.

2.1b. Staff Development

The development of ECRs is a priority for the UoA, and underpinned by our commitment to the Concordat on Researcher Development and Athena-Swan values (see also 5a for UCL's HR excellence in Research Award by the European Commission).

New hires negotiate start-ups (£30-40k), have priority for award of a PhD student, and are assigned a senior academic mentor. Mentors assist new staff to identify training needs and help develop their research objectives and strategy, which later feed into the first appraisal after probation ends. A 'New Staff Welcome Pack' provides an overview of how Departments work, key goals and deadlines, how to access resources, etc.

Probation and appraisals follow UCL/BBK policies (e.g., all staff are appraised annually, and line managers must undertake the appropriate training prior to giving appraisals [5a]). Promotion procedures are transparent and recognize excellent performance across all aspects of research, teaching, enterprise and institutional citizenship (as laid out, for example, in UCL's *Academic Careers Framework*). The UoA's success rate with departmentally supported promotion applications is 100%.

UCL and BBK provide a wide array of training, ranging from management and leadership to technical skills relating to online systems (5a). We also arrange training for staff within departments, such as: 'Where Do You Draw The Line' training on harassment and bullying); unconscious bias awareness; Plan S open access; UCL Environment Domain; ethical use of bibliometrics in research.

2.1c. Staff Recruitment

Implementation of our research strategy required an increase in the number of IEPS/IRDR staff through hiring campaigns to attract world-class intellectual leaders with an appetite for cross-disciplinary research of significant impact. This was supported by investment to provide incentives, including competitive salaries, start-ups, infrastructure, students, and support staff. This expansion is fully aligned with UCL/BBK Estates' strategy (5b.3). Our commitment to excellence demanded an international outlook: 7/14 of our new hires were recruited from overseas.

Our hiring program has placed the IEPS and IRDR in strong positions for the long-term. Staff losses are more than compensated for by new hires, with a net growth in REF-submitted FTE from 43 in 2014 to 50.35 now (+17.1%). Retention has been excellent: we lost only four Professors (including a husband and wife) to a major US competitor, and two lecturers to UK institutions. There have also been a low number of losses as a result of retirement/flexible working, one full and three partial retirements, plus two reduced FTE (one reverting to 100% in 2023).

Investment has enabled us to restructure our staff profile to ensure long-term sustainability. In particular, the UoA was becoming 'top heavy' with a large number of professors above the age of 50 and relatively few lecturers/ECRs. However, our 14 new hires mean that the staffing profile now comprises: 13 lecturers (including 6 ECRs), 11 Associate Professors, and 30 full professors. Changes to retirement rules, and a flexible working policy, have brought benefits in terms of retention and sustainability. Seven full professors (who would previously have retired fully) are at 0.6 FTE, allowing retention of expertise and leadership, and providing mentoring for ECRs.

In line with institutional policy (5a) and Athena Swan standards, all hiring has been undertaken using equal opportunities procedures. As a result of this proactive approach, we have increased the representation of REF-eligible women from 8 in 2013 to 13 now (despite losses through retirements and head-hunting by other institutions) and achieved a substantial increase in the proportion of HESA2 staff who are women (from 20.2% to 29.2%). Nevertheless, we note a very slight decrease in the percentage representation of female HESA3 staff, and the overall proportion of women remains low at 21%. It is hoped that our strong track record regarding female PhD students (see below) and HESA2 staff, will facilitate recruitment of more women in the near future. We will use informal routes (such as personalised contacts by staff to potential applicants) to encourage world class female researchers to apply for our new positions. We are also currently putting procedures in place in order to achieve Athena Swan Silver during the next three years.

There has been a marked increase in the proportion of BAME staff (5.9% in 2013 to 12.7% now), although this is largely driven by increases in HESA2 staff. As with female staff, we clearly need to do more to increase the representation of HESA3 BAME staff. We have made a pledge to *Proactively target BAME scientists in future recruitment rounds* by advertising the post through sites such as *The International Association for Geoscience Diversity* and the *Geoscientists of Colour* network. We will invite a Fair Recruitment Specialist onto the selection Panel to guide us through this process.

2.1d. Supporting ECRs/PDRAs

We host seven UKRI/Royal Society/Marie Curie Fellows, and 45 PDRAs. ECRs such as Research Fellows are valued: in the current REF census period two NERC Fellows in IEPS won permanent academic positions in open competition (Fox, Thomson).

PDRAs/ECRs are supported via:

- An induction (backed up by our Welcome Pack and wiki/FAQ) that covers safety, compulsory training in Diversity and Unconscious bias awareness.
- Information on training, secondments and careers disseminated via emails, staff meetings, mentors and appraisals. New lecturers undertake training to become fellows of the Higher Education Academy, and in PGR supervision. We provide help with grant writing (e.g., formal training, and feedback provided by our Head of Research [Brodholt] and the UCL Environment Domain).
- Reduced teaching and administrative workloads during probation.
- We run a highly successful and popular informal social event called 'Meet the staff', where anyone from a PDRA to senior professor is invited to give a brief informal talk about their professional and personal interests, followed by refreshments. This encourages interactions between staff at different career stages and across research fields, fostering collaborations and informal mentoring.
- ESUCL ran two ERC career development events in 2020 in response to covid19 – this will become a twice-yearly IEPS event.

2.1e. Staff exchanges/secondments

Long-term relationships between staff and external bodies are facilitated through hiring staff with relevant expertise and contacts (e.g., Rapley, Osborn, Edwards). Staff regularly access funding from the UCL Grand Challenges and Global Engagement schemes. For example, the relationship between Edwards, mining companies and the Chilean government, is viewed as strategically important and has been strengthened by a doubling in FTE and support from the UCL Provost's Global Engagement Fund.

The UoA supports close ties with industry by funding Impact and Case PhD studentships (2.2). Moreover, as demonstrated in 5b.4, we strongly encourage and support staff to take up consultancy roles working for an array of businesses ranging from publishers to sports stadium builders and mining companies. Approved external links are factored into Workload Models (WLMs).

