| Institution: |
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| University of Cambridge |
| **Unit of Assessment:** |
| B07 - Earth Systems and Environmental Sciences |
| **1. Unit context and structure, research and impact strategy** |

## 1 Unit context and structure, research and impact strategy

UoA B07 at the University of Cambridge is a community of 46 FTE staff undertaking research in Earth Systems and Environmental Sciences. Of these, 42 staff are based in the Department of Earth Sciences (DoES), three are based in the BP Institute (BPI), and one is based in the Department of Computer Science and Technology (DoCST). The UoA also encompasses the Sedgwick Museum of Earth Sciences (SM).

Since REF2014 this UoA has:

**Published transformative multidisciplinary science** (>1450 papers over the period, generating > 23,900 citations), with highlights including:

- initiating the project to drill the oldest ice core in Antarctica (*Wolff*);
- obtaining the first measurement of the nebular magnetic field (*Harrison*);
- creating a complete orbitally tuned Cenozoic climate record (CENOGRID – *Hodell*);
- imaging magma movement during volcanic eruptions in unprecedented detail (*White R*);
- redefining the mantle's deep carbon cycle and the role of Earth's surface in the carbon cycle (*Edmonds*, *Tosca, Turchyn*); and
- discovering the world's oldest modern bird fossil (*Field*);

**Taken the lead on major new environmental initiatives**, most notably directing the University's flagship Cambridge Zero (CZ) programme, establishing a new £6.7m CDT in Artificial Intelligence for the Study of Environmental Risk (AI4ER), and developing a new strategic partnership with the British Antarctic Survey (BAS) in the field of Ice Core and Climate Research.

**Made major investments in infrastructure and equipment** totalling £5.4M, including more than £2.6M in new equipment, £0.5M in laboratory upgrades, and £2.3M for a new Collections Research Centre for the SM.

**Increased grant funding** per annum by >50% compared to REF2014; hosted 29 independent research fellows; admitted and graduated an average of 20 PhD students per year with one of the highest on-time completion rates for PhDs across the University.

**Had our research excellence recognised by major awards** including the Wollaston Medal (*Jackson*), Murchison Medal (*Holness*), Wollaston Award (*Weller*), Presidents Award (*Shorttle*), Bigsby Medal (*Maclennan*), Coke Medal (*Bickle*) from the Geological Society of London, the Milankovic Medal (*Hodell*) from the European Geosciences Union, and The Philip Leverhulme Prize (*Tosca* and *Rudge*). Three staff were elected to FRS (*Holland*, *Woods*, *Holness*), bringing the number of active FRS in the UoA to six (13%).

**Improved equality and diversity** by doubling our total female academic staff, increasing BAME

representation in the academic staff by 50%, and obtaining 100% success rate for female academic promotions at both Readership and Professorial level, thereby increasing the number of female Professors to four (~25% of the current professorial cohort).

The core mission of the UoA is to place fundamental science at the heart of addressing present and future societal challenges. Our strategic vision is founded on the following guiding principles:

- **A vision for research** that pursues fundamental, curiosity-driven science leading to major breakthroughs in our understanding of the Earth and the Environment.
- **A vision for impact** that creates pathways to translate fundamental research into long-term societal and commercial benefit, identifies broad research priorities that are aligned with those of the UK government, research councils and stakeholders, and leads to growth and diversification of grant income.
- **World-class research infrastructure** through sustained investment in equipment and laboratories, enabling research activity to be maintained at the cutting edge.
- **Outstanding technical support and innovation**, with an emphasis on sustaining and developing expertise for the long term.
- **Well-funded postgraduate research programmes**, providing outstanding training to the next generation of scientists, and delivering sustainable growth in postgraduate numbers.
- **Attracting the best Earth and Environmental scientists** at all levels, ensuring we remain internationally competitive in the recruitment and retention of talent.
- **A supportive and collegiate work environment,** with an equitable workload model that creates the time and space for academics to pursue world-leading research.
- **Commitment to the development and promotion of researchers** at all career stages through effective appraisal and mentoring systems.
- **Effective financial and administrative support,** allowing researchers to focus more of their time on delivering their science goals.
- **Promoting equality, diversity and inclusion** in all areas, and a commitment to support the physical and mental wellbeing of all our staff, postdocs, postgraduates and undergraduates.

Our research strategy for the next REF period is "**Sustainable Earth**" and our research priorities include (but are not limited to):

- supporting the transition to a carbon-neutral future,
- delivering sustainable and responsible access to the Earth's natural resources, and
- understanding environmental risks in a changing world.

Our research operates across traditional boundaries, which is reflected in an open organisational structure that fosters intra- and inter-departmental collaboration within five broadly defined themes:

***Climate Change and Earth-Ocean-Atmosphere Systems***
[*Bickle, Branson, Davies, Hodell, Piotrowski, Rhodes, Tipper, Tosca, Turchyn, Shuckburgh, Skinner, Wolff*]

Our work in this area provides fundamental observations needed to develop and test theories of the Earth's past, present and future climate. Key research achievements in this area since REF2014 include:

- the development of novel chemical and isotopic proxies in both sedimentary and ice core records to describe past climatic states;
- the use of paleoclimate proxies to study changes in ocean circulation and related carbon storage;
- fundamental new ideas about the behaviour of Earth's system over glacial-interglacial cycles and during millennial-scale rapid climate change;
- transformative insights into how chemical weathering processes influence the carbon budget and the operation of Earth's thermostat;
- major advances in our understanding of the formation of carbonate minerals under a variety of chemical and microbial conditions, and attendant consequences for the carbon cycle.

This research theme has been bolstered by the appointment of *Tosca* as the Chair of Mineralogy and Petrology, *Shuckburgh* as a Reader in Environmental Data Science, two new University Lecturers (*Branson*, *Rhodes*), as well as major equipment investments and laboratory upgrades (see Section 3).

Beyond REF2021, Cambridge Zero (CZ) will be a major focus of multidisciplinary efforts across the University to address the challenge of climate change and the transition to a carbon-neutral future. We are also involved in major scientific initiatives: (1) a European programme to retrieve the oldest ice core record in Antarctica (1.5 Myr - *Wolff*/*Rhodes*); (2) leading an expedition of the International Ocean Discovery Program (IODP) to recover marine sediments from the Iberian Margin (Chief Scientist *Hodell*). We are in a strong position to correlate these important ice and marine sediment archives to provide an integrated understanding of past changes in the ocean-atmosphere system.

***Earth and Planetary Volcanology, Geochemistry and Petrology***
[*Bickle*, *Edmonds*, *Gibson*, *Holness*, *Maclennan*, *Neufeld*, *Shorttle, Wallis*, *Weller*, *Williams*, *Woods*]

Our work in this area focusses on the processes that take place inside the Earth and other planets, with applications to planetary evolution, natural hazards, environmental processes and resources. Key research achievements in this area since REF2014 include:

- quantifying and modelling mechanisms of volatile cycling between the Earth's outer envelopes and the interior;
- development of diffusion chronometry to place timescales on magma storage and transport in the crust;
- development of novel volcano monitoring techniques using unmanned aerial vehicles;
- advancing our understanding of economic metal deposits;
- demonstrating that phosphine gas detected in the atmosphere of Venus cannot be explained by any known abiogenic source.

This group has maintained international competitiveness by three new appointments and several major equipment investments (see Section 3). The new appointments allow us to maintain our fundamental strengths in the application of thermodynamics to planetary evolution (*Weller*/*Shorttle*) as well as expanding our horizons to exoplanetary science via a joint appointment with the Institute of Astronomy (*Shorttle*) and to the leading-edge of stable-isotope geo/cosmo-chemistry (*Williams*).

