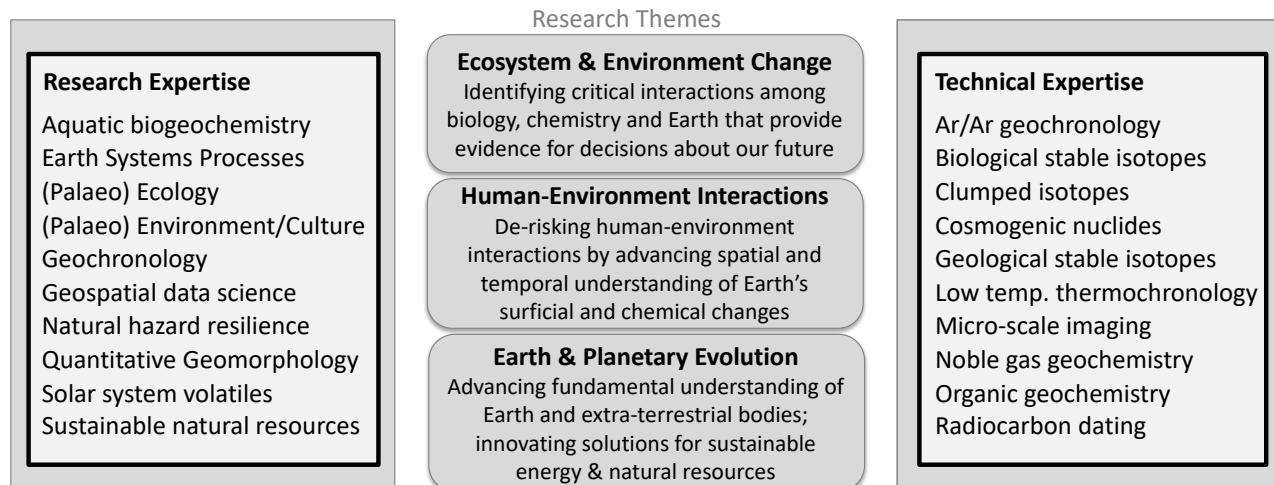


<b>Institution: University of Glasgow</b>
<b>Unit of Assessment: 7</b>
<b>1. Unit context and structure, research and impact strategy</b>

### 1.1. Unit structure and context

This Unit of Assessment 7 submission combines the strengths of three sub-units across the University of Glasgow (UofG) that contribute to our portfolio of Earth and environmental sciences research. The sub-units are the School of **Geographical and Earth Science's (GES) Earth Systems Research Group (ESRG)** - main campus (23.92 FTE), the **Scottish Universities Environmental Research Centre (SUERC)** - East Kilbride (17.4 FTE), and the **School of Interdisciplinary Studies' environmental scientists (SIS)** - Dumfries (2 FTE). This combination is hereafter referred to as the "Unit". The Unit comprises **44** Category A research staff who are supported by **33** technical staff and **66** postgraduate students who shape our current structure, which is consolidated into three inter-related research themes (Figure 1). Individuals named in **bold** below are current Category A staff; individuals in *italics* left during the assessment period.

**Figure 1.** Structure of Glasgow Earth Systems & Environmental Science Research



### Research highlights since REF2014

- SUERC remains one of the **world's largest facilities for Earth and environmental isotope chemistry** encompassing a wide array of expertise and advanced instrumentation. SUERC specialises in geochronology from deep time to the Holocene (Ar/Ar, cosmogenic, low temperature thermochronology and radiocarbon) and in environmental and geological tracers using stable isotopes, clumped isotopes and noble gas geochemistry and radiogenic isotopes. This is reflected in the continued operation of a major component of NERC National Capability operation via the National Environmental Isotope Facility (NEIF-SUERC) funded through a competitive £8.7M award (2019-2024, **Mark, Ascough, Barfod, Boyce, Fabel, Garnett, McGill, Newton**). We have invested £4.7M in new instrumentation and infrastructure, much of it funded in open competition (e.g., NERC Strategic Environmental Science Capital Calls).
- We have achieved critical mass in planetary science adding three Category A staff (**Daly, Einsle, Hallis**) and increasing the PDRA and PGR cohort. STFC funding to **Lee** and **Mark** has enabled our research into the origin and evolution of asteroids, the Moon and Mars, while **Hallis'** ground-breaking work showing the primordial origin of water on Earth (*Science*) has spawned new research. Our researchers contribute to direction of planetary research through contributions to the UK Space Agency Robotic Exploration (**Lee**) and Space Exploration Advisory Committees (**Hallis**) and AURORA Panel (**Mark**); iMOST for Mars sample return (**Hallis, Daly**) and the NASA Curation and Analysis Planning Team for Extraterrestrial Materials (**Hallis**).

- We have enhanced the breadth and depth of our research in environmental hazards by leading two work packages in the NERC Living Deltas hub (£1.2M to UofG, **Balke, Bass, Renaud**) and have captured >£1M from NERC to assess and predict environmental hazards related to hydrometeorological events (**Williams**), radionuclides in the environment (**Cook**), and ecological tipping points (**Balke**). NERC and ERC have supported >£2.8M for research that develops novel quantitative proxies for past climate and environmental change (**Fabel, Toney**), modern carbon efflux (*Waldron*) and consequences of climate change for biomineralization (*Fitzer*). Expertise in energy-related research is exemplified by EPSRC funding for geothermal research in East Africa (e.g., Combi-Gen **Boyce**) and over £1M income from natural gas-related research collaborations with Total and Petrobras (**Stuart**).

### **Sub-unit structure**

GES is an interdisciplinary School with human and physical geography and Earth sciences functioning collaboratively to create an inclusive research environment recognised by an Athena SWAN Silver award. The Human Geography Research Group submits to UoA14; whereas physical geography and Earth sciences as ESRG submit to UoA7. ESRG researches environmental hazards and risks associated with fluvial and coastal erosion, carbon cycle, geospatial science, and ecosystem thresholds including implications worldwide. Its researchers also focus on the evolution of planets and planetary processes, including Earth. Leadership in palaeoclimatology and planetary science is evidenced in international funding (ERC Starting Grant) and international roles in sample return consortia from various space missions (e.g., iMOST, NASA, JAXA). ESRG has reinvigorated the Unit's staff profile by making 15 of our 18 Early Career Stage Researcher (ECSR) appointments. New appointments have enhanced computation (**Keller, Shi**), data science (**Basiri, Einsle, Petrie, R Staff**) and applied environmental research (**Balke, Barrett, Bass, Moreau, Naylor, Williams**) and increased our expertise in cutting-edge isotope technology (**Clog, MacDonald, McIntyre**).

SUERC's world-class isotope laboratories (Section 3.3) and specialist expertise underpin the Unit's research themes. Our biomedical researchers submit to UoA3, while environmental and Earth science researchers submit to UoA7. SUERC's analytical infrastructure and long-established collaborative ethos underpins UK geoscience and ecological research. It is internationally renowned for expertise using isotopes as tracers and chronometers, exemplified by the incorporation of NERC NEIF node into SUERC's analytical capacity and laboratory facilities. Internally, there is strong cross-unit collaboration with research clusters around leading researcher expertise and funded projects that apply cutting-edge technology, for example, in: *Earth Systems Processes* - low temperature thermochronology to large-scale continent evolution (GLOW Laboratory, **Persano, Stuart**); *Solar System Volatiles* - combining micro-scale imaging and high-precision geochronology to address key problems in planetary evolution (**Lee, Mark**); *Quantitative Geomorphology* - cosmogenic nuclides to determine rates and timing of coastal erosion and ice-cap melt (**Fabel, Hurst, Stuart**); and *Palaeoenvironments* - organic geochemistry for developing new quantitative proxies to reconstruct palaeoenvironments (**Ascough, McIntyre, Toney, Staff**). SIS's environmental scientists (**Renaud, Shi**) work closely with ESRG researchers (**Balke, Bass**), bringing expertise in *Natural Hazard Resilience*, including hydrological modelling to address, for instance, environmental and agricultural risks in highly populated deltaic systems.

## **1.2 Management structure**

Each sub-unit has an internal management structure. GES and SIS have Executive committees comprising the Head of School, Director of Research, Director of Learning & Teaching, and other school representatives. SUERC's Executive Group comprises the Director, Deputy Director, Director of Research, Equality and Diversity Committee Chair and Financial Controller. Research strategy is shared among sub-units through representation on local research committees and via the GES Research Planning and Strategy Committee (chair **Toney**) and the College of Science and Engineering's (CoSE) Research and Knowledge Transfer Committee (**Boyce** and **Toney**). SUERC Director (**Stuart**) and GES Head of School (**Lee**) sit on the CoSE Management Group.