2.1f. Research impact/sabbatical leave

We adhere to UCL/Birkbeck policy on leave (5a). Staff are encouraged to discuss their requirements with HoDs. Leave required to transform research into impact is routinely granted, with the timetabling of teaching and administration adjusted via WLMs. Departmental and Faculty funds support travel to develop links with external agencies who use research in the context of Impact. Impact, as part of wider knowledge exchange, is recognised in appraisals and represents a key criterion when assessing promotions. UCL Faculties provides support in the form of Impact Coordinators who help staff develop and evidence their links with industry and other end-users/stakeholders. ESBBK provides seed funding for impact related research and workshops at departmental level, with an emphasis on supporting ECR's.

2.2. Research Students

2.2a. Overview

We have been very successful in recruiting high quality PhD students, hosting 60-70 at any given time. The current cohort is typical in being funded from a variety of sources including: NERC (17), NERC and EPSRC CASE Industrial partnership (6), STFC (8), UCL Impact awards (10), Charities (1), ERC, industry, UCL Graduate School competition and self-funding (26). In addition, the UoA maintains a cohort of 75-100 MSc students across three programmes, and 25 MSci students, each of whom completes a research project as part of their training. Approximately one-third of these M-level students go on to PhDs, and another third go into Earth Sciences-related industries.

2.2b. PGR recruitment

Students are recruited via open application processes that are widely advertised. Details of recruitment vary with funding scheme. UCL and BBK both receive allocated STFC PhD studentships and since 2014, the IEPS/IRDR have been part of the cross-disciplinary NERC London DTP, which also includes other UCL Departments, Royal Holloway, The Natural History Museum, Queen Mary, Kings and Brunel. The DTP operates a centralised recruitment process with a selection and interview panel comprising representatives from the various constituent departments. Criteria for selecting students are clearly laid out and have been approved by NERC. To encourage widening participation Birkbeck BAME PhD students can apply for the award of a stipend and fees.

The UoA's approach to PGR training is equitable: all students, including those studying part-time, have equal access to space, facilities and Conference Funding. PGRs can take unpaid study and parental leave.

2.2c. Quality of training

PGR training needs are considered at admissions and confirmed at arrival by supervisor and student. Training involves both generic skills and more specific needs based on the individual's preparedness and project. The DTP also has a 6-month training programme during which students spend a week in each potential host department, learn generic research and statistical skills, participate in fieldtrips, and develop the finer details of their project in collaboration with their supervisors.

Each student is assigned two supervisors from within the IEPS/IRDR, and may have a third, often from another UK or international HEI or industry. Training in PGR supervision is compulsory for supervisors (5a), and new lecturers/ECRs supervising their first PhD student are paired with a more experienced secondary supervisor. PGR training needs are assessed annually and progress is monitored via an on-line Research Log and annual reports, feeding into the formal process for upgrading from MPhil to PhD. These processes are managed by graduate tutors (2 ESUCL, 1 IRDR, 1 ESBBK), who also provide advice to both students and supervisors, and oversee pastoral care and welfare.

We consider conference presentations a vital part of training: PGRs have given >100 presentations at international conferences since 2014, including at the Gordon Research Conference, Lunar and Planetary Science Conference, and meetings of GSA, Goldschmidt, and the Society of Vertebrate Paleontology. DTP students are allocated a research fund for equipment, travel and consumables,

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with Departmental 'top ups' where needed. To mitigate against disadvantaging non-DTP students, Departments and a private Birkbeck benefactor fund research trips and conference attendance outside London.

UCL and BBK Graduate Schools, and Bloomsbury Postgraduate Skills Network, provide skills and career development programmes. Examples include scientific writing and paper production, thesis writing, teaching skills, programming, foreign languages etc. PGRs are fully integrated into the UoA's research environment through their participation in weekly Research Seminars, social events with staff, and thematic research conferences in which they are required to make presentations.

The quality of our PGR students and their training is demonstrated by the success of our graduates in terms of their outputs, thesis submission rates, and career prospects. The average completion time (from start to degree award) for a full-time PhD is 4.6 years. During the REF period, PhD students have produced 150 papers (median = 2/student). Careers data indicate that 40% go into academia, 30% into Earth Sciences-related industries, and 30% into other professional-level employment (100% overall employment rate for postgraduate-level careers, average 2018 starting salary =£35K). Exemplar post-PhD destinations for recent graduates include: space industry (NASA, iSPACE); The Natural History Museum; Lectureships (Plymouth, UCL); and Research Fellowships (e.g., NERC FLF).

2.3 Equality, Diversity and Inclusion (EDI)

2.3a. Overview

The UOA is a place where a diverse community of researchers is actively promoted and thrives. Our commitment to equal opportunities is emphasized by: ESUCL's completion of the Bronze level Athena Swan Charter (renewed 2020); Birkbeck's membership of the Mindful Employer's Charter and status as a Stonewall Diversity Champion; and Birkbeck's annual Pay Audits to measure the impact of EDI initiatives. Of 71 REF eligible and ineligible research staff, 30% are women, 43% are non-UK citizens, and the age profile is relatively flat (21% 25-34, 30% 35-44, 15% 45-54, 20% 55-64, 14% 65+). >60% of the current PhD cohort are women.

2.3b. Management and training

Our EDI Officer (Vocadlo) is a senior academic and Chairs our EDI/Athena Swan Committee. The ESUCL HoD (Upchurch) has a registered disability and works to promote progress on EDI issues both within the UoA and externally (e.g., he sits on The Royal Society's Diversity Committee). Staff with management responsibilities (e.g., Upchurch, Vocadlo) have undertaken training, such as 'Leading on Diversity' (5a) and this has been taken up by other staff in preparation for future roles (e.g., Ballmer, Mitchell).

2.3c. Creating an inclusive environment

The following policies and initiatives promote a diverse inclusive environment:

- It is policy to achieve a 50-50 gender balance in invited seminar speakers.
- HoDs use WLMs to monitor allocation of administrative and other tasks. These take account of factors such as career stage and maternity leave (e.g., it is policy to have reduced teaching loads during probation). WLMs are reviewed annually by HoDs and Departmental- EDI

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Committees, and conform to Athena-Swan guidelines.