Beyond REF2021 we will use our position at the forefront of many of these areas to lead interdisciplinary projects addressing societal challenges in the themes of: i) timescales of magmatic

and volcanic processes; ii) volcanic monitoring networks; iii) the mechanisms, efficiencies and associated hazards of Carbon Capture and Storage (CCS); iv) fluid flow, crustal processes and thermodynamics of geothermal and other forms of energy; and v) rocky planets and the evolution of life in solar systems beyond our own.

***Geophysics, Geodynamics and Tectonics***
[*Al-Attar, Copley, Cottaar, Jackson, Neufeld, Rawlinson, Rudge, Wallis, White N, White R, Woods*]

Our work in this area combines cutting-edge seismic and geodetic imaging of the Earth's interior and deformation with quantitative physical models of fundamental Earth processes and continuum mechanics. Key research achievements in this area since REF2014 include:

- a new understanding of the relationships between earthquakes, seismic hazard, mountain building, and the structure and rheology of the lithosphere;
- imaging magma movement in the crust using a Cambridge-led seismic deployment during the 2014 Holuhraun eruption in Iceland;
- new constraints on the geometry, spatiotemporal scales and temperature structure of mantle convection, and its relation to the Earth's topography and volcanism;
- a suite of new physical models of the subsurface flow of injected carbon dioxide, benchmarked by novel geochemical observations;
- new high-resolution images and analysis of oceanic structure and mixing using seismic data.

This group has been bolstered by two appointments: *Rawlinson* is the BP Foundation McKenzie Professor of Earth Sciences, focussing on Earth imaging and tectonics, and *Cottaar* is Lecturer in deep Earth seismology. These positions have reinforced our strong international reputation in understanding the interplay between plate tectonics and deep Earth processes.

Beyond REF2021, our aims are to develop new techniques for the seismic and geodetic imaging of Earth structure and deformation, gather novel data and observations, and perform state-of-the-art computational and experimental modelling, in order to: (i) establish the controls on the physical and chemical evolution of the lithosphere, convecting mantle, and core-mantle boundary; (ii) understand the dynamics and consequences of reactive flow of fluids through rocks, with relevance to the movement of igneous melts, and carbon dioxide injected into the subsurface; (iii) explore the societal implications of our work by quantifying and understanding earthquake hazard and sea-level change.

***Mineral Sciences***
[*Branson, Carpenter, Farnan, Harrison, Ringe*[*], *Tosca, Wallis*]

Our work in this area is focussed on the structure, dynamics and properties of crystalline solids and how these properties impact broader Earth, environmental and planetary processes. Key research achievements in this area since REF2014 include:

- major breakthroughs in the understanding of magnetic properties of minerals at the nanoscale, leading to new insights into the magnetism of the early solar nebula, differentiated planetesimals and Hadean zircons;

[*]A joint lecturer based 50% in the DoES and 50% in the Department of Materials Science and Metallurgy. For the purposes of REF2021 Ringe's outputs are submitted via UoA12.

- pioneering research into the longevity of radioactive waste glasses;
- atomic scale mapping of the chemistry of organic templates in biominerals;
- how magnetite authigenesis stabilised liquid water on the early Mars;
- new techniques for mapping stress at the microscale and quantifying its impact on the strength of Earth's lithosphere.

The group has been bolstered by four new appointments including *Tosca* as the new Chair of Mineralogy and Petrology, *Ringe,* a joint appointment with the Department of Materials Science, *Branson* in the field of biominerals, and *Wallis* in the field of rock and ice rheology.

Beyond REF2021, as a member of the core science team for the Mars 2020 mission, *Tosca* will focus on the geological and paleo-environmental evolution of the Mars 2020 landing site - Jezero Crater. Following the successful landing on Mars in February 2021, the UoA will be formally involved in the scientific discoveries made over the course of the mission, and in selecting the samples that will eventually be returned to Earth. The science of NanoPaleoMagnetism will be used to tackle important issues in environmental science, such as the quantitative development of magnetic proxies based on sound physical principles. A new microgeodynamics lab will develop models for the evolution of rock viscosity over seismic and glacial cycles. We will continue to take a lead on the topic of nuclear materials and explore new frontiers of research in biominerals and advanced electron microscopy.

***Palaeobiology and Palaeoecology***
[*Butterfield, Branson, Davies, Field, Harper, Liu, Tosca, Turchyn*]

Our work in this area focusses on major evolutionary transitions – in particular, the early evolution of eukaryotes, the Ediacaran-Cambrian 'explosion' of animals, and the Mesozoic-Cenozoic revolutions in marine and terrestrial ecosystems. Key research achievements in this area over the REF2021 period include:

- major discoveries and analytical insights into the origin, evolution and geographic distribution of birds;
- development of novel numerical tools to analyse the spatial dynamics of Ediacaran fossils, representing a step-change in our understanding of early animal evolution;
- documentation of widespread miniaturisation and meiofaunal expansion through the Ediacaran-Cambrian explosion.

This theme has been bolstered by three new appointments that capitalise on these established themes, while taking them in exciting new directions. We are now a centre of expertise in Proterozoic palaeobiology (*Liu*, *Butterfield*), bird evolution (*Field*), and biomineralisation (*Branson*, *Harper*). The establishment of a new University-funded post for the Director of the SM (*Hide*), appointed to manage the staff (9 FTE) and develop the research resources, has revitalized the SM's world-class research collections and associated Conservation Laboratory.

Beyond REF2021 collaborative research at the interface of biogeochemistry, sedimentology, mineralogy, climate and (exo)planetary geology will be a defining feature of future paleobiological research in Cambridge. While maintaining our strengths in systematic palaeontology, we plan to resolve fundamental issues of nutrient cycling (particularly phosphate) through deep time, and the co-evolutionary interplay of biological and planetary evolution.

**Impact Strategy**

Researchers in the UoA are not only at the cutting-edge of their individual subdisciplines, but frequently work at the interfaces among disciplines, where the greatest opportunities for creating impact lies. Our impact strategy sees members of the UoA take leadership roles in local, national and global consortia that are transforming the Earth Sciences from a discipline that focusses mainly on scientific problems, to one that increasingly seeks societal solutions that will help support the transition to a Sustainable Earth. This approach is exemplified by research that supports CZ:

CZ (https://www.zero.cam.ac.uk) is directed by a member of this UoA (*Shuckburgh*) and was launched in 2019 with a grant from the University of Cambridge and the Isaac Newton Trust. It is an ambitious climate change initiative aimed at transitioning to a zero-carbon world, bringing together the collective expertise of the University of Cambridge – from science and engineering to law and philosophy – to offer integrated, holistic and practical solutions to climate change and to bring these developments to bear at international, national, and local levels. CZ acts as a hub, integrating and enhancing the University's research impact by connecting more than 40 separate research groups and institutes across the University and amplifying Cambridge's voice as part of the international response to the global climate crisis. Its impact strategy is organised around four central pillars:

- **Research**: Pioneering research and innovation to drive technological and social change;
- **Education**: Inspiring education and training to provide the skills needed to deliver a different future;
- **Engagement**: Accelerating engagement with a broad coalition of stakeholders to collectively develop solutions;
- **Decarbonisation**: Leading by example to support decarbonisation.

The Research Pillar identifies six themes: 1) zero-carbon energy transition, 2) health and society, 3) resources and production, 4) resilient futures, 5) transport, cities and infrastructure, and 6) carbon drawdown and repair. Research across all six themes takes place within this UoA. A major research focus in the UoA aligned to Theme 6 is our work on CCS, which addresses hard-to-decarbonise sectors in the UK economy and, in conjunction with biofuels, will lead to a serious and significant means of achieving negative emissions. We are actively engaged in CCS projects with industrial partners and the British Geological Survey. We play a leading role in interpreting the geophysical and geochemical data from analogue field sites and active field trials in the US, Norway and Australia, including planning a new injection experiment at Otway in Australia run by CO2CRC Ltd. We also host a NERC Industrial Innovation fellow (*Bradbury*) who is using laboratory experiments coupled with machine learning and reactive transport modelling to explore microbial stimulation during CCS and subsequent mineralisation, influencing secondary porosity evolution. Research in this area is currently underpinned by six grants totalling £1.9M.