### 1.3 Research Objectives

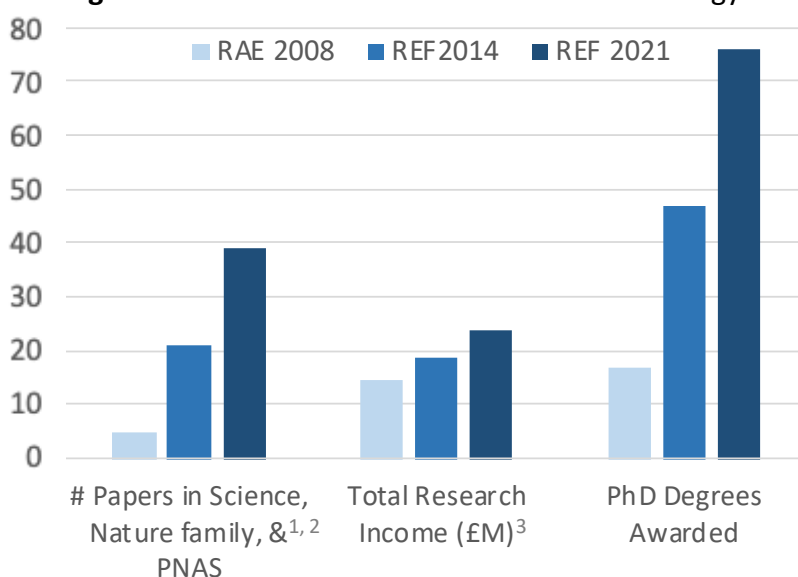
The Unit identifies the following strategic objectives:

- To maintain and enhance a global reputation for world-leading challenge-led and fundamental research across our research themes.
- To enhance research skillsets in data science, computational geoscience and cutting-edge analytical technology and integrate them across Earth and environmental sciences.
- Develop and diversify our ability to deliver solutions in partnership with stakeholders whilst leading discipline-specific expertise fundamental to our subjects.
- Create an environment where all staff and students can fulfil their potential to deliver high quality research that is attractive to internationally renowned, collaborative scientists.
- Deliver high calibre training for students and PDRAs to prepare them for careers in academia and industry.

### 1.4 Progress on REF2014 strategy

The upward trajectory of metrics of research activity from RAE2008 through REF2021 (Figure 2) reflects the realisation of strategies developed in 2008 and then elaborated in 2014. Between REF2014 and REF2021 the number of papers in high impact journals has increased by 86%, total research expenditure by 27% and the number of PhD awards by 58%. We have met the UofG commitment to making our research accessible with Open Access outputs increasing from 42% to 90% since 2014.

**Figure 2.** Success measures of our research strategy



<sup>1</sup> Does not double count co-authored papers.

<sup>2</sup> Excludes *Scientific Reports*

<sup>3</sup> For REF, SUERC income is split equally between UofG & UofEdinburgh

In REF2014 we defined a strategy based on strengthening and gaining critical mass in four research areas:

1. Climate change using terrestrial and marine proxies, including clumped isotope techniques;
2. Environmental hazard measurement and prediction, deploying sensors, remote sensing, geomatics;
3. Isotopes for hydrocarbon and geothermal exploration;
4. Extra-terrestrial research.

## Unit-level environment template (REF5b)

We have attracted researchers and fellows (11) from around the world (i.e., UKRI Future Leadership Fellow (FLF), Newton/Royal Society, Leverhulme), highly skilled instrumentalists (3) and interdisciplinary researchers (6) (summarised in Box 1). These new staff have reinforced our expertise and grown leadership in disciplines that are integral to the three research themes that have evolved from the process-based themes that were identified in REF2014: (i) surface; (ii) shallow crust; (iii) Earth-life; (iv) extra-terrestrial and mantle (see Section 2).

The new research themes defined in Figure 1 are designed to address emerging challenges (e.g., consequences of anthropogenic environment and land-use change and the shift to carbon neutrality) and maintain our strength in fundamental planetary and Earth science research. The new themes incorporate multi-disciplinary perspectives and collaborative decision-making that are important to solving emerging global challenges related to environmental risks and hazards, as well as sustainable energy and resources.

### 1.5 Research objectives for the next 5-years

In the next 5-years, we will use our research infrastructure to achieve the Unit's overarching research objectives (Section 1.3), enhancing our global reputation in challenge-led and fundamental research across our themes and providing opportunities for ECSRs (including PDRAs, PGRs) to develop research-based careers in academia and industry.

#### ***Ecosystem & Environment Change***

Building on leading contributions by **Fabel, Garnett, Kamenos, Moreau, Toney** (e.g., permafrost contribution to atmospheric methane, NERC project: IceCapMelt, ERC project: ALKENoNE), our research will address extremes arising from anthropogenically-induced changes to ecosystems and environments. Early and mid-career researchers (**Balke, Bass, Cameron, Clog, Hurst, McIntyre, Moreau, Shi, Staff**) are well-positioned to lead consortia, inform policy and conceive nature-based solutions related to, e.g., increased rates of mobilized fossil carbon from sensitive environments; increased rates and complex dynamics of coastal erosion and/or ice-sheet/cap decay; multiple stressors on habitats due to changing environments; reconstructing ultra-high resolution, quantitative records of past environments. New high precision  $^{14}\text{C}$  (**Freeman**), cosmogenic nuclide (**Fabel, Stuart**), Ar/Ar (**Barfod, Mark**) and luminescence (**Sanderson**) instrumentation will provide unrivalled chronological constraints crucial for quantifying rates of environmental change. High resolution mass spectrometry will be used to unravel the sinks and sources of atmospheric methane that refine projections of future Earth climate dynamics (**Clog**), while field-based mass spectrometry will allow greenhouse gas budgeting (**Bass**) and tracking the fate of injected  $\text{CO}_2$  (**Stuart**). Novel stable isotope techniques will be applied to animal ecology, particularly regarding the response of food web/diet and animal migration to climate stressors (**McGill, Newton**).

#### ***Human-Environment Interactions***

Novel systems approaches with communities and local government, as well as using data science to put data at the heart of decision making will be key to ensuring research impact. Our researchers have already demonstrated key contributions to shaping policy and practice around known and emerging issues, such as erosion risks to people and property (**Hansom, Naylor, Williams**), mitigating impacts of environmental and land-use change on agriculture/aquaculture (**Barrett, Renaud**); improving biodiversity and connectivity of habitats in areas with a legacy of built infrastructure (**Naylor, Williams**); reducing risk and increasing resilience of vulnerable communities to impacts of climate change (**Basiri, Petrie, Naylor**). New approaches will be enabled by the National Centre for Resilience (Director: **Renaud**) and the new UofG Centre for Sustainable Solutions (Director: **Toney**) that promote innovation by connecting researchers, policymakers and practitioners. We will exploit new isotope technology to explore the coincidences and consequences of past climatic, environmental and social change (**Ascough, Cook, Hamilton, Mark**).

#### ***Earth & Planetary Evolution***

In the coming years our researchers (**Daly, Hallis, Lee, Mark**) will pioneer discoveries into our solar system's origin leading analyses of samples returned from recent and impending missions, such as JAXA's Hayabusa2 mission to Ryugu, as well as from Mars and the Moon. New magnetic sector

## Unit-level environment template (REF5b)

mass spectrometry will open novel research into planetary interiors (**Ellam, Stuart**). We will address challenges and develop solutions with partners in sustainable extraction of natural resources for carbon-free solutions in the energy transition e.g., exploration for and extraction of key metals (Cu, Co, V) for battery technology and electricity transmission (**Boyce, Moreau**). New fluid isotope tracers will be used to quantify geothermal reservoirs, and trace economic natural gas and helium resources (**Boyce, Stuart**) often with industrial partners. Furthermore, our ECSRs have capacity to lead the field in computational modelling of Earth and planetary fluid processes (**Keller**), and applying machine-learning to planetary evolution (**Einsle**).

### 1.6 Encouraging Interdisciplinary Research

Interdisciplinarity is integral to our research. Our Unit attracts and hosts international seminar speakers from a range of disciplines who interact with our researchers weekly. Our submission includes staff who integrated into our Unit from physics, ecology, and archaeology backgrounds. Within the UofG we co-supervise M.Sc. and Ph.D. students with Schools of Physics, Engineering and Chemistry in CoSE, and Institute of Biodiversity and Animal Health, and have long-term collaborations with Engineering (geothermal research, **Boyce**; environmental compound- and position-specific isotopes - **Toney**), and Mathematics and Statistics (international <sup>14</sup>C calibration **Ascough, Cook**). We have close associations with Human Geography researchers in GES hosting workshops that create a natural pathway for interdisciplinary dialogues and research. For example, workshops on *stressed environments and communities* have led to co-supervised PhD projects (**MacDonald**'s ESRC-funded PGR on socio-environmental legacies of steel slag).

We have supported successful applications (**Einsle**) to the cross-disciplinary Lord Kelvin Adam Smith Fellowship (LKAS) scheme, established in 2012 to attract outstanding research scientists to conduct transformative research. We have also supervised 5 successful LKAS studentships, which supports PhDs with co-supervisors from two or more Schools in the UofG.

We actively recruit researchers with a track record of cross-disciplinary research. For example, **Basiri** (UKRI FLF, appointed to Chair of Geospatial Data Science) integrates research across CoSE with statisticians, computing scientists, and engineers, as well as urban social scientists in the UofG Urban Big Data Centre, the Institute for Health and Wellbeing and the Alan Turing Institute. This new hub addresses environmental problems related to big data, such as missing data and bias issues, as well as putting data at the centre of planning and decision-making.

### 1.7 Enabling and Facilitating Impact

#### **Fostering a Culture of Research Impact**

We have used workshops and externally facilitated discussion meetings to identify the potential impact of our research, and to develop synergies within the Unit and across CoSE. PIs work with the Research Impact team in CoSE to incubate and accelerate impact, and exploit relevant external funding opportunities (e.g., UKRI KE schemes). Impact is a fundamental criterion for institutional promotion and career progression at UofG.

Since REF2014 we have fostered research impact by establishing a knowledge exchange (KE) node in *natural hazards* research, now led by **Naylor** and **Williams**. Success is demonstrated by the KE awards to **Naylor** (NERC KE Fellowship £321k), **Waldron** (NERC Newton Fund £475k, £241k) and **Naylor, Williams** (NERC £90k) and impact-related prizes (e.g., Scottish Impact Award to **Hansom**).