- We ensure diverse representation on committees, using WLMs to achieve fair distribution of tasks. We have exceeded our HEIs' requirement of minimum 25% representation of women on hiring committees (typically 40-50%); 43% of the ESUCL Management committee are women; three of our six other committees are chaired by women.
- ESUCL has created LGBTQ and BAME Networks to support students and staff. In 2021, a Disability Network will be added, and these networks will be expanded to encompass the entire IEPS.

2.3d. Supporting staff

Resources—We have developed a wiki/FAQ section on our intranet that lists resources relating to wellbeing, including the *Employee Assistance Programme*, *Report Support* anti-harassment system, Occupational Health etc. (see 5a). There are Departmental wellbeing Champions who liaise with relevant staff at Faculty level and above. As well as examining the results of the biennial UCL Staff Survey, we carry out surveys at Departmental level in order to assess views on an array of issues (ranging from workloads to space allocation). Results are discussed at Staff Meetings and via emails etc. in order to formulate new working practises.

Leave—We follow institutional policy (5a) with regard to leave for professional or personal reasons. Staff have applied successfully for support for extended leave in order to focus on research (e.g., Shields obtained a Leverhulme Fellowship for this purpose). The term of PhDs are extended to compensate for absence due to ill-health, with financial support from Departments where needed. We actively promote the use of the post maternity leave sabbatical scheme, and reduce workloads for a designated period for those returning from parental leave. We encourage and support the use of 'Keeping in Touch' days during maternity leave. 'Recent return to work after extended leave' is factored into WLMs in line with Athena-Swan recommendations.

In response to additional workload and stress resulting from the impact of Covid19, our HEIs introduced additional closure days at Christmas and Easter, and we have allowed unused holiday allocations to be rolled over from one year to the next.

Flexible working—Given the necessity for travel and absences inherent in earth sciences research (e.g., fieldwork) we apply a particularly flexible approach, with remote working allowed provided staff inform HoDs regarding locations/dates and arrange suitable cover for teaching/administrative duties. To ensure Departmental cohesion and efficient working, we ask staff to be present during core hours in term time unless they have valid reasons for absence. Meetings and seminars are scheduled for core hours. Our practice has been transformed by the constraints imposed by Covid19: use of Teams, Zoom etc. is now routine, and we anticipate that the benefits of remote working will be exploited widely post-Covid.

Protected characteristics—Staff and PGRs are encouraged to raise any disabilities, health issues, or other personal circumstances that have hindered their ability to achieve their objectives. Those with disabilities are supported through several funding sources beyond those provided by The State and UKRI: institutional and departmental funds are available for assistive technology and other support. For example, when Upchurch became ESUCL HoD, he was provided with a

Unit-level environment template (REF5b)

PDRA/personal assistant to aid with everyday tasks and support research. Staff requests for standing desks, kneeling chairs etc are routinely granted.

We inform staff of funding available for additional costs due to caring responsibilities, ill health, disability etc. incurred during conference or fieldwork travel. For example, staff are helped to build child care costs into UKRI grant applications as part of our internal grant review process. The UCL MAPS Faculty operates a 'Carers' Fund, and additional resources have been provided during Covid19'. Staff with disabilities are supported in their applications to the Access To Work scheme. These examples illustrate the types of information in our wiki/FAQ re wellbeing and our 'New Hires Welcome Pack'.

Wellbeing—We implement a multifaceted approach to promoting wellbeing, drawing on the resources provided by our HEIs (5a). We have two wellbeing champions, a wellbeing wiki/FAQ online, discussions at staff meetings, and training. Managers offer opportunities to discuss issues such as stress and other personal circumstances during appraisals, and Departmental Managers refer staff and students to Occupational Health support or the *Employee Assistance Programme* as required. These efforts are supported by Faculty-level initiatives, such as the MAPS '2018 away day' which provided training and resources.

During Covid19, staff and PGR morale and stress levels have been surveyed regularly. Online 'coffee mornings' and other events have been organised to maintain mutual support and interactions. We have provided additional resources to improve home working conditions (e.g., tablets, monitors, office chairs).

2.3e. EDI and REF submission

The REF process was explained to staff in advance via meetings and emails, covering: reassurance that this was a group effort and completely divorced from issues such as promotions; criteria used by REF panels; specific rules pertaining to ECRS, part-time staff, those with disabilities etc.; composition of our REF Output Selection Committee; and progress with scoring and selection. We carried out one-to-one conversations with staff to understand the strengths and weaknesses of particular papers. The finalised list of selected outputs was circulated to all staff.

We deployed the following procedure in order to identify our best outputs that reflect the breadth of our research, while mitigating against bias:

- *Diverse Committee*—Our REF Committee comprised 4 men and one woman (in line with the current sex ratio of staff in our UoA). One of the five committee members has a registered disability. Committee members covered two career stages – Associate Professor and full Professor, with four from UCL and one from Birkbeck. The main criterion for membership was provision of the required breadth of expertise across the diverse fields in our UoA.
- *Review and calibration*—Staff identified their best outputs, with author scores and a brief commentary on the significance, originality and rigour of each. Outputs were scored independently by the five REF committee members. Scores were then compared, with discussion of cases where reviewers differed markedly in their assessments (though this was very rare). 170 of the highest quality outputs were then sent to four external reviewers for comment and scoring.

- *EDI checks*—The distribution of outputs relative to the proportions of staff with various protected characteristics were checked, and suggests that our submission represents a fair selection for gender, age, grade, ethnicity and disability, the number of selected outputs is approximately in line with that expected given the FTE, with under-represented groups often slightly or moderately ‘over-contributing’. It is not possible to assess how outputs relate to staff with other protected characteristics (e.g., sexual orientation, religion) because sample sizes are too small (70-75% of staff did not provide the required data).

3. Income, infrastructure and facilities

3.1. Research Funding

3.1a. Funding sources and amounts

18 submitted staff have 28 active UKRI or European Commission grants/fellowships, including large consortia and prestigious grants such as core funding in support of CPOM; NERC Large Grants (Ferreira, Shields), and three ERC grants (Brantut, Ferreira, Pogge Von Strandmann. IEPS/IRDR have also won 20 research grants from UK and international industry (e.g., USAF Research, BG Group, Cornish Lithium, De Beers, Exxon Mobil, Hess Corporation, Petrobras, Radioactive Waste Management, UK Sport) and from third-stream sources (e.g., US Department of State, Richard Lounsbery Foundation, Alfred P. Sloan Foundation, CAFOD, Royal Academy of Engineering) (see 5b.4 for more examples). External funds received through sources not reported in HESA returns include: time on US particle beam facilities: NSLS, APS, and ALS (Dobson, Wood); and INCITE grants from the US Department of Energy for supercomputer time at a total value of £5M (HECToR-equivalent, Alfè).