Through its Engagement Pillar, CZ works with stakeholders outside the University – in government, industry, the third sector, locally, nationally and internationally – enabling University insight to meet real-world needs (a more detailed summary will be provided in Section 4). Through its Decarbonisation Pillar, CZ works with the collegiate University to help to develop, coordinate and facilitate its own rapid transition to a zero-carbon future. In July 2019, the University of Cambridge became the first university in the world to announce a 1.5°C Science Based Target for carbon reduction and recently announced its decision to divest from fossil fuels and ensure that research within the University is compatible with its ambition to support the transition to a carbon-neutral

world. Work to deliver the University's net-zero ambitions is led by the Sustainability section within the University's Estates Division with strategic oversight provided by the Environmental Sustainability Strategy Committee (ESSC) on which the Director of CZ (*Shuckburgh*) sits.

Our REF impact case "Sustainable ventilation: design of ventilation systems to reduce energy consumption in buildings, and to reduce air-borne infection transmission in hospitals" (*Woods*) is an excellent example of the broader impact created within this UoA, aligned with Themes 1, 2 and 5 of CZ. This case study leverages our expertise in the experimental and mathematical modelling of fluid flow more generally to model ventilation flows in buildings, a topic that has taken on enormous importance in light of the global pandemic and the emerging concerns around aerosol transmission of the SARS-CoV-2 virus.

A major strand of the UoA impact strategy is focussed on the geological and mineralogical aspects of the nuclear energy sector, aligned with Theme 1. Research into a site and a process for nuclear waste disposal in the UK through the development of a Geological Disposal Facility safety case forms the basis of our REF impact case "Research into UK-specific nuclear waste glass saves UK government more than GBP64 million and guides government policy regarding plutonium disposal" (*Farnan*). Our work in this area is sustained through our involvement in local, national and international activities dealing with wide-ranging aspects of the nuclear industry (see Section 4).

The UoA also provides national and international leadership in the field of natural hazards through our Deputy Directorship (*Copley*) and membership (*Edmonds*/*Jackson*/*Penney*/*Wimpenny*) of the Centre for Observation & Modelling of Earthquakes, Volcanoes & Tectonics (COMET), whose long-term impact on international and UK science has been recognised by being funded through the NERC 'National Capability' funding stream. COMET is a national community with considerable size and impact, bringing together world-leading scientists across ten UK universities and the British Geological Survey. COMET funds staff, scientists, postdocs and students to collaborate on a wide range of projects in the fields of seismic and volcanic hazards, working closely with many global collaborators, along with the Natural Environment Research Council, the National Centre for Earth Observation and the European Space Agency. These subjects form the basis of our two remaining REF impact case studies: "Increasing resilience to earthquake risk in developing countries (*Jackson/Copley*) and "Automated ultra-violet sensors and UAS platforms developed in Cambridge to monitor volcanic gases become critical components of volcano monitoring networks worldwide to protect life, property and livelihood" (*Edmonds*). The first of these describes the results of the "Earthquakes without Frontiers" project, a consortium of eight UK institutions and partners from 11 other countries that aims to increase resilience to earthquakes in vulnerable countries. The second describes a ground-breaking spectrometer system that remotely and safely monitors the flux of sulphur dioxide gas from active volcanoes. The data arising from these systems are used to monitor volcanoes and forecast eruptions. Since 2013, this technology has been adopted by >10 volcano observatories and the information from the monitoring networks has been used to inform the development of industry (e.g. geothermal energy plants); and decision-making regarding evacuation zones and alert levels.

**Interdisciplinary Work**

Cross-disciplinary collaboration and research with the UoA is encouraged through a friendly atmosphere, joint studentships, joint-teaching of flexible, novel fourth year Masters 'options' courses, and joint-supervision of fourth-year research projects. In addition to the many interdisciplinary activities of CZ, the UoA leads numerous cross-University communities and

organisational structures that foster interdisciplinary research and impact as well as multiple DTPs and CDTs with a strong interdisciplinary focus:

- The BPI is an interdisciplinary institute studying multiphase flow, involving collaboration between Earth Sciences, Chemistry, Engineering, Chemical Engineering and Biotechnology, and Applied Maths and Theoretical Physics. It is directed by a member of this UoA (*Woods*), another of the academic staff (*Neufeld*) is also in this UoA, and the other four academic staff are submitted in UoA12 (2), UoA8 & UoA10. The BPI provides a direct interface between the UoA and major industrial and other partners. The research spans subjects ranging from volcano dynamics, CCS, ocean mixing and ice sheet evolution through to microscopic encapsulation technology, fundamentals of wetting and corrosion, flow in permeable rocks, and granular flows.

- The UoA leads the NERC Cambridge Climate, Life and Earth DTP (C-CLEAR - Chair *Edmonds*), in partnership with the Departments of Zoology, Plant Sciences, Genetics, Chemistry, DAMTP, Geography, Archaeology, and BAS, and its predecessor, the NERC Earth System Science DTP.

- The UoA hosts and directs the new £6.7M UKRI CDT in Artificial Intelligence for Environmental Risk (AI4ER) which began in 2019. The AI4ER CDT brings together academics from 13 departments across the University and BAS, as well as 36 stakeholders drawn from industry, policy and civil society.

- The UoA hosts the Cambridge component of the Nuclear Energy Futures EPSRC CDT (Director *Farnan*) in partnership with Imperial College London, the University of Bristol, the Open University and Bangor University, and its predecessor, the EPSRC ICO (Imperial Cambridge Open universities) CDT in Nuclear Energy.

- The UoA hosts a world-class and unique facility for Resonant Ultrasound Spectroscopy (*Carpenter*) which attracts international collaborators in engineering, physics, solid state chemistry and materials science.

The UoA is deeply committed to supporting interdisciplinary work through our three lectureships jointly appointed with the DoES and the Department of Materials Science and Metallurgy (DMSM), the Department of Applied Maths and Theoretical Physics (DAMTP) and the Institute of Astronomy (IoA). Each Lecturer is fully embedded in both departments and shares teaching and administrative duties equally between the two (e.g. by examining for each department on alternate years). Following the successful DoES/DAMTP joint appointment of *Neufeld* in 2011, the School of Physical Sciences created eight new joint Lectureships based on our model. The UoA successfully bid to host two joint appointments in the areas of Multi-Scale, Multi-Dimensional Imaging of Natural and Synthetic Materials (*Ringe*) and Exoplanets (*Shorttle*). The appointment of *Shorttle* cements our strategic decision to expand our research and teaching activities in the area of planetary science and creates new connections to 2019 Nobel-prize winning exoplanetary research in the Departments of Physics, Cosmology and the IoA. The appointment of *Ringe* further strengthens an already close relationship between the UoA and the Department of Materials Science and Metallurgy (DMSM) and creates a formal link to the Wolfson Electron Microscopy Suite expanding our access to state-of-the-art electron microscopy facilities and expertise.

**Open Research Environment and Research Integrity**

The UoA follows the University of Cambridge Research Data Management Policy (https://www.data.cam.ac.uk/university-policy) as expressed in the University's Open Research Position Statement (https://osc.cam.ac.uk/open-research/open-research-position-statement). Beyond the REF open access requirements, we encourage staff to make their work freely available; as a result over 25% of our outputs are in gold open access journals.

The SM curates over two million rock, mineral and fossil specimens, which are available for both academic research and public engagement. The strategic mission of the Sedgwick Museum is to bring positive benefit to people by sharing knowledge and understanding of the Earth Sciences. The public galleries of the Sedgwick Museum are physically located within the DoES site in central Cambridge. Research and teaching collections are located in new dedicated facilities next to the DoES site in NW Cambridge.