Impact is embedded in the collaborative relationships that **Boyce** and **Stuart** have developed with companies exploring for minerals, and natural gases respectively. Impact culture within both research nodes is fostered by regular PhD-PDRA interaction with industrial/external partners. Most publications include industry co-authors, and researchers typically go on to work in industry or in industry-funded academic positions.

## Unit-level environment template (REF5b)

### **Research infrastructure**

We have invested £3.5M in instrumentation and £1.2M for infrastructure improvements to support our world-leading expertise in geochemistry techniques. We have found that the recognition of expertise is key to impactful relationships with external partners. Three of our Impact Case Studies (ICSs) are directly linked to our research infrastructure and expertise.

### **External Partnerships**

We are *early adopters* of analytical technology and have skills in technique development that has led to several patents. Over the REF period we have focused effort on forming long-term strategic partnerships with key instrumentation manufacturers. The largest is the unique Technology Agreement Partnership we have with ThermoFisher Scientific. We lead a consortium with business partners, National Electric Corporation (USA) and Pantechnik S.A. (France), commercialising a patented technology for long-lived radionuclide analysis (PIMS) that was invented and developed in the SUERC AMS Laboratory (**Freeman**).

We have used state-of-the-art analytical techniques and proven research expertise to develop strong research-focussed relationships with the hydrocarbon industry via formal research collaborations with Total S.A. (France) and Petrobras (Brazil) (**Stuart** ICS), and with the mineral industry via training programmes and CASE PhD awards (Scotgold Resources Ltd, Boliden Tara Mines **Boyce**). Our partnership with Rare Whiskey 101 has successfully refined techniques for tracking fake Scotch malt whisky, while our long-term relationship with Cellmark Forensics has resulted in bone <sup>14</sup>C analysis becoming a routinely applied forensic tool for all UK Police forces (both **Cook** ICSs). The natural hazards node works in partnership with environmental engineering (Arup), energy (Scottish and Southern Energy) and water resources (Scottish Water) with secondments with external partners (i.e., **Williams** to CBEC Eco-Engineering Ltd).

### **International Research**

We lead and contribute to challenge-led international agendas in developing countries through a range of funders (Section 3). The diversity of funders enhances the vitality and sustainability of our impactful research abroad from landmine risks in Myanmar (**Barrett**), paired novel geothermal energy technology with potable water solutions in Ethiopia (**Boyce**), to understanding how food, drink and environment influenced the social and political evolution of ancient cultures in Northern Iraq (**Toney**).

### **Recruiting for Impact**

We have recruited 21 Category A staff over the assessment period in order to build critical mass and enhance research in priority areas. Two of the four priority areas have impact potential. Evidence of excellence in research impact was a key criterion for all appointments and new staff have mentors to foster impact development, creating a sustainable pathway for the longevity and reach of our impact culture.

## 2. People

### 2.1 Staffing Strategy & Evolution of the Current Staff Profile

Our staffing strategy is driven by recruitment to strengthen core research areas defined in REF2014 and research themes (Box 1). 32% of our Category A staff are international and the number of Category A staff (44, FTE=43.3) has increased by 8 since REF2014. In tandem with this growth, there has been a considerable reinvigoration of our staff profile with 48% appointed since REF2014. A combination of staff retirements (5, 11%) and leavers who have taken up research chairs (*Koehn, Li, Phoenix, Xu*) or national leadership roles (*Cusack* - Dean of Natural Sciences, University of Stirling; *Hoey* - Vice Provost, Brunel University; *Waldron* - Director of Research and Skills, NERC) has enabled recruitment of 18 early career researchers (**Clog, Balke, Barrett, Bass, Cameron, Daly, Einsle, Hallis, Hurst, Keller, MacDonald, McIntyre, Naylor, Neill, Owen, Petrie, Williams, Staff**) many from prestigious institutions (e.g., **Basiri** - UCL, **Clog** - Caltech, **Einsle** - Imperial, **MacDonald** - Imperial, **McIntyre** - ETH-Zurich, **Keller** - Stanford). We have appointed mid-career researchers (**Shi**) and research leaders (**Basiri, Moreau, Renaud**) while strengthening computation

## Unit-level environment template (REF5b)

(**Keller, Shi**), data-driven (**Basiri, Einsle, Petrie, Staff**) and challenge-led (**Balke, Barrett, Bass, Moreau, Naylor, Williams**) research and increased our expertise in cutting-edge isotope technology (**Clog, MacDonald, McIntyre**), which are strongly represented across our research themes.

**Box 1:** Recruitment into strategic priority areas:

### ***Ecosystem & Environment Change***

Climate change using terrestrial and marine proxies: we developed and retained RSE fellow: **Kamenos** marine palaeoecologist, multi-stressor impacts on marine corals and Leverhulme fellow **Staff** - Quaternary geochronologist, Bayesian statistical modelling chronological data; and recruited **Cameron** - glacial microbial ecologist, **Clog** - clumped isotope geochemist, **McIntyre** environmental organic geochemist, **Petrie** GNSS and geospatial science.

### ***Human-Environment Interactions***

Environmental hazards: recruitment of **Basiri** - geospatial data science (UKRI FLF); **Balke** - biogeomorphologist, thresholds and windows of opportunity for coastal habitats; **Bass** - aquatic and terrestrial biogeochemist; **Barrett** - remote sensing for habitat inventories, pollution risk, socio-ecological sustainability and agricultural improvements; **Hurst** - geomorphologist in actively tectonic landscapes and coastal erosion; **Moreau** - applied and fundamental geomicrobiologist; **Naylor** - biogeomorphologist, nature-based approaches to coastal and urban climate change risk/adaptation; **Renaud** - vulnerability, risk and resilience of social-ecological systems; **Shi** - hydrologic modeling of water resources and climate extremes; **Williams** - fluvial geomorphologist and geospatial scientist; **Thomas** - biogeomorphologist of critically endangered pearl mussels.

### ***Earth and Planetary Evolution***

Isotopes for hydrocarbon and geothermal exploration: increases in research funding and impact (Section 3); however, recruitment in Earth evolution has been driven by emerging priorities recruiting: **Keller** - computational geoscientist of magmatic processes; **MacDonald** - clumped isotopes and carbon sequestration by industrial waste; **Owen** - modern and ancient fluvial processes and reservoirs; **Neill** - lithospheric processes in geothermal energy, volcanic hazards, and critical metals.

Extraterrestrial research: recruitment: **Hallis** - meteorite analysis for planetary formation; **Daly** - high-resolution geochemical analysis of planetary materials for understanding solar system evolution; **Einsle** - mineral physicist and data geoscience applied to Earth's evolution.

Recruited research leaders (**Basiri, Moreau, Renaud**) enhance cross-theme activity, mentor our growing ECSR cohort, and lead interdisciplinary research initiatives addressing societal challenges. Twelve staff who were ECRs during the REF period have achieved promotion with assistance of formal UofG mentoring structures of our Early Career Development Programme (ECDP) and leadership training courses, such as, Aurora Leadership, Academic Leadership, Aspiring or Emerging Leaders, Senior Research Leaders, and University Leadership. Attendance on courses is split 50:50 among males and females. Our mentees are thus progressing through to senior roles in the Unit. Researchers promoted this REF cycle include: Senior Lecturers - **Ascough, Balke, Barrett, D. Brown, Fabel, Persano, Thomas, Williams**; Readers - **Kamenos, Naylor**; Professors: **Mark, Toney**. Senior staff help set the strategy for the Unit's research culture, and are now emerging national leaders (*Cusack, Hoey, Waldron*).

## Unit-level environment template (REF5b)

### 2.2 Equality, diversity and inclusion

During this REF period, gender diversity across the Unit rose from 22% (8 of 36) female staff in 2013/14 to 27% (12 of 44, 2019/20). This increase stems from a proactive approach to reshape our sub-units by engaging with self-assessment and creating strategic action plans through Athena SWAN. ESRG increased its proportion of female staff from 21% (4 of 19) in REF2014 to 38% (9 of 24) in REF2021. This change was instigated via concerted awareness raising via our local SWAN@GES brand of Athena SWAN (AS) Bronze (2014-2017) and continued actions and awareness raising through our Silver award and action plan (2017-2022).

SUERC's profile shifted from 24% (4 of 17) female researchers in REF2014 to 17% (3 of 18) in REF2021. SUERC self-assessed their profile and achieved AS Bronze in 2019. SUERC's self-assessment and action plan was commended by the AS panel for its honesty and ambition. SUERC's action plan includes measures to increase diversity by establishing search committees to diversify applicant pools for new posts; proactively supporting promotion and regrading of existing staff; and metric-based monitoring of the efficacy of actions to improve diversity. The opportunity for change through new appointments is slow due to a historically low staff turnover rates (only three appointments since REF2014). However, in part due to its maturing demographic, SUERC will actively seek to recruit a more diverse cohort over the next 5-years. SIS (2) also holds an AS Bronze award since 2017.

Across the Unit, we have clear lines of communication for issues arising from all staff, including those with protected characteristics. Bespoke arrangements are created as needed to carry out research productively, but are not discussed explicitly here, because there are low numbers of staff using these options and it would impinge on their privacy.

The Unit followed UofG Code of Practice for output selection. Outputs were selected and configured to maximise the Unit's GPA even if outputs were allocated unevenly across staff, staff at different career stages, or not allocated to their senior author.