The UoA's grant income during the REF period was £25.2M (60% from UKRI and 40% from charities, industry etc.), with an estimated additional £26.2M in the form of benefit-in-kind income (an average of c. £7.3M/year).

3.1b. Strategies for generating grant income

Grant income is generated by staff as individual PI's or as part of larger collaborations across our HEIs, the UK, and internationally. All staff are asked to prepare at least one UKRI proposal per year. We maximise income by:

- Rigorous in-house review of proposals prior to submission. This helps maintain our success rate at NERC and ERC at 25-30%, among the highest in the UK, and well above the 20% Demand Management cut-off required by NERC.
- Appointment of a senior staff member (Brodholt) as research coordinator to assist the development of successful grant applications and balance income across a healthy diversity of funding sources. Part of this role is to identify existing and new funding sources and disseminate relevant information.
- UoA staff make full use of expertise and dedicated support in sourcing and managing external income, provided by Faculties, UCL Office of Vice-Provost (Research), the Finance Division and the European Office for guidance on ERC grant applications. Trends in funding are brought to the attention of HoDs at Faculty Leadership Team meetings. During the current REF

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period, UCL created its 'Environment Domain', which includes staff who provide training and feedback on grant proposal writing (5a).

3.2. Infrastructure, Major Investments and Research Clusters*3.2a. Refurbishments/upgrades/expansions*

There is strong institutional commitment to the discipline as shown by the support for expansion within both the UCL and Birkbeck components of the UoA. A key strategic goal of our REF2014 submission was to bring all ESUCL and key ESBBK staff together into a single renovated building with completely updated facilities. This was achieved via the £28M refurbishment of the KLB, completed in April 2018. The KLB has state-of-the-art teaching and research labs, social hub spaces, and new staff offices. An additional £650k has been invested in new petrological and binocular microscopes and other new lab equipment (see below).

While maintaining strong links to the natural hazards component of Earth sciences, the IRDR is expanding to include humanitarian and other societal aspects of disaster mitigation and relief, and thus represents a major plank of our strategy to bridge the gap between scientific research and societal benefits. In 2018, the IRDR was re-housed in refurbished and expanded accommodation on the main UCL campus (a £580K investment).

ESBBK has benefitted from £1.5M investment in new research infrastructure including: dedicated space for postgraduate students; a clean room for geochemistry in support of a joint appointment with ESUCL; an upgraded electron microprobe facility and new ICPMS for the joint IEPS London geochronology Centre.

These substantial investments transform our research, support more competitive major grant applications, and facilitate staff retention and recruitment.

3.2b. Facilities/technical support

We have world-class infrastructure comprising; laboratory facilities; geophysical and other field equipment; an excellent library with extensive e-holdings; computer suites; nine different mass spectrometers; and rock-analysis facilities (thin-section preparation, SEM, WDX electron-probe, X-ray diffraction). We are supported by 6 full-time laboratory technicians, and 2 other technical staff. Staff and PGRs can commission bespoke mechanical and electronic equipment built in-house. Laboratories such as the BEIF, London Geochronology Centre, and Geochemistry Laboratory, form the hub of many of our inter-disciplinary and inter-institutional research networks, and are pivotal for delivering impact.

Departments were closed during the first Covid19 Lock Down. However, we introduced new safety protocols in June 2020 which have allowed us to re-open, and keep open laboratories and teaching spaces.

Facilities, and the activities they support (Fig. 1) include:

- The Environmental Sedimentology Facility houses an XRF core-scanner and multi-sensor core-logger which measures elemental abundance and magnetic-susceptibility/gamma-ray density in sedimentary cores for high-resolution reconstructions of climate-induced changes in

Unit-level environment template (REF5b)

sediment supply. LC/MS allows measurements of biomarker-based palaeotemperatures from marine and terrestrial organic matter.

- The Micropalaeontology Laboratories (including a light microscopy lab added since 2014) enable imaging and quantifying microfossil assemblages via optical and scanning-electron microscopy, and geochemical analyses, underpinning palaeontological and palaeoceanographical research. They feature clean, controlled environments to prepare calcareous, siliceous, and organic-walled, microfossils, and perform taxon-specific morphometric and geochemical analyses.
- The London Geochronology Centre uses and develops geochronology and thermochronometry to understand continental deformation and links to the surface environment. An international reputation for innovative methodological advances and leading research is reflected by over 130 publications and co-authors in 38 countries from 106 institutions (in the REF period). Developments since REF2014 include: upgrades to research infrastructure (laser-ablation ICPMS, laser and digital microscope); and expanded membership (Fox).
- The Mineral Physics and Haskel Laboratories support measurements of the physical and chemical properties of potential constituent minerals of the interiors of Earth, the telluric planets and icy moons. Measurements can be performed at elevated pressure and variable temperature in the deformation multi-anvil press and diamond anvil cell combined with X-ray powder diffraction, X-ray imaging, Raman and FTIR spectroscopy. Several of these globally unique facilities were developed in house, and support our activities at international synchrotron and neutron diffraction facilities. During the REF period, the laboratories provided core support for £6.8M of RCUK/Royal Society/European research grants, involving 2 RCUK fellows, 8 post-docs and 11 PGRs.
- Rock and Ice Physics Laboratories support measurements of the evolution of physical and mechanical properties under cryospheric and crustal conditions. Recent developments include: a new polyaxial and tomography cell for deforming EPICA-borehole ice samples to formulate anisotropic flow laws for the Antarctic ice sheet; triaxial-deformation ensemble with permeability, wave velocity, electrical and 3-D microseismicity measurements to formulate a chemo-thermo-hydro-mechanical model of crustal dynamics; and environmental SEM with high/low temperature and deformation stages to study the micromechanics of ice/rock deformation.
- Liu has created a 'flight lab' for the storage and maintenance of drones used in remote sensing of volcanic emissions. This supports the activities of other staff (e.g., Mitchell) who use drones to acquire field observations.
- Geochemical analysis of Earth materials underpins environmental research, supported by a suite of 6 new laboratories and seven spectrometers, five acquired since the 2014 REF. The BEIF is a cross-faculty stable-isotope laboratory with four spectrometers hosted by ESUCL. Two continuous flow ThermoFischer Delta V IRMS analyse a range of stable isotopes in solid carbonate and other materials. H & O isotopes in water samples are measured using a Picarro L-2103-i CRDspectrometer. Ultrahigh precision and sensitivity analyses, e.g. clumped isotopes and very small samples, are measured on a Nu Perspective IS. Sample preparation facilities include a diamond-coated wire saw, micromill, microbalance, stereomicroscope