The UoA promotes the University Research Integrity and the Good Practice Checklist, highlighting the Concordat to Support Research Integrity as part of the induction for new staff with research responsibilities and on our website. The Code of Practice for Research Students sets out what students should expect during their study in terms of supervision, support and assessment, as well as what the University expects of research students. The University signed the San Francisco Declaration on Research Assessment (DORA) July 2019. Our researchers are encouraged to complete the University series of Research Integrity Training with both online and face-to-face courses.

## 2. People

### Staffing strategy and staff development

The UoA provides a supportive, collegiate and inclusive work environment. An external Strategic Research Review carried out in 2017 noted that "*The positive atmosphere the Panel encountered in the Department amongst the faculty, postdocs and PhD students was noted to be laudable and reflected the strong and effective efforts by the Department to develop a top level academic and research environment.*" We consider this to be among our most valuable recruitment and retention tools. The external Strategic Research Review further noted that "*The review papers showed that although a number of world-class researchers have retired over the past ten years, the Department have done an excellent job of recruiting high quality and creative early-career researchers to the faculty. Many are rising stars who have won awards and/or are growing into future leaders within the discipline.*"

Since REF2014, 12 academic appointments have been made: seven male and five female. For these posts, approximately 32% of applicants were female and of those shortlisted for interview, 34% were female. The ultimate goal is to shortlist equal numbers of male and female applicants and the department has been experimenting with generating separate male and female shortlists which are evaluated separately in order to create a 'gender neutral' final short list for interview. This practice will continue in the future. Our proactive approach has doubled the number of female academics over the past REF period (from five to ten), with 100% success rate for both female (three to Professor and two to Reader) as well as male (four to Professor and four to Reader) applicants over this time interval. The number of female Professors has now risen to four (25% of the current in-post Professors), from just one female Professor (6%) at the start of the period. The appointment of *Edmonds* as Director of Research (who also acts as *de facto* Deputy Head of Department) has increased the representation of female academics in senior leadership roles. We currently operate an informal workload monitoring system. Teaching and administrative loads are kept low and fairly distributed through our "no teaching buy-out" policy – all members of the Department contribute at a level commensurate to their career stage and experience. We are working on the development of a formal, quantitative workload model to further support the equitable distribution of teaching and administration tasks across UoA.

Our staff development strategy is informed by staff and student surveys which assess the evolution and effectiveness of staff development procedures including: Induction and Probation, Training and Development, Career Progression, Senior Academic Promotions, Leadership and Management, Work-Life Balance, Flexible Working, Core Hours, Caring Responsibilities, Pay and Benefits, Equality and Diversity, Bullying and Harassment, and Communication. The survey results are compared directly with previous surveys and discussed in a series of focus meetings with individual groups (Support Staff, Postdoctoral Researchers, PhD students and Academic Staff) led by the Chair of the Welfare Committee (*Woods*).

New academic staff are mentored by a senior academic, who provides guidance on probation, career development and promotion. They are also encouraged to attend relevant University training courses, and we run our own training for supervising and demonstrating. Lighter teaching and administration loads are maintained for newly appointed staff. The HoD meets yearly with new academic staff during their five-year probationary period, and post-probation academic staff have

appraisals every other year or when they wish. A Promotions Committee, comprising the HoD and senior staff familiar with the Senior Academic Promotion scheme provides encouragement and guidance on promotion, and ensures that academics have a network of mentors from which they can obtain impartial and confidential advice.

Academic staff are entitled to paid sabbatical leave at the rate of one term for every six terms of service, up to a maximum of three terms at any one time. Additional periods of sabbatical leave are available to those whose research plans have been disrupted by carrying heavy administrative loads e.g., HoD.

**ECR Support**

Since REF2014, the UoA has introduced a formalised mentoring scheme to guide ECRs through the process of applying for Independent Research Fellowships. ECRs are given a two-stage process of preparation for fellowship interviews: the first stage provides feedback on their research presentations; the second stage is a formal mock interview with academics that have served as chairs or members of fellowship panels. The External Strategic Research Review noted that "*the Panel agreed that the mentoring scheme for postdocs and early career faculty was extremely beneficial.*" As a result of this scheme, since REF 2014 twenty-nine independent research fellows have been appointed (four NERC, one 1851 Exhibition, one RS URF, four Leverhulme, five Marie Curie, six JRFs and eight funded by overseas fellowships and the Royal Society International fellowship scheme (the Simons Foundation, Blavatnik, CIFAR, Swiss National Science Foundation, Weiner-Anspach, & the Humboldt Foundation Feodor Lynen Research Fellowship)). To support their career development, postgraduates, postdocs and research fellows are provided with opportunities to contribute to undergraduate teaching, e.g. by providing guest lectures and research seminars to undergraduates, providing sabbatical cover, co-supervision of undergraduate research projects and demonstrating on undergraduate field trips and in undergraduate practical classes. For teaching-related activities, they are paid at the standard University rates.

Regular 'postgraduate' and 'postdoc' forum events enable direct conversations with ECRs about their research environment needs and how we can help meet their needs. A dedicated postdoc email list keeps our ECRs up to date with training, grant, fellowship and job opportunities. The Postdoc Academy, founded as the Office of Postdoctoral Affairs in 2013, coordinates professional development, entrepreneurship/industry collaborations, leadership, networks, pastoral services and mentoring support for postdocs.

We encourage our postgraduate students to undertake internships in government departments or similar, such as those held at the Parliamentary Office of Science and Technology (POST). Since REF2014, eight of our postgraduate students have taken up this opportunity (*Branson, Miller, Jennings, Lawrence, Woods, Honour, Crawford, Mason*) and have contributed directly to position papers that have subsequently been used by ministers and others. Several of our postgraduate students have gone on to positions in the Civil Service in Whitehall or with their intern partner (e.g. *Lawrence, Honour, Woods*, *Nicholl*) and will subsequently have a long-lasting impact on the implementation of environmental policy and development of advice to government.

## Research Students

The UoA admitted an average of 20 PhD students per year during the period 2014-20. Studentships are funded from diverse funding sources, including various DTPs and CDTs (NERC ESS (2014-18 intakes) and C-CLEAR DTPs; EPSRC Nuclear Energy; AI4ER), grant, trust, and scholarship funded, funded through industry, and self-funded.

Postgraduate numbers have been further supplemented by the introduction of the Master of Advanced Studies (MASt) course in Earth Sciences (equivalent to the MSci course taken by our 4th year students) and the MRes course in Environmental Data Science (the 1st year of the 1+3 AI4ER CDT). The MASt course, like our fourth-year course, has a 40% research component and was introduced in 2019 to widen participation in our postgraduate courses. Success of the MASt in increasing diversity will be closely monitored over the next REF period. The MRes in Environmental Data Science brings ten students per year. Over the past five years 24% of our UKRI funded PhD students have held CASE awards, involving industrial sponsorship.

In addition to their research supervisor(s), all postgraduate students are assigned a postgraduate advisor to provide independent academic mentoring and support, a postgraduate student "parent" from a previous year group to provide informal peer support and advice, and access to three postgraduate tutors who oversee the wellbeing of research students at a cohort level, in addition to a postgraduate tutor in their Cambridge College. One of these Departmental postgraduate tutors is the Director of Postgraduate Education (*Farnan*), who also chairs the Postgraduate Affairs Committee (PAC). Three Postgraduate Student Representatives provide a highly effective mechanism for communication between the postgraduate student body and the UoA leadership via frequent Town Hall events as well as their membership of the PAC, Welfare and EDI committees. As members of the Collegiate University, all postgraduates have access to a rich network of pastoral and financial support through their Colleges. Student progress is monitored by termly reports and by formal interviews with two independent academic assessors at the end of their 1st and 2nd years. As a result of our student monitoring and support we have one of the highest PhD submission rates, within four years, across the University (>90% on average over the past five cohorts, higher than the national average of 73%).