### 2.3 Staff development

At the university level, a series of policies and activities support, reward and celebrate our research culture, including being a signatory to the Concordat to Support the Career Development of Researchers. Newly appointed academic staff at grades 7 and 8 join ECDP. This programme provides learning and development opportunities in all aspects of the academic role to aid in progression from Grade 7 to Grade 8 within three years and to Grade 9 (e.g., senior lecturer) in a further five years. Our data show that ECRs (those on ECDP) thrive in our environment and capture their first grant award within two-years in a permanent post. Our senior researchers provide subject-specific support and guidance as mentors for ECDP. A much larger proportion of our staff are on ECDP (32%) than were ECRs in REF2014 (14%) (Table 3), delivering new energy and drive to our research portfolio.

**Table 1.** Staff profile REF 2014 versus REF2021 (Note: we use ECDP as an indicator of early career stage researchers)

Theme	REF2014			REF2021		
	Total Staff	ECDP #	ECDP (%)	Total Staff	ECDP #	ECDP (%)
Ecosystem & Environment Change	18	2	11%	20	5	25%
Human-Environment Interactions	2	0	0%	9	2	22%
Earth & Planetary Evolution	16	3	19%	15	7	47%
<b>Total:</b>	<b>36</b>	<b>5</b>	<b>14%</b>	<b>44</b>	<b>11</b>	<b>32%</b>



Our senior research leaders support mid- and early-career researchers through annual objective-setting, hosting promotion workshops, and assistance with funding applications. Collegiality is explicitly valued in the University's promotion criteria and rewarded through an annual Research Culture Award (**Kamenos** 2019, highly commended **Keller** 2020). Our progressive culture of diversity and inclusion is underpinned, reflected on and monitored as part of the AS Silver action plan in GES and the Bronze action plans in SUERC and SIS. The Unit embeds good practice through implementation of:

- a core-hours culture.
- support structures to increase women's understanding and confidence of promotion processes. We recognised that fewer women put themselves forward (21% of promotion applications despite 29% female staff in the eligible pool (22) from 2010/11 to 2012/13). Since 2013, biannual promotion workshops and active encouragement of female staff has resulted in 36% of applications from females (10 out of 28 applications) since 2013 with 100% success for female applicants.
- clear maternity or shared parental leave policies with assistance to gain financial support upon staged return. Our three female returners accessed £28k in total to support their research activities in staged transitions back into work.
- higher visibility of internal and external female role models via 'Career Stories' over coffee with seminar speakers exposes ECSRs to different career pathways and work-life balance strategies.

Sub-unit Equality and Diversity committees continually monitor demographic profiles to identify emergent issues in equality, diversity and inclusion. These committees look beyond gender, which is the focus of Athena SWAN. Our evolving agenda commits us to tackle gender, race and LGBTQ+ inequality through an open, sensitive and transformative approach covering issues such as work-life balance, career development opportunities for women and early career colleagues, mentoring, and progression.

## 2.2 Career Development Opportunities

We develop and enable all research staff (R&T and R-only) through:

- Reduced administrative and teaching loads via leave for research/impact development - Research and impact leave is available to all staff (fixed-term, open-ended, part-time) and is enabled by Graduate Teaching Assistants (GTAs) (n>300 since 2014) who underpin laboratory/fieldwork elements of course delivery and teaching support. Focus-groups showed many GTAs plan to pursue academic careers. Teaching experience is important to this trajectory and so we provide substantial training for GTAs on teaching methods and skills. Researchers with significant salary recoup through grant income are given reduced teaching and administrative workloads without official leave.
- Support for acquiring research funding - Our Research Committees provide internal proposal and manuscript peer-review and mock fellowship interviews. These supplement comprehensive grant-writing workshops through ECDP at College level.
- Rewarding grant capture - We reward successful grant capture enabling additional research by returning a proportion of grant overheads to individual PIs (two-thirds of each project's contribution in the previous year is returned).
- Supporting ECSRs - We have a central fund that supports >40 staff and research students to attend national (~20%) and international (~80%) conferences annually.
- Providing flexible working arrangements - The ability to remotely operate analytical equipment has improved efficiency and data quality. Consequently, many researchers work from home via formal time off *in lieu* (TOIL) schemes.
- Strategic leadership opportunities - Early and mid-career staff are given strategic leadership opportunities to promote career development. Appropriate training and shadowing of senior staff is provided, as well as reductions in administration and teaching duties. E.g., Head of

## Unit-level environment template (REF5b)

ESRG is filled by a collegiate Lecturer or Senior Lecturer with grant capture and shows future research vision (*Phoenix* 2014-2016, **Toney** 2017-2019, **Barrett** 2019-current).

- Research Leadership training is offered at all levels including a Senior Research Leadership programme that convenes cross-UofG senior researchers, provides 360-reflective leadership practice, and high-level opportunities for strategic career development.

Career Development for Early Career Researchers - ECDP participants engage with an associated 'Rewards for Excellence' scheme (won by **Balke**, 2018; **Hallis** 2020). Senior researchers contribute training on grant-writing, social media profiles and career development. ECDP includes a graduated introduction to a full teaching load from 50% in Year-1, increasing to 100% in Year-3. All ECSRs have successfully completed this programme since 2014. Our ECSRs are emerging as leaders through high-impact outputs, prestigious/competitive grant capture (Section 3.1), leading impactful research (Section 1.7), and national and international esteem indicators (Section 4.5).

Since 2015, as an Athena SWAN action, we provide biennial career transition workshops for all academic, technical and professional staff that are co-produced and delivered by the College Director of HR. Each workshop has been well attended (>70% of staff and PGR) across all demographics (e.g., contract type, gender). Pre- and post-workshop surveys indicated that the workshops improve individuals' understanding of promotion and increase confidence in transition to the next career stage. The workshops identified the need for pro-rated career pathways for part-time and fixed-term staff, and follow-on work co-designed and co-produced bespoke promotion criteria for part-time staff with HR. These criteria have been used in successful promotions for two part-time staff in ESRG.

Our research leaders voluntarily take part in University-level mentoring schemes, for example, **Boyce** provided mentorship to **Toney** via the University-level AS programme (starting 2013) and supported **Toney's** successful promotion to Senior Lecturer in 2015 and Professor in 2018.

Career Development for Technical Staff – The 33 technical staff across the Unit underpin research productivity, quality and value, as well as, delivering training to research students and staff. UofG is a signatory to the Science Council-led Technician Commitment that recognizes that the career progression and pathways for technicians are different from the academic trajectory. Beyond UofG offerings, we invest in training in the latest technology provided by instrument manufacturers, e.g., ThermoFisher, Agilent, and CPD training provided by, e.g., Royal Society of Chemistry. Many of our technicians have PhDs and contribute more than routine support to projects. We have adopted CRediT principles and a Code of Practice for how technicians should be included on peer-reviewed publications. We provide flexible working, e.g., support part-time work (15% of our cohort) or condensed hours (15%). Four technicians are studying for PhDs.

Our technicians provide leadership within the workplace, e.g., contributing to Health and Safety and Executive Committees, and beyond, e.g., by providing SQA-approved courses on technical glass blowing across Scotland. They are encouraged to engage externally; Salik won a personal award for his service as a peer reviewer of Technician Commitment signatory self-assessments and action plans, and best poster at the Signatory Event in Birmingham (2019). Our technical staff underpin our widening participation initiatives helping develop our Nuffield Research Placement projects, widening participation Summer Schools for Access, and 'Girls into Geoscience' (first held in Scotland, led by **Owen** in August 2019, virtually in 2020).

### 2.3 Research Students

The CoSE Graduate School provides a range of training and development opportunities and wellbeing initiatives for PGRs, promotes research excellence and integrity, provides support and guidance (e.g., College Research Student COP) and develops PGR supervisors.

Doctoral degrees awarded have increased from 48 in REF2014 to 76 in REF2021. Awards to students who identify as BAME has increased gradually from 21% (2013/14) to 36% (2019/20). International PGRs (57%) add to the diversity of our research community. Our cohort is well-balanced ranging from 50 to 59% female students in any given year since 2014, and the number of

## Unit-level environment template (REF5b)

degrees awarded to female PhD students averages 51% (39 of 76), and annually comprises between 33% and 67%. While we use conventional methods of PhD recruitment (e.g., [FindaPhd.com](http://FindaPhd.com)), our advertising strategy takes advantage of disciplinary and interdisciplinary listservs such as GEOGFEM, ESWN, and the Women and Geography Specialty Group of RGS-IBG, the Scottish Transgender Alliance and GRAMNET to help diversify our applicant pool.

Doctoral degrees awarded has increased from 4 per year (2013/14) to 15 (2019/20). Each student has a mandatory co-supervisor to provide pastoral support. 40% of our staff have completed First Aid Mental Health Training to help recognise, respond to and support students experiencing mental health issues.

Our key PGR strategy over the assessment period was to increase the cohort by:

- Involvement in Doctoral Training Programmes across several HEIs. ESRG/SUERC are partners in NERC IAPETUS DTP (I and II) with Durham, Newcastle, Stirling, St. Andrews, and Heriot Watt Universities. SUERC is also a partner in the University of Edinburgh, NERC E3/E4 DTP and supports several other DTPs through NERC Facilities. 20% of our students since 2014 are part of the IAPETUS DTP. These students benefit from a strong network of expertise and supervision across partner HEIs. In November 2016 **Toney** and **Mark** led a 3-day Isotope Training workshop for 21 students from the NERC IAPETUS DTP.
- Increasing internal and external funding offers to attract excellent PGRs. PGR funding in the last 5-years comes from a diverse range of sources: RCUK, industry (ThermoFisher Scientific, Air Monitors Ltd, Boliden Tara Mines, Assmang) and governmental sources. Specific awards come from the Carnegie Foundation, NERC IAPETUS DTP, NERC CASE studentships, Industry-funded, and international government studentships from China, Libya, Brazil, Iraq, Honduras and Malaysia.