Unit-level environment template (REF5b)

and drill. The cross-faculty ICP facility measures major and trace elements in solution using two ICP-MS, ICP-OES, ion chromatograph and a Leco C/S analyser. New since REF2014, the metal isotope facility comprises two (UCL and BBK) metal-free Class 10,000 laboratories containing Class 100 laminar flow hoods for sample purification. The suite hosts a Nu Plasma 3 multi-collector ICP mass spectrometer. Any metal cations can be analysed for isotope ratios, and the facility currently focuses on Li, B, Mg, Mo, Cu, Zn and Sr isotopes. Other UCL departments and universities are frequent users. Since its inception in 2017, it has led to over 40 publications, and 20 international collaborations, including with industry and carbon sequestration.

3.3. Funding, infrastructure and EDI

KLB and IRDR refurbishment make our facilities fully wheel-chair accessible. Staff with protected characteristics are supported re grant applications via: WLMs; appraisals/mentoring; adjustments to internal review deadlines; sabbaticals (5b.2).

3.4. Facilities Outside the UoA/Benefits In Kind/Sponsorships

UoA researchers are highly successful in obtaining access to facilities outside their HEIs. They are supported in these efforts by institutional resources (e.g., Legal Services checks the wording of Non-Profit Agreements). 17 UoA staff have been involved with 22 major projects with in-kind benefits, spread across the UK and 10 other countries and amounting to an equivalent value of c. £23.4M. Exemplar highlights include:

- High Performance Computing—The HECToR Mineral Physics Consortium is led by Brodholt and uses 8% of the total time on the machine, and 40% of the NERC allocation, (=£4M over the REF period. CPOM relies regularly on national capability computers (i.e. ARCHER, Jasmin), Alfe received £13.9M-worth of computing time from Oakridge facility, USA.
- Synchrotron and Neutron beamtime at ESRF, Diamond Light Source, ISIS etc. (Thomson, Wood) worth £3.3M.
- ICDP Trans-Amazon and Onshore Tanzania Projects (Wade, \$2.5M).

4. Collaboration and contribution to the research base, economy and society**4.1. Collaborations, networks, partnerships**

UoA staff have co-authored peer-reviewed manuscripts with scientists from >100 other national and international HEIs, and 90% of submitted outputs are with external researchers. All academics are involved in collaborations, projects, or networks with HEIs, industry, commerce, and/or third sector, with 11.6% of our outputs including a non-HEI (e.g., industrial) co-author. Funded collaborative projects have collectively involved >20 UK HEIs (and partners such as BAS, BGS) and >100 HEIs in 33 other countries. During the REF period, 26% of UoA staff are (or have been) PIs, Co-Is or key participants in 17 research collaborations funded by major (i.e., £1M+) grants involving multiple institutions and/or industrial partners. Exemplar activities include:

- Leadership in:

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- The Thomas Young Centre in the area of materials modelling, bringing together 100 research groups from four London HEIs (<https://www.thomasyoungcentre.org>). This uses UCL high performance computers (Grace, Myriad, Kathleen), supported by £1.5M/year institutional investment.
- The UCL-QMUL-Southampton-Oxford-Imperial-Queen's (Belfast)- Kent Tier 2 regional HPC centre Thomas (upgraded to Thomas2), supported by two £4M EPSRC grants (PI A. Michaelides, UCL), in addition to £2M running costs each.
- The Centre for Polar Observation and Modelling (CPOM), is a NERC funded collaboration involving UCL, Reading, Leeds, and Bristol, and is part of the National Centre for Earth Observation. CPOM is built around the launch of the ESA mission Cryosat-2 (led by UCL) and processing of satellite data (supported by £0.5M/year in NERC national capability funding, and leveraged three-fold in grant income).
- The UCL Hazards Centre works closely with end-users on geophysical and meteorological hazards with UK government departments, international humanitarian agencies and global financial institutions.
- Engagement with UCL Grand Challenges, as exemplified by the IRDR under the directorship of Sammonds and championed by 24 academics from the IRDR, IEPS, Statistical Science, Space & Climate Physics, Civil Engineering and Institute for Global Health, and invested in by UCL with six new academic staff since 2014 taking the total to 10. The expansion of the IRDR is a MAPS Faculty strategic priority. IRDR led the successful UKRI bid for the £5.1M Network Plus on Gender Responsive Resilience and Intersectionality in Policy and Practice and the Belmont 'Climate, Environment and Health' Forum with a €1.3M project on 'Community collective action to respond to climate change influencing the environment-health nexus'. These activities led to influence on policy (e.g., The policy brief from the 2nd International Conference on the Rohingya Crisis in Comparative Perspective, 2020, was taken up by UK and Bangladesh Governments).
- Leadership in a number of multi-department laboratory facilities including BEIF and the Cross-Faculty ICP Facility (5b.3). Our research on groundwater resources and pollution is organized around the Cross-Faculty ICP Facility and *in-situ* field measurements. We emphasise Knowledge Exchange through workshops co-convened with collaborating scientists and stakeholders (e.g., 'Aquifer poroelasticity in Bangladesh: observations, modelling and implications for groundwater resources monitoring', Dhaka, 2017). We work closely with IISWBM (Kolkata), Universities of Karachi, Dhaka and Rajshahi, and with public-sector bodies (Bangladesh Water Development Board, National Institute of Hydrology [India], National Center for Water Resources Planning and Investigation [Vietnam], and the British Geological Survey), supported by Commonwealth, Tempus, UNESCO, and Schlumberger Scholarships and Fellowships.
- Hammond leads the UK-DPRK-US-China Mt. Paektu group of scientists who are working to understand the eruption history and present state of the volcano to identify hazards and risks of future activity (supported by the Royal Society, NERC, Lounsbery Foundation, and US Government, £753k).
- Boudagher-Fadel leads an international UN-funded project on the geological and hydrogeological mapping of Lebanon, involving local students and international scientists.