The UoA provides a rich range of training opportunities for postgraduate students. A regular training bulletin is sent to all postgraduate students advertising the large number of training activities available throughout the University and beyond. All students in the UoA, regardless of their funding, are entitled to attend activities organised by the C-CLEAR DTP, including their first year "Advances in Climate, Life and Earth Sciences Programme". A three-day training course in field-safety and outdoor first aid runs twice a year, providing postgraduate students, postdocs and staff with an accredited qualification in outdoor first aid. An outstanding library is staffed by a full-time librarian who provides training and assistance to postgraduate students in all aspects of accessing the published research literature, both hard copy and online.

## Equality, diversity and inclusion

The UoA was awarded Athena-SWAN Bronze status in April 2016. We subsequently established an Equality and Diversity Committee, with the aim of completing tasks on the action plan and

working towards ‘Silver Status’ in 2020. Due to COVID-19, our application deadline for Silver status has now been extended to 2021. The E&D committee became the Equality, Diversity, and Inclusion (EDI) committee in 2020, with a broader remit to tackle issues of diversity across all protected characteristics including race, disability, sexual orientation and gender, both within the UoA and within the geosciences more generally. Some notable successes from our new EDI action plan are the *Geoscience in Context* seminar series and discussion group that intends to broaden understanding of geoscience’s place in society, the history of the subject, its modern practice and its role in shaping the future. The UoA is also a founding member of the *earth2earth* seminar series (https://earth2earthseminar.com), which aims to engage the UK Geosciences community with inspiring science from internationally leading researchers, while promoting inclusivity and diversity, supporting the advancement of ECRs, and highlighting geoscientists’ contributions to addressing global environmental challenges.

The UoA is committed to providing a healthy and fulfilling working environment for staff and students. Our website provides links to key policies and advice to support staff and student wellbeing, including Dignity at Work, Breaking the Silence, Occupational Health, Counselling Service, and Personal and Professional Development. The Welfare Committee conducts surveys to assess and monitor progress in staff and student wellbeing. Over 90% of the UoA members participated in the last survey, and the results have been analysed in detail across gender, race, and staff type by an independent statistician hired by the department. The survey paints a largely positive picture of the UoA, and this has inspired us to continue our programme of improvement. We recognise the sector-wide issues of bullying and harassment that can exist within all academic environments, and we have engaged our postgraduate and postdoc communities to develop best practice for research supervision and field teaching within the UoA, backed by a bespoke supervision agreement that sets out clear, enforceable expectations for both students and supervisors. Our postgraduate and postdoc survey on this issue has been shared with HR in the School of Physical Sciences as an exemplar of good practice.

## 3 Income, infrastructure and facilities

### Research Funding and Funding Strategies

The average research grant income per annum of the UoA over the REF2021 period was over £5M, >50% higher than the REF2014 period. In addition to research grants awarded, we received donations of £6.8M from six commercial partners over the REF period. These have included contributions for building projects (the Colin Forbes building and the DoES/BPI Digital Lab) and £3.9M of additional contributions to build the capital of the endowment of the BPI. The University has also demonstrated strong support for this UoA over the same period by providing £1.6M contribution for building the Collections Research Centre and £1.4M towards instrumentation and infrastructure costs which, with matching funding, has allowed us to fund over £2.6M of new equipment.

A dedicated Grants Administrator is responsible for facilitating the preparation of grant and fellowship proposals, providing a central source of information about new and upcoming funding calls, running the internal review process, archiving proposals for the use by subsequent applicants, and organising grant writing workshops for ECRs. Institutionally, the three-year average success rate with NERC applications is 27% and therefore we are not subject to NERC Demand Management.

Our future funding priority is to increase and diversify research funding streams by:

- Increasing multi-disciplinary collaborations (e.g. in the field of planetary/exoplanetary science) that create new opportunities to bid for funding beyond the NERC remit (e.g. STFC, EPSRC and ESA);
- Exploring new opportunities for impact-related funding (e.g. Strategic Priorities Fund, Industrial Strategy Challenge Fund and the Global Challenges Research Fund);
- Targeting applications to innovative fellowship programmes, for example UKRI Industrial Innovation Fellowships (e.g. *Bradbury*).
- Maintaining our involvement in European network activities, such as the **E**lectron and **X**-ray microscopy **C**ommunity for structural and chemical **I**maging **T**echniques for **E**arth materials (EXCITE) network, awarded to Co-I *Harrison* beginning in 2021.

During the REF2021 period, UoA staff (and related staff) were awarded:

- ERC Advanced Investigator Grant: WACSWAIN: Warm climate stability of the West Antarctic ice sheet in the last interglacial (*Wolff*)
- ERC Starting Grant: ZOOMDEEP: Zooming in on the core-mantle boundary (*Cottaar*)
- ERC Starting Grant: SPECs: Sustainable plasmon-enhanced catalysis (*Ringe*)
- UKRI Future Leaders Fellowship: Modernisation, diversification, and domination: Macroevolutionary origins of living bird diversity (*Field*).

The REF2021 period has also seen the completion of:

- ERC Advanced Investigator Grant: NANOPALEOMAG: A multiscale approach to paleomagnetic analysis of geological materials (*Harrison*)
- ERC Advanced Investigator Grant: WIHM: Water Isotopes of Hydrated Minerals (*Hodell*)
- ERC Advanced Investigator Grant: NEWLOG: New Directions Linking Ocean Geochemistry, Biomineralisation and Palaeoclimate (*Elderfield*)
- ERC Starting Grant: CARBONSINK: Life beneath the ocean floor, the subsurface sink of carbon in the marine environment (*Turchyn*).

This record of major grant success at the highest levels of international competitiveness demonstrates excellence across the entire breadth of the UoA research themes (Climate, Geophysics, Mineralogy/Petrology, Paleobiology and Biogeochemistry).

**Organisational Infrastructure Supporting Research and Impact**

CZ has been established as the primary organisational vehicle for the delivery of impact through research and innovation in the area of climate change and the transition to a carbon-neutral world. Beyond CZ, the UoA has developed formal institutional collaborations with BAS in the fields of environmental research, specifically, but not exclusively, in ice-core and sediment-core research. Through these activities we aim to develop and promote a world-leading hub for paleoenvironmental and paleoclimatic research in Cambridge. This collaboration was cemented by the coordinated hire of *Rhodes* in the DoES and *Bauska* at BAS, which provides critical mass and sustainability in ice-core climate research. The first fruits of this new strategic partnership are emerging with an initial joint investment of £60k in the development of the UK's first laboratory for continuous gas analysis from ice cores. Ice core researchers in the DoES and BAS share their research at monthly "ice core forum" meetings, which are regularly attended by other scientists in this field working in the Departments of Geography and Chemistry.

**Operational infrastructure supporting research and impact**

Since REF2014 we have made major investments in equipment, laboratories and buildings to support research and impact activities across the UoA:

**New equipment** investments have been made**,** including:

- FEI QEMSCAN 650F Field-Emission-Gun Scanning Electron Microscope (£872k)
- Cryocell LA-ICP-MS (£235k)
- Neptune Multi-Collector ICP-MS (£265)
- High-precision water isotope analyser (£78k)
- Powder X-ray Diffractometer with a Mo Source (£220k)
- Mobile Seismometers (£339k)

**Funding has been secured** and tenders issued for new equipment that will be installed shortly after the REF2021 census date, including:

- Field-Emission Gun Electron Probe Microanalysis (FEG-EPMA) **(**£1.5M).
- Nu Instruments nu PERSPECTIVE Isotope Ratio Mass Spectrometer (£265k)

- ThermoScientific Isolink Peripheral (£50k)

The QEMSCAN forms the centrepiece of our natural materials characterisation suite, providing high-resolution secondary and backscattered electron and CL imaging, automatic mineralogical analysis, and simultaneous chemical and crystallographic mapping. The FEG microprobe to be installed in 2021 will be the newest of only three such instruments in the UK and ensures that UoA will continue to be a centre of excellence in chemical microanalysis, serving the School of Physical Sciences' strategic goals in *Energy*, *Sustainability, New Materials*, *Global Change* and *Natural Hazards*. The continued investment in our extensive geochemical facilities allows us to undertake high-precision rapid analyses of trace elements in materials as diverse as ice cores, cell tissues and minerals. This has led to multi-disciplinary collaborations across the University (e.g. with Addenbrookes, Archaeology, Materials and Chemistry) funded by the ERC and MRC.