Our students take advantage of the CoSE Graduate School's mobility fund. Typically 4 students per annum visit overseas institutions to collaborate and learn new techniques, which has enhanced funded projects (e.g., ERC, NERC, Leverhulme, STFC). The Unit provides a supportive environment that includes informal coffee socials for mentoring and networking among PGRs by PDRAs and research staff. These have become especially active (virtually) and important during the Covid-19 pandemic. PGRs have opportunities to meet external seminar speakers to get career stories and exposure to different routes into academia and industry. PGRs self-organise and lead an annual progression conference to share research. We encourage ECSRs to gain experience by co-supervising PGRs. We run workshops and signpost UofG studentship awards, giving preference to ECSRs for studentship allocations when available. All PGRs including MSc-by-research are actively involved in presenting research at discipline-specific national and international conferences (e.g., AGU, ASLO, BOGS, EGU, Goldschmidt, LPSC), promoting their international reputation and supported by our local Conference Support fund. On average ~80% of our Conference Support and ~60% of our Research/Impact Enabling support is awarded to PGRs.

External PGR training: We host >50 visiting UK and international PhD students annually, for intensive training in the principles and laboratory practice of analytical geoscience. Many student projects are facilitated by direct, peer-reviewed access to the five NERC Facility laboratories. NERC Facility staff provide annual "Introduction to the Principles and Practice of Stable Isotope Geochemistry" open to all NERC PGRs. Staff teach on national and international graduate schools and have developed programmes, e.g., **Stuart** and **Persano** annually run week-long PGR courses in Low Temperature Thermochronology at Chinese Universities (Beijing, Chengdu and Nanjing).

### 3. Income, infrastructure and facilities

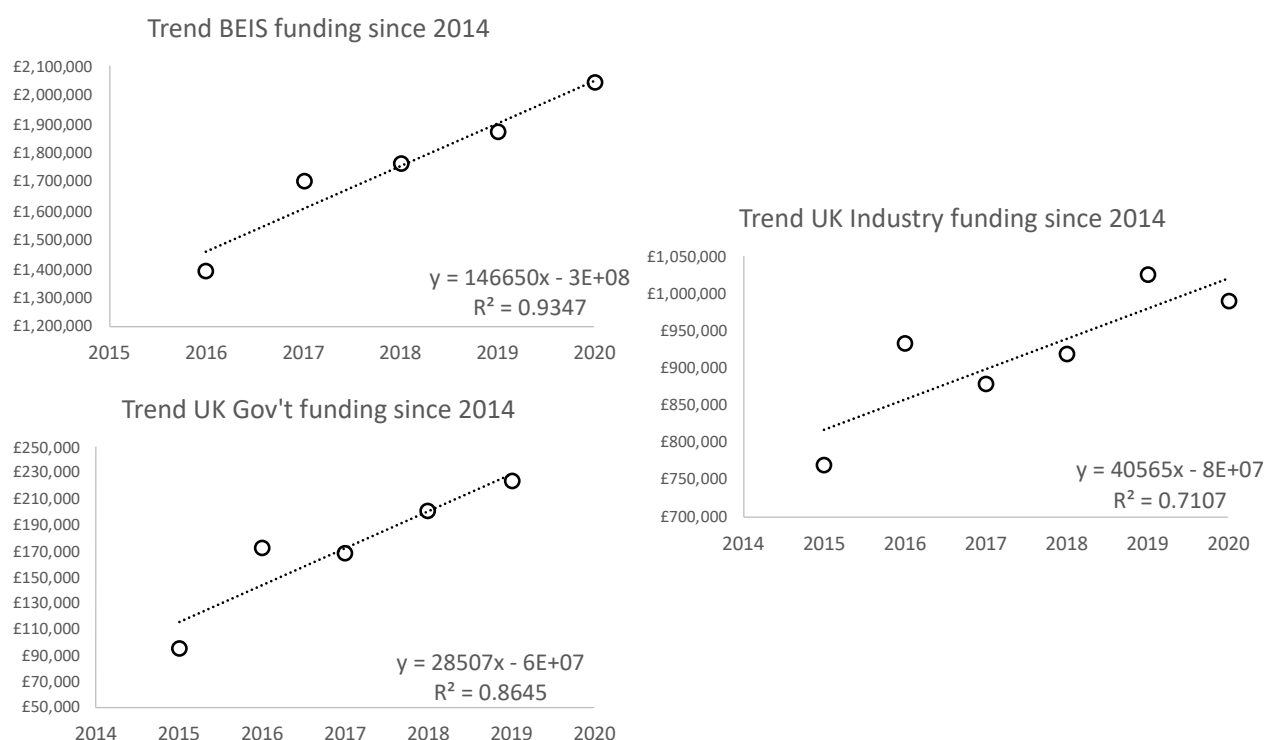
#### 3.1 Research Income

Over the REF period our Unit has focussed on diversifying funding streams and growing research income. Our research income has remained steady since 2013/14 averaging £3.4M ± £0.3M/year. In REF2014, 88% of our income came from BEIS research councils (59%) and UK industry (29%). The broad base of our funding is now more diversified with 51% (£12.3M) from BEIS Research councils and a majority of the remaining sources from UK industry (24%, £5.6M), EU funding (11%,

## Unit-level environment template (REF5b)

£2.5M), and UK government bodies (7%, £1.7M). Increasing trends in BEIS funding by ~£147k/year since 2016, UK government funding by ~£29k/year since 2015, and UK industry/commerce by £40.6k/year since 2015 (Figure 3) are partially masked by a drop in EU funding after 2016.

**Figure 3.** Trends in research income by HESA funding category

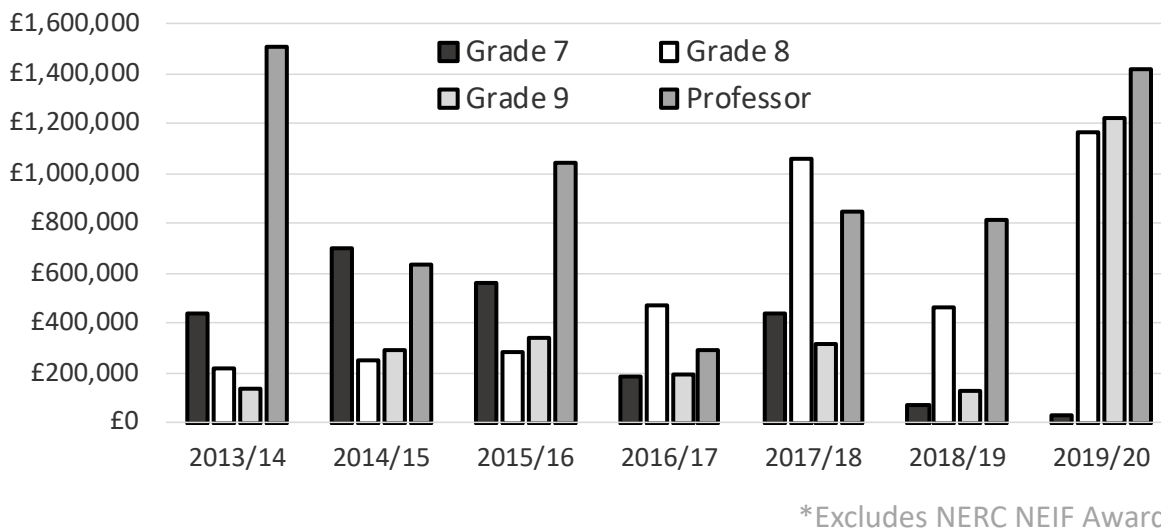


Our focus on developing our ECSRs (18 this REF period) is notable in our trajectory with our Grade 8 and Grade 9 staff capturing 62% of our new award income in 2019/20, compared to on average ~41% in previous years and Professors capturing the majority of awards (up to 65%) in previous years (Figure 4). These data reflect the progression of our ECSRs who are emerging as new research leaders, replacing the former top income earning professoriate who have moved onto national leadership roles.

We expect our trajectory over the next 5-years to continue to rise with known awards already approved and in the pipeline, e.g., the newly commissioned NEIF-SUERC facilities (£8.7M, 2019-2024), NERC highlight topic CuBES (£1.9M, 2020-2025 to **Boyce**, Co-PI), recruitment of **Basiri** (£1.2M, 2020-2028 UKRI FLF), leading work packages in the NERC Living Delta's Hub (£1.2M, 2019-2024 to UofG, **Balke**, **Bass**, **Renaud**, Co-Is) and new NERC projects, e.g. ScotIce (£668k, 2019-2022 to **Fabel**, PI).