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- Participation in the Integrated Ocean Discovery Program (Bown, Wade, Pickering) leading to multiple papers by multinational science party (e.g., Hull et al., *Science*,: 36 authors from UK, USA, Japan, South Korea, France, Germany, Spain and Denmark).
- Participation in the International Continental Scientific Drilling Programme (ICDP): PI Homann (with 9 other researchers from South Africa, Germany, France, Switzerland, Belgium, USA, Japan, Australia, and Netherlands); And Liu/Pogge Von Strandmann, 'Volcanic Forcing and Paleogene Climate Change (PVOLC).
- Brodholt is the Lead for the Deep Volatiles Programme funded by NERC (£8M), involving 10 UK institutions.
- Liu leads 'Aerial-based Observations of Volcanic Emissions (ABOVE)' funded by the Alfred P. Sloan Foundation. Collaborators: Chalmers Univ. (Sweden); Universities of New Mexico, Palermo, Mainz, Costa Rica, Bristol, Cambridge; and Rabaul Volcanological Observatory (Papua New Guinea).
- Science 4 Clean Energy (S4CE,) Horizon 2020 project, involving Jones, Mitchell and Oelkers, plus 22 other institutions (€9.8M in total, €1.6M to UCL).
- Shields was the Science Coordinator for the NERC programme: *Long-term Co-evolution of Life and the Planet* (2011-2016) (£1.6M) and NERC-NSFC UK-China strategic response research programme: *Biosphere Evolution, Transitions and Resilience* (BETR) (2017-2021) (>£2M). Shields also played a key role in initiating these thematic NERC calls.

4.2. Wider contributions to economy and society***4.2a. Consultancy, Economy and Environment***

Our research culture embeds engagement with end-user communities to promote, communicate, share and transfer specialist knowledge and expertise, with industry, governments, NGOs and media organisations. Impact and knowledge exchange (IKE) are a mandatory element within IEPS staff appraisal and fostering sustainable relationships with industry partners is a vital strand of our approach to delivering environmental benefits both in the UK and abroad. Our reach is international and wide ranging: UoA staff have been involved with approximately 118 such interactions during the REF period, including organisations from the UK and 23 other countries. We estimate that consultancy and licensing fees, grants, other financial assistance (e.g., contributions to PhD studentships) and support in kind (e.g., logistics during fieldwork) amount to c. £26M, though some has been shared with other collaborating institutions. Exemplar IKE highlights include:

- Work for the Portuguese, Greek and Italian seismic monitoring agencies (Ferreira, Roberts), Panama Canal Authority (Carter), and Geological Surveys of Hong Kong and Cyprus (Carter, Boudagher-Fadel).
- Expert advice to policy- and other decision-making bodies: House of Lords Report on Arctic Sea Ice Decline (2014), House of Commons Science and Technology Committee Report on Communicating Climate Science (2014) (Rapley); UK Climate Change Risk Assessment,

Unit-level environment template (REF5b)

Evidence Report, UK Government Statutory Risk Assessment (2017) (Osborn); Royal Society JISC and CRAC reports on disability in STEM (2020) (Upchurch); IPCC SROCC report (Stroeve).

- Research licensing (e.g., Saunders, with eight industrial companies worldwide).
- The IRDR and UCL Hazards Centre provide direct pathways to transmit our research in areas such as hazard, pollution, environmental and climate change to key users in the insurance industry, governmental bodies and international humanitarian and development agencies. Examples include: The Ministry of Disaster Management and Relief, Bangladesh (Ahmed); CAFOD, Ministry of Mining, Chile, Department for International Trade, UK, Aon Benfield, UN Environment Programme (Edwards); World Bank remediation of arsenic pollution in the Bengal Basin (McArthur); and Risk management standards for Solvency II EU Directive (Roberts, Sammonds).
- Energy sector engagement activities include major oil companies (Petrobras, Total, Haliburton, BG, Nexen, Aramco, Statoil Hydro, Chevron) and other energy providers (Reykjavik Energy, Mitchell, Oelkers) and related industries (Radioactive Waste Management Ltd, Meredith, Mitchell) and Carbfix (Oelkers).

4.2b. Engagement with diverse communities and public

All staff participate in outreach and engagement with non-academic audiences, including public lectures, community teaching projects, media interviews, social media, websites, and performances. We have given 248 (UK) and 61 (overseas) public talks (more than double the number in the previous REF period). Blogs, online interviews and YouTube are widely used to publicise research (e.g., ESUCL YouTube Channel, FAULT2SHA channel managed by IRDR's Faure Walker). Our twitter feeds have >7000 followers, our new Instagram account (started mid-2020) reached 1000 followers in its first six months, and we have presences on LinkedIn and Facebook. Staff achieve wide exposure via media engagement in their roles as commentators, advisors to, or participants in, radio and television news, science, and documentary programmes. Since 2014, they have made >320 such contributions, for example: CBC/BBC, 'Day in the life of Earth', 2018, (Bristow), Netflix, 'Into the Inferno', 2016, (Hammond); BBC, Royal Institution Christmas Lectures, 2020 (Shields, Wade); BBC, The One Show (Liu). Other highlights include:

- Tsamados/Stroeve: UK sea ice workshop and public event (UCL, 2016)—A public forum where leading sea ice scientists reflected on rapidly declining Arctic sea ice cover in the context of long-term climate change.
- Brodholt/Vocadlo: NERC-funded Geobus—Provides Earth Sciences activities related to our research and careers talks to primary and secondary schools. This reaches an audience of c. 20,000 pupils/year. Activities have been successfully transferred to remote learning during Covid19.
- Dobson: secondment at The Slade School of Fine Art—Developed a new blue pigment, leading to popular science articles in New Scientist and Science.
- Liu: Photographic exhibition on field research, sponsored by L'Oreal-UNESCO (currently on display in the Carnegie Institute, Washington DC) and via a YouTube documentary.