**Major research infrastructure upgrades** have also taken place, including:

- Construction of a new cold room for sediment cores (£24k);
- Reconfiguration/refurbishment of our clean lab suite, including expansion of air handling system (£276k);
- A new sample preparation and optical microscopy laboratory (£68k);
- Reconfigured/refurbished Boron-free clean labs (£70k);
- Full establishment of the NanoPaleoMagnetism Laboratory funded through a £2M ERC Grant to *Harrison*.

A £2.3M investment has enabled the construction of the Colin Forbes Building, a dedicated Collections Research Centre for Earth Sciences located adjacent to the SM's Conservation Unit and Archive in NW Cambridge. This new facility replaces a previous rock storage facility located in a former commercial unit that was fast approaching the end of its useful life. The Colin Forbes Building provides high-quality, high-density, climate-controlled storage for the SM's internationally important research and teaching collection, vastly improving its accessibility to the broader community, with further investment (£90K) by Arts Council England enhancing digital collections access, volunteering opportunities and public engagement with the research collections. The Museum is one of eight participating collections in a new JISC/Wiley-funded archive digitisation project, which will enable Adam Sedgwick's historically important notebooks to be available to researchers internationally.

**New university-funded technical support roles** have been created to support the expansion of activity in the plasma-based and clean geochemistry laboratories (a permanent laboratory manager and a new technical officer). The support staff team of the Godwin laboratory for palaeoclimate research is led by two highly experienced technical staff. Our microanalytical labs (electron microscopy, FEG-EPMA, XRD) are also served by two highly experienced permanent technical staff. The UoA hosts two workshops, one serving the DoES main site and the second the BPI, served by six permanent technical staff with expertise in metal, wood, plastic work and electronics. The UoA also employs seven Computer Officers serving all members of the UoA.

**Infrastructure sharing**

The Godwin Laboratory for Paleoclimate Research provides analytical services for stable isotope analysis across the University, the UK and internationally, spanning research areas of

geochemistry, food authenticity, material science and provenance (biological and inorganic), agriculture and environmental science, forensic science, medicine and nutrition, carbon cycle (including CCS), hydrology, ecology, and testing of international standard reference materials (solids and gases). Within Cambridge we analyse samples for the Departments of Archaeology & Anthropology, Astronomy, Chemistry, Classics, Earth Sciences, Epidemiology, Geography, Material Science, Physics, Plant Sciences and Zoology. Within the greater Cambridge area, we provide stable isotope services to Anglia Ruskin University and the British Antarctic Survey. Our Resonant Ultrasound (RUS) Facility serves a wide community of mineralogists, physicists, materials scientists and engineers interested in measuring the elasticity of materials. Our electron microscopy and X-ray analysis facilities have a broad user base both within Cambridge (Geography, Physics, Materials Science, Engineering, Archaeology, Chemistry) and beyond (UEA, Durham, Leicester, OU, Birkbeck, Southampton, Oslo, Trondheim, Amsterdam).

UoA staff are major users of national and international research facilities to facilitate research in mineralogy, petrology, geochemistry, palaeontology and planetary science. During the REF2021 period, our scientists performed experiments at national and international X-ray synchrotron and neutron scattering facilities (Diamond, ESRF, BESSY II, ALS, SNS, Canadian Light Source, ISIS, ILL). We benefitted from international technical infrastructure and access to existing material to obtain marine (IODP, NERC) and ice (EPICA, BAS) cores, allowing access to material used in numerous publications.

## 4 Collaboration and contribution to the research base, economy and society

### Collaborations, Networks and Partnerships

New grant-funded networks have been established or led by members of the UoA during the REF2021 period:

- CZ (*Shuckburgh*)
- COMET (*Copley*)
- Earthquakes without Frontiers (*Jackson*/*Copley*)
- Deep Carbon Observatory (*Edmonds*)
- Deep Volatiles consortium (*Maclennan*/Rudge/*Shorttle*/Williams)
- Earth and Planetary Magnetism (*Harrison*)
- Materials for Neuromorphic Circuits (MANIC) (*Carpenter*, *Salje*)
- Multiferroic Domain Walls Consortium (*Carpenter*, *Salje*)

*Edmonds* served on the board of Deep Carbon Observatory (DCO), a decade-long programme funded by the Alfred P Sloan Foundation to understand the cycling, forms and origins of carbon in Earth's core, mantle and crust. *Edmonds* chairs one of the principal four communities of the DCO - Reservoirs and Fluxes - as well as the Synthesis Group, charged with integrating scientific results of the programme from across the >80 institutions and ~1000 international researchers. The DCO has produced >1500 peer-reviewed publications, 12 synthetic books/collections of review articles/special issues, and leveraged >$20 million in additional grant funding.

The UoA played a key role in the UK's NERC-funded Deep Volatile Consortia, a five-year network of three closely related consortia. *Williams* was involved in the original scoping activity that lead to the NERC Volatiles Consortia Grant call and *Williams*, *Rudge* and *Maclennan* are Co-PIs on one of the three consortia that resulted from it. These consortia trained a cohort of 12 PhD students and ~ 20 ECRs (including *Shorttle*) and leveraged two further NERC grants to *Williams* and *Maclennan* (~ £1.4M combined) and two further NERC consortia grants where *Williams* and *Shorttle* were involved as Co-PIs (~ £1.6M combined).

Since 2016 the UoA has developed a partnership with MIT in the field of Earth and Planetary Magnetism via an International Science and Technology Initiatives (MISTI) Global Seed Funds award (*Harrison*) which provides travel funding for the exchange of researchers, postgraduates and undergraduates between the DoES and MIT. A major success of this programme was the subsequent awarding of a £800k NERC grant to *Harrison*, together with project partners at MIT, to pursue a project on Hadean paleomagnetism, leading to high-impact papers in Geology (2018), PNAS (2019) and Science Advances (2020).

*Carpenter* and *Salje* are partners in the Marie Curie Training Network "Materials for Neuromorphic Circuits (MANIC)", a €4.1M programme running from 2019-23 to create materials that can function as networks of neurons and synapses by integrating conductivity, plasticity and self-organization. *Carpenter* and *Salje* are also participating in an EPSRC-funded consortium with Queen's

University, Belfast, Warwick University and University of St Andrews to characterise and harness novel functionalities of domain walls in ferroelectric, ferroelastic and multiferroic materials with regard to their use in a new generation of device applications.

**Engaging with recipients of research**

Members of the UoA have worked with partners within the Collegiate University to build relationships and engage with a broad range of people and organisations, including: 1) the Cambridge Institute for Sustainability Leadership (CISL), which works directly with senior leaders, CEOs and boards of leading companies to align their strategy and commercial decisions with the Paris Agreement and drive the transition to net zero across their operations; 2) the Centre for Science and Policy (CSaP), which aims to improve public policy through the more effective use of evidence and expertise, by creating opportunities for public policy professionals and academics to learn from each other; and 3) the Maxwell Centre**,** which links leading University research across Physical Sciences, Technology and beyond with industry and policy by providing collaborative working space and an engagement programme for its stakeholders. CZ, together with CSaP, have set up the CZ Policy Forum, bringing together over 80 senior academics from across the University to address climate change through a multidisciplinary lens.