Active encouragement to apply for seed funding for innovating solutions to problems in developing countries through Scottish Funding Council GCRF has laid the foundation for future cross-disciplinary networks and consortia:

- Merging art and science to create sustainable futures in Malawi (£47k) and Africa more broadly (£75k) - **Barrett** with UofG colleagues in Arts (Bisschoff), Engineering (Burnside), Education (Capsada-Munsech)
- Promoting sustainable tropical livestock production in Colombia (£23k) **Barrett** with Veterinary Medicine (Jonsson), Agriculture (Arango)
- SFC GCRF Nature-based solutions for river management in the Philippines (£35k) **Williams**

**Figure 4. Proportioned Award Value by Grade**

While we encouraged and supported EU funding routes during this REF period (**Hamilton** - ERC Advanced, **Koehn** - FlowTrans ITN, **Toney** - ERC Starting Grant, 5 Marie Curie Fellowships, **Boyce** - LoCAL EU Coal and Steel Fund), we recognised risks given uncertainty around Brexit. As a result, staff have developed portfolios targeting wider international schemes, which are showing considerable success, e.g. (awards reported in proportion allocated to UofG):

- NERC-Newton Scheme, The transmissive critical zone: understanding the karst hydrology-biogeochemical interface for sustainable management (**Waldron, Naylor**, £489k)
- NERC SE Asia Hazards, Catchment susceptibility to hydrometeorological events: sediment flux and geomorphic change as drivers of flood risk in the Philippines (**Williams**, £381k)
- STFC, A journey from the solar nebula to planetary bodies: cycling of heat, water and organics (**Lee**, £313k)
- NERC-Newton Scheme, MOonitoring Mangrove ExtENT & Services (MOMENTS): What is controlling Tipping Points? (**Balke**, £289k)
- Leverhulme, Setting artefacts free: an independent chronology for British Iron Age brooches (**Hamilton**, £258k)
- Historic Scotland, Living on Water - Early Iron Age - Lake Dwelling Communities in Scotland (**Hamilton**, £259k)

From 2013/14 to 2019/20 the top funders of our research awards by total apportioned value, include: NERC (£8.9M - excluding NERC facilities, 58% of all awards); the European Commission and ERC (£2.2M, 14%), Leverhulme Trust (£826k, 5%), STFC (£593k, 4%), with the remaining 20% (£3.0M) of our awards spread across >50 different funding sources. Our diverse research base enables us to lead and collaborate to capture a wide range of funding sources.

### 3.2 Strategy to grow research income:

We project research income growth given our Unit's strengths and forward-looking strategy. We have identified several funding sources that reflect our future trajectory, including:

- Strategic and directed funding schemes: NERC funding beyond discovery science schemes has included Newton Fund CZO initiative with NSFC (£450k to **Waldron**), Urgency grants (**Hurst** and **Naylor** - New Zealand Earthquakes, £22k; **Hoey, Barrett** and **Williams** - Environmental Risks to Infrastructure, £381k) and Highlight Topics (**Boyce** - CuBES, £95k; **Hurst** and **Naylor** - coastal processes, £27k). We have strong links with local governments at home and abroad and aim to build Strategic Programme initiatives around routes to carbon neutrality along with rethinking and revaluing natural and environmental resources.
- Broadening UKRI funding beyond NERC: We aim to build on successes with BBSRC (**Barrett, Cusack, Thomas**), EPSRC (**Boyce, Cusack, Fitzer, Kamenos, Lee, Naylor**,

## Unit-level environment template (REF5b)

*Phoenix, Stuart, Waldron, Williams*) and STFC (*Hallis, Lee, Mark, Phoenix, Toney*). A critical mass of staff undertake research in the remit of Research Councils beyond NERC. Champions for each Research Council with responsibility to inform staff of impending funding schemes and assist in developing proposals and collaborations raise awareness of opportunities. Our breadth makes us well-placed to exploit future cross-council funding initiatives in fields like heritage science, the energy transition, and carbon sequestration by waste products.

- Industrial collaboration: We have long-established relationships with international food, mining, exploration and hydrocarbon industries, among others. We are well-placed to continue dialogues that bring together industry-facing researchers to discuss problems, approaches, and joint solutions. We have established a new role in the Unit for external engagement to build links internally and externally, with an aim for these industry collaborations to meet the target carbon neutrality by 2050.

In addition to practices described in Sections 1.6 and 1.7 and the focus we place on people through career development opportunities (Section 1.2), we will improve our provision of various schemes across the Unit, paying particular attention to:

- Mentoring early- and mid-career researchers through regular one-one meetings with experienced researchers.
- Assuring proposal quality through internal and College peer-review, where appropriate (e.g. Future Leader Fellowship schemes).
- Holding focused research planning workshops with external/international/industrial partners (e.g., HALO Trust, International Center for Tropical Agriculture) that have engaged us through ongoing strategic developments (e.g., collaborative project development, academic exchanges, co-supervision of PGRs).
- Encouraging international research links through, i.e., a research enabling fund and exploit our international-level expertise through high profile seminars and discussion groups.
- Buying out researcher time from teaching and/or routine lab work to develop proposals.
- Ensuring use of Impact Acceleration Funding opportunities across the UKRI remit.

### 3.3 Facilities, Technical Support and Advanced Equipment:

Facilities: Our Unit has a world-leading capability in mass spectrometry and allied techniques, such as luminescence and radiochemistry. SUERC hosts one of the largest concentrations of such instrumentation in the world and has developed a global reputation for its analytical expertise. This complements expertise and instrumentation in ESRG. Over the REF period we invested >£3.5M in state-of-the-art instrumentation to maintain our capability, including new mass spectrometers (e.g., CI-MS, TIMS, NGMS, LA-ICPMS and GC-IRMS), front-end capability (e.g., lasers and gas benches) and hardware/software upgrades. This has required >£1.2M investment in infrastructure. Funding sources include UK Research Councils, industry, and strategic investment from CoSE. Our facilities and infrastructure are crucial to research collaboration across the UK and abroad, as well as to academic and commercial partnerships with industry and government.

For example, >50 scientists and PGRs visit us annually to receive in-depth training, obtain high-quality isotope data and develop interpretative skills. The international reach is reflected in the high percentage of international co-authors in our Unit's outputs (e.g., Armenia, Australia, Canada, China, Japan, Ireland, Italy, Myanmar, Netherlands, Pakistan, Spain, Sweden, Switzerland, Tanzania, USA). Below we highlight the main laboratories relevant to UoA7.

We strive to maintain and expand our unrivalled breadth of stable isotope technology. Our stable isotope laboratories have 13 mass spectrometer-based systems that focus on geoscience, environmental science and ecology (**Newton & Boyce**). CF-IRMS are also dedicated in the Radiocarbon laboratories (**Hamilton & Ascough**). Clumped isotope science is a rapidly expanding field. **Clog** runs a ThermoFisher-253 *Plus* instrument for carbonates and the high-resolution 253 *Ultra* for analysis of rare isotopologues of gases, one of a handful of these instruments world-wide.

## Unit-level environment template (REF5b)

We have laboratories with world-leading capability for Ar/Ar dating (**Barfod, Mark**) and noble gas isotope analysis (**Stuart**). This includes 8 static gas magnetic-sector mass spectrometers, 3 of which were purchased in the REF period, all with dedicated gas extraction systems. The SUERC Radiogenic Isotope laboratory (**Ellam**) hosts two thermal-ionisation mass spectrometers, including a new ThermoFisher *Triton Plus* purchased in 2020. SUERC and ESRG host 2 inductively-coupled plasma mass spectrometers (ICPMS), with SUERC acquiring a state-of-the-art ICPMS optical emission spectrometer in 2019 and ESRG acquiring a laser ablation ICPMS in 2016.

The Accelerator Mass Spectrometry (AMS) laboratory (**Fabel, Freeman, McIntyre**) is equipped with two National Electrostatic Corporation (NEC) instruments in a dedicated building on the SUERC site. It performs ~10,000 analyses annually ( $^{14}\text{C}$ ,  $^{10}\text{Be}$ ,  $^{26}\text{Al}$  and  $^{36}\text{Cl}$ ). The AMS also developed, patented and hosts the first operational Positive Ion Mass Spectrometer (PIMS), developed in-house with NEC and Pantechnik.

The Luminescence laboratory (**Sanderson**) is equipped with three thermoluminescence readers developed in-house, including a 24-sample automated system, and two spectrometers for photo-stimulated luminescence. It has low-level beta counting and high-resolution gamma spectrometry equipment (**MacKinnon**) for environmental radioactivity determinations.

An integrated Low Temperature Thermochronology capability (GLOWlab Persano, Stuart) is a joint ESRG-SUERC operation, incorporating U-Pb, fission track and (U-Th)/He analysis.

Our organic geochemistry facilities include the Biomarkers for Environmental and Climate Science (BECS) laboratory (**Toney**), which enables the extraction (accelerated solvent extractor), preparation (advanced organic chemistry wet lab), characterisation (GC-MS), quantification (GC-FID) and compound-specific isotopic composition (GC-IRMS) of hydrocarbon molecules. Our organic geochemistry complements these techniques and expertise with the co-development of compound-specific radiocarbon analyses (**Ascough, McIntyre, Staff, Toney**) and added catalytic hydrolysis for analysis of recalcitrant organics (**Ascough**).

In addition to rock, mineral and water preparation facilities, suites of clean rooms and wet chemistry laboratories, the Unit hosts specialist sample characterisation and preparation laboratories that complement our analytical capabilities. For example, a suite of Radiocarbon preparation laboratories (**Cook, Hamilton, Ascough & Garnett**) for archaeological (e.g., bones, teeth, ceramic) and environmental (e.g., organic solids and gases) material for AMS  $^{14}\text{C}$  determination; and stable isotope vacuum extraction systems for O, H, S and C tracing and analyses of minerals, fluids and organic matter (**Boyce, McGill, Newton**). The Imaging Spectroscopy and Analysis Centre (ISAAC)(**Lee**) hosts two field-emission SEMs equipped with X-ray spectrometers (energy- and wavelength-dispersive) and electron backscatter diffraction systems for high-resolution materials characterisation. ISAAC is integrated into the UofG Kelvin Nano-characterisation Centre that has a suite of transmission electron microscopes and focused ion beam instruments.