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- Dodd et al. 'Oldest fossils' (Nature, 2017)—Total accumulated monthly audience figure for public outreach was >2.2 billion people worldwide.
- Each year, IEPS hosts the 'Festival of Geology', sponsored by the Geologists' Association. This includes talks and hands-on activities for a lay audience, and attracted >1000 online visitors in 2020.

4.3. Indicators of wider influence

4.3a. Highly cited researchers

Fifteen (28%) of current members of the UoA (Alfe, Atkinson, Bristow, Carter, Downes, Mannion, McArthur, Oelkers, Pogge Von Strandmann, Roberts, Shields, Stroeve, Upchurch, Vermeesch, Wade) and two category B staff (Lithgow-Bertelloni and Stixrude, present 2014-2018) are listed in the PLoS databases of the 100,000 most cited researchers representing the top 1.5% of 6.9M publishing scholars. (<https://doi.org/10.1371/journal.pbio.3000384>)

4.3b. Elected Fellowships

UoA staff elected as fellows of learned societies include (*= election since 2014): Brodholt, Price, Stixrude, Vočadlo (Mineralogical Society of America); Crawford (Royal Astronomical Society); Pickering (GSA); Price, Rapley* (Academia Europaea); Price (AGU, Mineralogical Society of Great Britain and Ireland); Upchurch (Linnean Society of London); Wade* (The Paleontological Society).

4.3c. Awards and prizes

Twenty (37%) of UoA staff have received awards in recognition of outstanding achievements, since 2014 ranging from 'best paper awards' through to prestigious medals and honorary memberships. A total of 28 awards have been presented by organisations based in the UK and 11 other countries. Highlight exemplars below:

Staff	Award
Atkinson	Honorary Life Member, National Speleological Society of America (2016)
Brantut	International Mineral and Rock Physics Early Career Award, AGU (2015)
Bristow	Thesiger-Oman international Fellowship (2017)
Brodholt	Price Medal of the Royal Astronomical Society (2015)
Carter	Dodson prize for thermochronometry research (2018)
Dobson	Friedrich Wilhelm Bessel Research Award, Alexander von Humboldt Stiftung (2014)
Liu	L'Oreal-UNESCO, Women in Science Award [2018]
Meredith	Louis Neel Medal 2016, EGU
Mitchell	Bullerwell Lecturer (2018)
Oelkers	Urey Medal for contributions to Geochemistry over a lifetime (2019) Schlumberger Medal, Mineralogical Society (announced Dec. 2020)
Papineau	WITec's Paper Award 2019 Silver
Pogge Von Strandmann	Max Hey Medal, Mineralogical Society of Great Britain and Ireland (2016)
Shields	Leverhulme Professorial Research Fellowship (2019)
Stroeve	Julia and Johannes Weertman Medal, EUG
Vermeesch	2018 Best Paper Award, <i>Geoscience Frontiers</i>

Wade	Bigsby Medal. Geological Society (2020)
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4.3d. Journal reviews/Editorships

Staff have provided reviews for 279 Earth/Environmental science journals. 26 staff have held handling/associate editor positions for 30 journals during the REF period. 26 staff serve(d) on the editorial boards of 25 journals, including sector-leads such as *EPSL* (Brodholt), *Tectonics* (Carter) and *Palaeontology* (Upchurch), and wide-readership journals such as *Phil. Trans. Roy. Soc. A* (Kilburn, Sammonds). Shields is Chief Editor, Journal of the Geological Society (London), and Carter held this post from 2016-2019. Osborn is Founding Editor-in-Chief and Editorial Board Chair of *UCL Open: Environment*. Price is a member of the College of Expert Reviewers.

4.3e. Service on Strategy Boards and governmental agencies

54% of UoA staff sit on a total of 95 (52% international) advisory groups and committees for governments, NGOs, scientific working groups etc. Highlight exemplars below:

Staff	Organisation
Atkinson	Scottish Environmental Protection Agency (2010-present) UK Department of Health (2011-2017)
Bown	Secretary-General, International Commission on Stratigraphy (2014-2016) Geological Society Stratigraphy Commission (2014-Present)
Bristow, Crawford, El-Maarry, Jennings, Rapley, Stroeve, Tsamados	NASA and/or ESA
Brodholt	Hong Kong 2014 RAE Physical Sciences Panel
Edwards	Founding member, Mine Tailings Working Group, Chile (2015-2016)
Fearnley	Co-founder, workgroup, World Organisation of Volcano Observatories Secretary, Cities and Volcanoes Commission, International Association of Volcanology and Chemistry of the Earth's Interior
Ferreira	RESIF (French Natl. Geophys. Infrastructure) GEOSCOPE (French global seismic network) Irish Centre Research Appl. Geosc.
Hammond	UK representative, International Association of Seismology and Physics of the Earth's Interior
Jones	Executive Committee, Deep Carbon Observatory (2010-2019)
Kilburn	INGV-Dip.to di Protezione Civile, Task Force on volcanic alert levels, Italy UK Higher Education Mission to Turkey
Mannion	Executive committee, paleobiology database
Meredith	Convenor, International Review Panel, Earth System Science Program, Chinese University of Hong Kong (2018)
Price	UUK-ICo Working Group on the use of personal data in research Chair, REF 2021 Panel B Chair, UK Forum for responsible Research Metrics Chair, ERU Research Policy Committee Advisor, STEM REF Review

Unit-level environment template (REF5b)

Rapley	Advisory Board, Science Museum (2019) Advisory Board, Carbon Limiting Technologies; (2016) Chair, ESF, Space Science Committee Chair, London Climate Change Partnership (2013-2019) International Review Team, Korean Polar Research Institute (2015) ESRC Centre for Climate Change Economics & Policy project (2014-2015)
Sammonds	UK Alliance for Disaster Research Committee
Shields	Chair, International Subcommittee on Cryogenian Stratigraphy Chair, UK Earth System Science group
Stroeve	Sea ice advisory role, GCOM/COOS/WCRP Ocean Observations Panel for Climate AAAS Arctic Observing Network ENVISAT AATSR LST validation team
Wade	UK representative, (Science Support and Advisory Committee of the Europe Consortium for Ocean Research Drilling) (2012-2015) North American Commission on Stratigraphic Nomenclature, GSA (2014)
Wood	ISIS Facility Access Panel 1: Diffraction (2014)

4.3f. UK and overseas Research grant awarding bodies: reviews and panels

Collectively, 83% of UoA staff have conducted hundreds of reviews for 62 grant awarding bodies in the UK and 32 other countries. Exemplar organisations include: Australian Research Council; Dept. Energy (USA); Deutsche Forschungsgemeinschaft (Germany); EPSRC; ERC; European Space Agency; ESRC; Leverhulme; MRC; NASA; NERC; National Science Foundation (USA); The Royal Society; STFC; UNESCO.