The annual BPI Masterclass, now in its 16th year, is an intensive programme of talks from experts working in the broad areas of energy supply and demand, both in industry and the university. The focus is on technology challenges and opportunities, including examples of the use of science and engineering in the energy industry. The Masterclass covers a broad range of themes, from conventional supplies, renewable supplies to energy efficiency, and it provides new insights about both long- and short-term challenges for the energy infrastructure. An important aspect of the Masterclass is the opportunity to learn about and debate some of the important questions concerning different energy sources, about energy efficiency and climate change.

The UoA engages significantly with the nuclear industry on the theme of materials for the safe storage of radioactive waste. Locally, *Farnan* is Chair of the Cambridge Centre for Nuclear Energy, the Cambridge Director of the Nuclear Energy Futures EPSRC CDT and a founding member of the inter-departmental Cambridge MPhil in Nuclear Energy. Nationally, *Farnan* leads the EPSRC Carbides for Future Fission Environments (CaFFE) Research Consortium and is Co-PI on the EPSRC Accident ToLerANT fuels In reCycling (ATLANTIC) consortium. Internationally, *Farnan* is a Project Leader in the EU H2020 Modern Spent Fuel Dissolution and Chemistry in Failed Container Conditions (DISCO) project. Through the Cambridge Centre for Nuclear Energy *Farnan* is working with the OECD Nuclear Energy Agency (Cambridge is one of the founder members of the Global Universities Forum convened by the NEA this year) and engineers and economists at Cambridge to take a systems approach to deploy affordable nuclear power as demanded in UK Nuclear Sector deal (2018). A number of DoES staff (*Farnan*/*Redfern*/*Woods*/*Bickle*) are involved in providing advice to government on aspects of the nuclear industry.

An Overseas Development Assistance project led by *Tipper* is supporting a better understanding of the impact of dams on rivers and deltas, and how chemical dissolution in flood plains pollutes groundwater, causing arsenic poisoning in Cambodia, Burma and other SE Asian nations. A two-day training workshop was held in Yangon, August 2017, attended by representatives from the Department of Meteorology & Hydrology, Directorate of Water Resources and Improvement of River Systems, Ministry of Environmental Conservation and Forestry as well as the NGOs AIRBM, ALARM and MEI and the University of Yangon. Finally, members of the UoA benefit greatly from

our “Industrial Associates Scheme” where exchange between industry and academic leaders takes place in an annual meeting, providing routes to market for ideas that emerge in the course of our pathways to discovery.

**Wider contribution to the economy and society**

In addition to the four submitted impact cases, a number of our research themes have developed significant impact both in the UK and overseas.

The work of *Salje*, in collaboration with colleagues in Xi’an, China, has produced methods for detecting and interpreting acoustic warnings of rock failure associated with mine collapse. Work of *Carpenter* to measure the anisotropic elastic properties at high temperatures of repaired segments of turbine blades is ongoing through the Rolls Royce/Cambridge University Technology Centre. In collaboration with researchers in Materials Science, *Carpenter* has used RUS extensively to characterise additively manufactured nickel-based superalloys for Rolls-Royce to use in their next generation of more efficient gas turbine engines. *Liu* has worked on outcrops in Mistaken Point, Newfoundland, which contributed to that locality being ratified as a UNESCO World Heritage site. Further afield, *Harrison’s* work on meteorites and their magnetic properties has directly influenced the joint NASA/ESA mission to Psyche.

**Public Engagement with Diverse Communities**

A key component of our public engagement strategy centres around the SM and its core mission to: a) facilitate, enhance and stimulate international research, b) bring a relevant, inspiring and evidence-led approach to learning and enjoyment for our public audiences, c) enhance student learning and support their skills development, and d) take a leading role in the museums, archives and cultural heritage sectors. Each year, the Sedgwick Museum hosts more than 100 research and archive visitors, answers around 200 research enquiries, provides 500 specimens for student teaching in Cambridge and in six other universities, and welcomes 150,000 public visitors and 4000 schoolchildren. The appointment of a dedicated full-time Director (*Hide)* provides new strategic leadership. Close alignment between the public engagement goals of the UoA and the Sedgwick Museum is achieved through the Museum Steering Committee chaired by the DoES HoD and comprising DoES staff who advise on use, development and curation of the research and teaching collections. The creation of a new Communications and Public Engagement Officer facilitates joint engagement activities. Recent examples of this strategy in action are the Museum’s ‘Illuminating the Start of Complex Life’ display of research on the Ediacaran age rocks of Newfoundland, Canada, which was awarded a University of Cambridge Vice-Chancellor’s Research Impact and Engagement Award for Collaboration in October 2019, and an outreach project by joint Lecturer *Ringe* (funded by grants from the Institute of Physics and the Royal Society of Chemistry) which developed learning activities in everyday physics for visually disabled individuals.

Members of the UoA engage and empower the public by highlighting environmental challenges and providing opportunities and platforms for open discussion. *Shuckburgh* has contributed to flagship events at the Festival of Ideas (a conversation with Ed Miliband MP) and the Science Festival, given a number of high-profile public lectures, including the WWF Annual Science Lecture

2019, the Turing Lecture for Earth Day 2020, the Guardian Live event "The climate emergency", and co-authored the best-selling *Ladybird Book of Climate Change* with HRH the Prince of Wales and Tony Juniper in 2017.

**Response to national/international priorities**

CZ co-founded the UK Universities COP26 Network (now 50 member universities), which has become the principal way UK academia is interacting with the UK government with respect to planning for the UN's COP26 climate conference in 2021. Through the COP26 Network, members of the UoA regularly engages with and advises the Cabinet Office COP26 team, providing direct input to the UK Government team in the form of evidence, advice and access to academic expertise. *Wolff* chairs the Royal Society's working party on Climate Change Science and has led the preparation of a number of briefing papers for government about reports from the Intergovernmental Panel on Climate Change.

On an international level, CZ has led the University's involvement with the Global Alliance of Universities on Climate (GAUC), an international partnership of 13 leading universities. Its mission is to advance climate change solutions through research, education, and public outreach, and to partner with industry, non-profit and government organisations to promote rapid implementation from local to global scales.

The AI4ER CDT, which began in 2019/20, will produce 50+ postgraduate research students over eight years, trained in technical and scientific leadership, policy, innovation and entrepreneurship skills. This supports two of the four Grand Challenges identified in the UK's Industrial Strategy, namely, to put the UK at the forefront of the AI and data revolution and to maximise the advantages for UK industry from the global shift to clean growth.

The SM extends the UoA reach beyond science and research policy through its role as a major cultural provider, part of the Arts Council England National Portfolio through its role in the University of Cambridge Museums consortium. The Museum's inclusion programmes respond to nationally identified priorities around social inequality and health & wellbeing, access to higher education and STEM careers, and access to cultural and learning opportunities; they target the 10% most deprived areas and communities as identified through the National Index of Multiple Deprivation. The Museum makes an active contribution to the UN's Sustainable Development Goals, for example: Quality Education (SDG4) Reduced Inequalities (SDG10) and Climate Action (SDG 13), Peace, Justice and Strong Institutions (SDG16).

**Indicators of wider influence and esteem**

*World and UK rankings*

The UoA is currently ranked joint 3rd in the 2020 QS World University Rankings for Earth and Marine Sciences. It is currently listed as the top destination in the UK for geological science in the Complete University Guide.