Our field-based instrumentation includes the Environmental Sensing & Analysis Facility (ESAF) (**Balke, Barrett, Bass**), which includes laser scanners, total stations, DGPS, UAVs, RGB multispectral and thermal sensors and hand-held VNIR spectroradiometers and a portable Picarro gas analyser for *in situ*  $\text{CO}_2$  and  $\text{CH}_4$  measurements. The Marine Mesocosm Facility (MMF) (**Kamenos**) has 128 remotely monitored mesocosms for exploring the impact of  $\text{CO}_2$ -associated global change on marine biotic and geochemical systems.

NERC Facilities: Since the mid-1990s several laboratories have been embedded within the NERC Services and Facilities portfolio. Following a NERC review of National Capability, in 2019 we successfully bid to host an innovative delivery platform called the National Environmental Isotope Facility (NEIF). The award (PI, **Mark**, £8.7M over 5-years) supports six laboratories:

- $^{40}\text{Ar}/^{39}\text{Ar}$  geochronology: **Barfod** (co-I)
- High-temperature stable isotopes: **Boyce** (co-I)
- Stable isotopes in life science: **Newton & McGill** (co-I)
- *In situ* cosmogenic radionuclides: **Fabel** (co-I)

## Unit-level environment template (REF5b)

- Radiocarbon: **Ascough** (co-I) and **Garnett** (co-I)
- AMS laboratory: **Freeman** (co-I) & **Fabel** (co-I)

NEIF provides UKRI-eligible researchers access to world-class expertise and analytical capability in geo-, eco- and environmental science, managed and peer-reviewed (bi-annually) by NERC steering committees. The Facilities deliver ~30 projects/year, which support NERC Discovery Science, Programmes, Large Grants and Highlight Topics, and peer-reviewed governmental and industrial research. As a result, over the REF period, the Facility laboratories have trained >120 UK PhD students, producing >80 PhD theses, and contributed to >400 peer-reviewed papers.

Advanced equipment: we work with technology companies using our expertise to develop new instruments and applications. For example, with NEC and Pantechnik we have co-developed and patented a new type of mass spectrometer, PIMS, which is in production and set to drastically reduce sample preparation times for radiocarbon applications. Our strategic partnership with ThermoFisher Scientific has resulted in new developments in clumped isotope software and hardware, and noble gas isotope and Ar/Ar instrumentation.

Technical support: The strong laboratory-based component of the Unit means that a highly valued and skilled and well-supported technical staff cohort is fundamental to our research success. For example, technicians out-number REF-returned research staff 26 to 18 in SUERC, and they comprise 23% of ESRG staff (7 to 24). The contribution goes beyond the routine; in most cases our technicians maintain and trouble-shoot complex instrumentation and are skilled in the development of novel software and hardware solutions. We have maintained technician staffing levels at their pre-2015 levels. Over the REF period over ~25% of the highly skilled, long-serving technical staff have retired. Replacements are typically early career, many joining with BSc, MSc and PhD degrees.

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

### 4.1 Strategy to grow research collaborations, networks and partnerships

The Unit will continue to play a leading role in shaping a research base that provides evidence for political, societal and organisational decision-making around global environmental and resource challenges. Crucially we will continue to engage with learned societies (e.g., Royal Scottish Geographical Society, Geological Society of London (GSL), Universities Geoscience UK, Royal Society Edinburgh), consult with external partners and alumni employers to understand how our research can best contribute to shifting societal and economic priorities. Additionally, we will provide leadership for high-profile international projects such as missions with return samples from planetary bodies; and security of supply of critical metals for the global low-carbon future.

The Unit will use its research themes as the foundation for supporting existing and emerging collaborations, networks and partnerships. Researchers in all themes lead and contribute to international and interdisciplinary collaborations (Sections 1.5 and 1.6). Our research leaders are opening pathways to larger, international networks and partnerships through a number of initiatives, such as:

(1) Our Unit leads new methods for collaboration via the Centre for Sustainable Solutions (CfSS) (established April 2020, Director: **Toney**). CfSS is working in partnership with Glasgow City Council and Policy Scotland in the lead up to COP26. An important focus is on blue-green transformation using the city as a driver of change to accelerate systems approaches to leadership for sustainability. **Naylor** and **Toney** are active members of the COP26 Universities Network led by the Grantham Institute, Imperial College, to lead scientific communication and showcase UK research approaching COP26 in Glasgow. CfSS has engaged researchers across our themes in new networks and partnerships and is providing the infrastructure to maintain these as a legacy following COP26. Topics now part of ongoing consultations with Glasgow City Council include:

- **Ecosystem & Environment Change** - nature-based solutions (**Balke**) for creating green corridors and spaces (**Naylor**) that connect environmental and human health benefits;
- **Human-Environment Interactions** - re-naturing floodplains (**Shi, Williams**) and converting



## Unit-level environment template (REF5b)

- polluted/derelict land into carbon sequestration sites using industrial waste (**MacDonald**).
- **Earth and Planetary Evolution** - low-carbon energy solutions creating new networks of mine-water for geothermal energy (**Boyce, Moreau**).

(2) Our planetary science researchers have taken advantage of new virtual norms due to Covid-19 engaging with prestigious colleagues, hosting an international seminar series. Seminars provide network building opportunities for ECSRs (including PGRs/PDRAs). The seminars attract key international researchers, due to the roles that our researchers play on notable committees, including UK Space Agency (UKSA) Robotic Exploration Committee (**Lee**) and Space Exploration Advisory Committee (**Hallis**); UKSA AURORA Panel (**Mark**); iMOST for Mars sample return (**Hallis, Daly**) and NASA Curation and Analysis Planning Team for Extraterrestrial Materials (**Hallis**). **Daly** and **Lee** are participating scientists for JAXA's Hayabusa2 mission to the asteroid Ryugu, and **Daly** is a fellow of the Royal Astronomical Society. **Mark** is a member of grant panels for STFC Astronomy, UKSA, STFC, on BEIS Mars Sample Return Curation Facility Working Group, and Chair of Scottish Planetary Science Research Network. Research into space exploration capture the minds of the general public with whom our planetary group engage regularly (Section 4.3).

(3) In addition to the strategic industrial partnership building (Section 1.3), **Boyce** has expanded opportunities for collaboration, networking and partnership building in sustainable natural resources as Lead Organiser and Chair of the largest biennial meeting of the Society for Geology Applied (SGA) to Mineral Deposits, Life with Ore Deposits on Earth. Over 700 delegates from >50 countries attended this meeting in Glasgow, 2019. Societies like SGA, Mineral Deposits Studies Group (MDSG) - GSL and Applied Mineralogy Group provide platforms to help develop networks and partnerships for initiatives like CuBES (NERC grant, above) and networking opportunities for ECSRs, PDRAs/PGRs.

(4) Our research leaders have shaped the Scottish funding pools, SAGES and MASTS (e.g., *Hoey* SAGES Director 2011-2015; **Lee** and **Stuart** on Executive Committee 2017-present), which have supported our ECSRs through travel and workshop grants. Our local Conference and Research/Impact Enabling fund (Section 2.2) provides support for travel to initiate and sustain academic or industrial collaborations, seed funding for pilot projects, and networking and knowledge exchange for impact-generating activities. This scheme has enabled our ECSRs to maintain and build collaborations internationally.

### Supporting International Collaborations:

**Hallis** received funding in 2016 to continue and build collaborations in Hawaii and Washington DC, resulting in ion-microprobe and Raman spectral datasets that have been published in *Science* and in *Meteoritics and Planetary Science*. The collaboration with the Smithsonian Museum in Washington DC has enabled **Hallis** to become a team member on the Raman Laser Spectrometer onboard the ExoMars Rosalind Franklin rover, which was due to launch for Mars in July 2020 (postponed to 2022).

## 4.2 Evidence and support for relationships with key research users

Our move toward more challenge-led research has enhanced our partner-base of governmental organisations, charities and industries and is evidenced by the increase from 38% (£7.1M of £18.8, REF2014) to 46% (£11.1M of £23.9M, REF2021) of the Unit's income (e.g., Scottish Government, Scottish Funding Council, Scottish Natural Heritage, Historic Environment Scotland, Carnegie Trust, Leverhulme Trust, Total, iCrag, Arup, Statoil, Sixty-5 Technologies, Boliden Tara Mines, Scotgold Resources SGZ, Assmang). This substantive and growing network enables the Unit to convene the right partner collaborations to develop and respond to calls for evidence and funding and to create solutions to seemingly intractable problems.

Our researchers engage with and develop relationships with key research users and beneficiaries in government and local authorities by developing white papers and other forms of advice to planning authorities (examples in Coastal ICS). **Kamenos** has held advisory roles for UK government (Defra (2014-2017), Cefas (2017-2018)) and industry (e.g., Falmouth Harbour Authority, 2014-2016) giving

## Unit-level environment template (REF5b)

critical advice, providing insights into trajectories of marine biodiversity and services to prioritise national marine management under the Defra Foresight Future for the Seas scheme.