63% of UoA Staff are or have been members of NERC, STFC and/or EPSRC peer review colleges and/or Royal Society panels since 2014. Currently, 19 staff serve on peer review committees at NERC (13), STFC (2) UK Space Agency (2), EPSRC (1), and Royal Society (1), including a NERC panel chair (Brodholt), CIAF panel (Roberts) and deputy-Chair NERC Geophysical Equipment Facility Steering Committee (Hammond). Price is a council member of STFC, and Brodholt was a member of the NERC Science Board (previously SISB) (2014 -2018). Other examples in table below:

Staff	Panel
Alfe	ARCHER embedded Computational Science and Engineering support (eCSE), UK DFG European Science Foundation
Bristow	NASA Mars Data Analysis Program 2015, NASA Solar System Workings panel 2019
Brodholt	NERC HPC Strategy Committee (2018-present) NERC HPC Steering Committee (2014-present) Research Council of Norway Expert Committee (2016, 2017)
Burgess	NERC Advanced Training Short Courses Assessment Panel, (2017)

Unit-level environment template (REF5b)

Carter	Evaluation committee (SPARK), Swiss National Science Foundation (2018-present) Panel Chair: Research Council of Norway (2017)
Crawford	ESA Human Spaceflight and Exploration Science Advisory Committee (HESAC); (2014–2018) Chair, Committee on Space Research (COSPAR) Sub-Commission B3: The Moon (2017–)
El Maarry	NASA New Frontiers Mission Selection and NASA-ROSES programs
Ferreira	steering committees - NERC's Geophysics & Geodesy Facilities, and ANR (French research funding agency);
Jennings	NASA Solar System Workings Program
Pickering	ECORD Science Evaluation Panel
Rapley	Chair, NERC, Royal Society, Royal Society of Arts, Wellcome Trust Initiative on Climate science communication" (2016) Chair, The European Space Sciences Committee, Expert Committee on Space Sciences of the European Science Foundation, 2020-
Sammonds	Strategic Advisor, NERC-ESRC Increasing Resilience to Natural Hazards Programme Chair, Natural Hazards Advisory Group, NERC European Science Foundation, MicroDICE network Steering Committee
Stroeve	NSDGeosciences Advisory Committee Member
Vermeesch	National Environmental Isotope Facility (NEIF) steering committee

4.3g. *Society Leadership*—Staff service on learned society councils and committees includes:

Staff	Role/Body
Brodholt	British Geophysical Association (2014)
Crawford	Vice President, Royal Astronomical Society (2018-2019)
Carter	The Geological Society Awards Committee and the Publications and Information Committee (2016-19)
Downes	President, Mineralogical Society of Great Britain and Ireland (2016-2018)
Hammond	Treasurer, British Geophysical Association
Jennings	EGU science committee, GMPV section
Little, Pogge Von Strandmann	Geochemistry Group committee, Mineralogical Society and Geological Society
Meredith	Chair, EGU Louis Neel Medal Award Committee (2019-2022)
Mitchell	Physical Properties of Earth Materials group, Mineral and Rock Physics committee, AGU
Oelkers	Goldschmidt Officer, European Association of Geochemistry (2013-2016)
Pogge Von Strandmann	Vice President, Mineralogical Society of Great Britain and Ireland
Stroeve	Vice President, International Glaciological Society
Tsamados	Science officer, cryosphere/sea ice division, EGU
Upchurch	Diversity Committee, Royal Society Programme and Diversity Committees, Society of Vertebrate Paleontology
Wade	Paleontological Society's Schuchert Award Committee (2016-2019) Geological Society, Awards Committee (2020-present)

4.3h. *PhD examiner roles*

40 staff have served as external examiners for 115 (UK) and 98 (29 other countries) PhDs.

4.3i. *Research-focused training*

25 UoA staff have delivered 73 training courses aimed at PhD students/ECRs, and CPD for non-academic professionals. These have taken place in the UK and 26 other countries. Highlight examples include: multiple NERC-funded micropalaeontology short courses (UK, 2016-2018, Bown/Wade); 2 CPD courses, Ministry of Health (Oman, Fearnley); GCRF funded workshop, disaster risk reduction (North Korea, 2019, Hammond); GCRF drone monitoring workshop for Papua New Guinea regional disaster coordinators (2019, Liu).

4.3j. *Conference Leadership*

Staff have led or been on the advisory boards and organising committees of 76 international conferences and workshops including: UNESCO Paris climate change meeting (Stroeve), Royal Society Theo Murphy international scientific discussion meeting, 2016 (Mitchell). 55% (up from 35% in the last REF) of staff have convened conference sessions (n=97) at major international meetings including AGU, EGU, GSA.

4.3k. *Invited Presentations*

Staff have given 361 (UK) and 486 (>40 other countries) invited presentations, approximately 40% being plenary/keynote lectures, representing a threefold increase since REF2014. In addition to AGU, EGU, GSA, and Goldschmidt, the breadth of our reach includes: Key note speaker in the International Conference on Earth and Environmental Sciences & Technology for Sustainable Development, Dhaka University, with the President of Bangladesh (Sammonds); The World Economic Forum, The United Nations Framework Convention on Climate Change, 2017, (Stroeve), Science Diplomacy, Washington DC, 2015 and South Korea National Assembly, 2019 (Hammond), 12th International Symposium on Antarctic Earth Science, India, 2015 (Upchurch), Thermo 2016, Brazil (Vermeesch).