*Prizes/Honours*

During the REF2021 period, members of the UoA have been honoured with over 30 major awards, medals and honours from national and international bodies, including:

- CBE (*Jackson*)
- OBE (*Shuckburgh*)
- Fellow of the Royal Society (*Holland*, *Holness*, *Woods*)
- Fellow of the American Geophysical Union (*Bickle*, *Hodell*, *White*)
- Fellow of the Mineralogical Society of America (*Holness*)
- Milner Centre for Evolution, University of Bath, 50th Anniversary Prize Fellow (*Field*)
- British Antarctic Survey Honorary Fellow (*Harper*, *Wolff*)
- Gold Medal of the Royal Astronomical Society (*White*)
- Wollaston Award – The Geological Society of London Early Career Award (*Weller*)
- Philip Leverhulme Prize, Earth Sciences (*Tosca*, *Rudge)*
- President's Award of the Geological Society of London (*Shorttle*)
- Francois Frenkiel Award, best paper award in Physics Review Fluids (*Neufield*)
- Wollaston Medal, Geological Society of London (*Jackson)*
- Murchison Medal, Geological Society of London (*Holness)*
- Milankovic Medal, European Geosciences Union (*Hodell)*
- Mineralogical Society of America Award (*Tosca*)
- David and Marvalee Wake Award, Society for Integrative and Comparative Biology (*Field*)
- Cas Lindsey Prize, Canadian Society of Zoologists (*Field)*
- Wager Medal, International Association Volcanology and Chemistry of the Earth's interior (*Edmonds)*
- Hamilton Award, Society for the Study of Evolution (*Field)*
- Keiliti Aki Young Scientist Award, Seismology at the American Geophysical Union (*Cottaar*)
- Fowler Prize, Royal Astronomical Society Prize for Early career achievement in Geophysics (*Copley*)
- Schlumberger Award, Mineralogical Society (*Carpenter)*
- President's Medal, Paleontological Association (*Butterfield*)
- Coke Medal, Geological Society of London (*Bickle*)
- ThermoFisher Scientific Volcanic & Magmatic Studies Group Award (*Edmonds*)
- Society of Systematic Biologists Publisher's Award (*Field*)
- Philip M. Orville Prize (*Field*)
- Richardson Medal, International Glaciological Society (*Wolff*)

In addition, our members were honoured as named lecturers:

- Marchi Lecturer, Italy (*Woods*)
- Bullerwell Lecturer for the British Geophysical Association (*Cottaar*)
- GFD Principal Lecturer, "Sustainable Fluid Dynamics" (*Woods*)
- Emiliani Lecture at the American Geophysical Union Meeting (*Hodell*)
- Daly Lecture at the American Geophysical Union Meeting (*Edmonds*)
- Hallimond Lecture for the Mineralogical Society of Great Britain and Ireland (*Gibson*)
- Mineralogical Society Distinguished Lecturer (*Williams*)

*Providing expert advice*

UoA members were frequently called upon to provide expert advice to both national and international governments, governmental agencies, scientific organisations and societies during the REF2021 period, including:

- Advisor to the All Parties Parliamentary Group on Climate Change (*Shuckburgh*)
- Commissioner on IPPR's Environmental Justice Commission (*Shuckburgh*)
- Member of NHS Net Zero expert panel (*Shuckburgh*)
- Presentation to Civil Service Fast Stream Environment Network (*Shuckburgh*)
- Chair of the Royal Society Working Party on Climate Change (*Wolff 2018-)*
- Chair of the Royal Society Global Environment Research Committee (*Wolff* 2016-18)
- Lead UK author for the joint Royal Society/NAS publication "Climate Change: Evidence and Causes" (*Wolff*)
- Ministerial-appointed (DECC and then BEIS) member of the UK Committee on Radioactive Waste Management (*Redfern*)
- Input to the Nuclear Decommissioning Authority (NDA) and Radioactive Waste Management (RWM) on implementing deep geological disposal (*Woods, Bickle*, *Farnan*)
- NDA Environmental Safety Case Independent Panel (*Woods*)
- Testimony on CCS to the Energy Select Committee (*Neufeld*), the Royal Society (*Bickle*, *Woods*) and Industry (*Bickle*, *Neufeld*, *White N*, *Woods*)
- Advice to UK Government (GO-Science, COBR, SAGE, NERC, DFID) for 2.5 years following the Nepal (Kathmandu) earthquake of 2015 (*Jackson*), and following multiple other earthquakes (*Jackson*, *Copley*).
- Multiple workshops about Earthquake Hazards in Iran, India, Kazakhstan, and Italy (at an ICTP/UNESCO establishment and involving participants from many countries on the DAC list) (*Jackson*, *Copley*)
- Member of Royal Society Steering Groups for Shale Gas Extraction, and future marine resources (*Bickle*)
- Parks Canada Burgess Shale Research Review Panel (*Butterfield*).

Our members sat on 20 advisory boards during the REF2021 period, including chairing the Science subgroup of the European Project for Ice Coring in Antarctica (*Wolff*), and served as panel members for multiple UKRI, EU and other international funding bodies, including:

- NERC Peer Review College Chair (*Edmonds* 2017-21)
- Chair of the NERC Ion Microprobe Facility steering committee (*Edmonds* 2014-18)
- Chair of the NERC Cosmogenic Isotope Facility steering committee (*Wolff* 2015-19)
- NERC Training Advisory Board and DTP-2 Working Group (*Edmonds* 2016-18)
- Members of the NERC and UKRI FLF Peer Review College (*Butterfield*, *Copley*, *Field*, *Harrison*, *Hodell*, *Holness*, *Maclennan*, *McCave*, *Redfern*, *Rudge*, *Tosca*, *Turchyn*, *White N*, *White R*, *Williams*), including serving on NERC Panels multiple times.
- Grant Panel, European Research Council (*Holness* 2015-)

In addition, members of the UoA have served on numerous assessment and grant review panels, both nationally and internationally (e.g. Research council of Norway – *Piotrowski*, NASA – *Turchyn*, Daphne Jackson Trust – *Tosca*). *Tosca* is also a member of International Mars Science Return Science Objectives Team and Planning group.

*Societies*

Members of this UoA have taken leading roles in national and international scientific societies during the REF2021 period, including:

- *Carpenter* (2016-20) President of the European Mineralogical Union
- *Rawlinson* (2018-) President - British Geophysical Association
- *Gibson* (2018-20) Vice President of the Mineralogical Society
- *Holness* (2019-) President of the Geochemistry, Mineralogy, Petrology and Volcanology (GMPV) section of EGU
- *Gibson* (2018-) Chair Volcanic & Magmatic Studies Group (Geological Society of London & Mineralogical Society)
- *Turchyn* (2015-) Chair Marine Studies Group (Geological Society of London)
- *Edmonds* (2014-18) Secretary of the Science Committee at the Geological Society of London
- *Turchyn (*2017-) Secretary of the Geochemical Society (International)
- *Weller* (2019-) Secretary, Metamorphic Studies Group (Geological Society of London)
- *Edmonds* (2017-19) Secretary for the AGU Volcanology and Petrology Section
- *Liu* (2019-) Elected Council Member of the Palaeontographical Society
- *Gibson* (2010-) UK Teaching Accreditation Panel, Geological Society of London
- *Harrison* (2011-16) Committee Member of the Mineral Physics Special Interest Group
- *Tosca* (2012-16) Committee member of Clay Minerals Special Interest Group
- *Bickle* (2015-18)*, Gibson* (2019-) Geological Society of London, Members of the Awards Committees
- Weller (2019-) Science Officer of the Geochemistry, Mineralogy, Petrology and Volcanology (GMPV) section of EGU
- *Pilia* (2014-16) Executive committee member for the Emirates Society of Geoscience
- *Williams* (2016) Elected council member of the European Association of Geochemistry

Members of this UoA have undertaken over >40 journal editorial roles during the REF2021 period, including for *Science*, *Elements*, *EPSL*, and *PNAS*. Our members have also been involved in the organisation of 16 major international and national scientific conferences, most notably the Chair of the 2019 Goldschmidt Geochemistry Conference (*Williams*).

The number and quality of activities that UoA members lead on, or participate in, is testament to the high esteem in which the UoA's research and staff are held. They also show that the UoA is in a good position to lead and influence UK and international agendas in Earth sciences after REF2021.