### Example of Beneficiaries Beyond Academia (1):

From 2013-2016, **Renaud** was a PI on a two-phase project, 'Development of International Water Quality Guidelines for Ecosystems (IWQGES)' funded by United Nations Environment Programme, which was a direct request by countries in the UN Environment Assembly (UNEA). **Renaud** led the projects that set targets for ecological status, suggestions for monitoring freshwater ecosystems and provided scientific background to underpin the recommendations. He oversaw the synthesis of "A framework for freshwater ecosystem management",<sup>1</sup> an official body of work endorsed by UN member states. Additional requests by the UN for updated case studies show that this framework is continually referred to by member states and has ongoing relevance.

### Example of Beneficiaries Beyond Academia (2):

Our work informs other agencies. For example, **Kamenos** was part of the core writing team for the 'Assessment of carbon budgets and potential blue carbon stores in Scotland's coastal and marine environment' (2014) for Scottish Natural Heritage that identified overlooked carbon stores in the coastal environment. This report provided the basis for ongoing assessments of blue carbon as resources in Scotland's inshore marine protected areas (SNH commissioned report No. 957, 2017). It was also used as evidence in a strategic government document<sup>2</sup>, which identifies blue carbon as a focus for the Scottish Government through harnessing the potential of our natural assets and protecting our natural resources.

Partners call on our expertise, e.g., by BGS to foster formal early access sampling opportunities regarding the £9M UKGEOS site in Glasgow (**Boyce; Moreau; Bass**) to ensure that a comprehensive suite of pristine rock, fluid and microbiological samples were collected and analysed rapidly during the initial drilling in 2019/2020, providing critical "t<sup>0</sup>" data to underpin future research on this major platform.

Maintaining our networks and partnerships requires short-term research leave and teaching/administration cover, to devote time to these activities.

### Supporting Urgent Research:

In spring of 2017, **Hurst** was relieved of teaching duties to carry out research on a NERC urgency grant. Enabled by MASTS research pool, he spent 10-weeks in New Zealand mapping and modelling seismic hazards along marine terraces. This resulted in two subsequent facilities grants with Australia's Nuclear Science and Technology Organisation (ANSTO, ~£40k), project partnership on a \$1M Marsden Grant, and co-supervision of 4 PGRs, one based at the UofG.

## 4.3 Engagement with the Public and Diverse Communities

It is critical to engage with diverse communities through research. Our contribution to the UK and international research base is substantial and our research contributes to a rich range of public engagement events, such as:

- Exhibitions: Royal Society Summer Exhibition in 2016 – 'Storing Sky as Stone'
- Collaboration with Glasgow Science Centre: planetarium talks, chair panels on Scotland's role in space, provide hands-on activities with meteorites, 'design your own lunar lander' as part of the Apollo Landing Party
- Collaboration with Local Schools (100s of secondary/primary students): Our strong link with Calderglen High, East Kilbride, received a HMI evaluation of "excellent" and has been chosen by Education Scotland as an exemplar for the "Journey to Excellence" professional development resource. Stirling High School workshops on meteorites and planetary science, St. John Ogilvie High School, STEM in the Gorbals, Careers Launch for space careers

<sup>1</sup> [www.unenvironment.org/resources/publication/framework-freshwater-ecosystem-management](http://www.unenvironment.org/resources/publication/framework-freshwater-ecosystem-management)

<sup>2</sup> <https://www.gov.scot/publications/nation-ambition-governments-programme-scotland-2017-18/pages/8/>

## Unit-level environment template (REF5b)

- Edinburgh for high school students, career stories with Gordonstoun Secondary and “Bang goes the Borders” geological outreach events in Melrose.
- Providing context to Community Groups on climate change: **Toney** interviewed by Orchardhill Parish Church Minister, Grant Barclay, on why climate change is still relevant given Covid-19 to > 250 members virtually (2020).
  - Scotland’s first ‘Girls into Geoscience’ (GiG, August 2019): **Owen** led the GiG Team, including 4 PhD students, 1 post-doc, 2 professional members of staff, **Hallis, Thomas, Naylor, and Toney**. The GiG event was attended by 25 school pupils from Scottish locations (Aberdeen to Ayr) and as far south as Buxton, England. Teachers and representatives from the Highlands and Islands Enterprise also attended. The day showcased talks by Jessica Smith (Atkins Global), Anna Hicks (BGS) and Amy Gilligan (University Aberdeen) who shared personal journeys and passion for geoscience, followed by hands-on laboratory sessions.
  - Strategic partnerships: CfSS, SEPA, the *Herald* and the Global Footprint Network partnered to raise awareness of Earth Overshoot Day (2020) through two international panels (including **Toney**) with > 500 online attendees and a full-page op-ed piece in the *Herald*.
  - The Pint of Science: PGRs and PDRAs organize the Glasgow Pint of Science since in 2015. Each year talks have been given by at least two PGRs (Holdsworth, Hollinsworth, McCahill, O’Brien, Pickergill, Simpson, Young, Wanmer), post-docs (Cohen, *Fitzer*, Plancq, Schoenrock) and research staff (**Balke, Cusack, Daly, Hallis, Hansom, MacDonald, Phoenix, Toney**). Pickersgill is the Chapter Manager of the Pint of Science for Scotland.
  - Invited Panel Member (**Toney**), the Just Festival, Edinburgh (2016): “Climate Change: On the Edge of the Earth” exploring if the Paris Agreement will alter behaviour and carbon dioxide emissions. Addressing what is being done to help vulnerable people of the world respond to these threats and whether disaster can be avoided.

### 4.4 The Unit’s contribution to sustainability of the discipline

Geology and the broader geosciences are challenged to remain relevant to and for society as we transition towards a sustainable future. Our research is changing to meet the needs of external partners, societal challenges, and funding priorities. We protect the legacy of geosciences through research-led teaching, where we are consciously equipping our students with ethical and critical skills to apply their knowledge sustainably. For instance, *Economic Minerals* places emphasis on sustainable practices and *Basins and Reservoirs* shifts primary focus away from fossil fuel exploration to carbon storage and geothermal applications.

The Unit is integral to agenda-setting in the development of NERC Highlight Topics (*Waldron*) and UKRI Research Programmes. The Unit plays leading roles in shaping national research agendas (e.g., **Boyce** Chaired Expert Panel and was on Executive Board of the >£15M SoS Minerals NERC Programme with EPSRC). We steer funding allocated in national and international programmes, e.g., NASA’s Emerging Worlds (**Hallis, Daly, Lee**); the CFDDP Campi Flegrei feasibility/risk of deep drilling (**Mark**); Swiss, Dutch, Indonesian, Austrian and Vietnamese funding councils (**Renaud**); Chinese, Norwegian, US and Canadian Research Council panels (**Boyce, Ellam, Stuart**); Carnegie Trust for Universities of Scotland (**Stuart**). Researchers regularly contribute on NERC panels (**Balke, Barfod, Boyce, Fabel, Kamenos, Mark, McGill, Newton, Stuart, Toney, Waldron**). We play key roles in determining future environmental agendas through membership and chairing of governmental panels (e.g., **Stuart, Waldron**, Scottish Government Independent Expert Panel on Unconventional Gas; **Ascough**, Environmental Protection Scotland Air Quality Expert Advisory Group; **Mark**, NERC NEIF Strategy Board).

Our researchers are mindfully leading and engaging to keep our science relevant given changing national and international agendas:

- Student-led research projects gather data on mental health and resilience implications of recent UK floods (**Thomas**).
- **Williams** conducts research on river restoration via a Royal Academy of Engineering Industrial Secondment, produced a decision-making tool regarding pipelines, and has a follow-on PhD project with SEPA.
- Our researchers have risen to the climate emergency challenge through improving

## Unit-level environment template (REF5b)

- understanding of coastal erosion and hazards through Dynamic Coasts (Coastal ICS), **MacDonald's** research into socio-environmental legacies of steel slag in Scottish communities, **Balke, Bass** and **Renaud's** research in developing delta-level interventions to respond to and mitigate against foreseeable coastal system tipping points.
- Our researchers play lead roles in larger interdisciplinary initiatives, **Toney** is a Key Member of PAGES Working Group 2019, ACME: "Arctic cryosphere change and coastal marine ecosystems".
  - We play key roles on the UGUK Executive Committee (**Owen** – Early Career Representative) and on the Pre-University Recruitment and Awareness Working Group (**Owen**) and Influencing Policy and Policymakers Working Group (**Toney**) tasked with safe-guarding the future of geosciences.
  - **Boyce** is collaborating on UKRI-funded research into new, sustainable resources of Cu to meet the demands of the electrification of the UK transport fleet by 2035.
  - **Stuart** leads research into smarter exploration tools, to reduce the environmental footprint of exploration drilling, to find new helium deposits and sits on AAPG Global Helium Resources committee.
  - Together with partners in UofG Engineering, **Boyce** and **Moreau** are shaping efforts to ensure mine-water geothermal energy plays a key role in ensuring that the UK meets its carbon neutrality targets by 2050.

### 4.5 Indicators of wider influence, contributions to and recognition by the research base

Our researchers hold key positions on decision-making prize allocation panels, e.g., BSG Awards (**Owen**); C.C. Patterson Award Committee - International Geochemical Society (2019-2021, **Toney**); Goldschmidt Medals Nomination Committee (2018-2020, **Moreau**); Lindgren Award for Society of Economic Geologists (2015-2017, 2017 Chair, **Boyce**); SEPM Nominating committee (**Owen**, 2018).

We are encouraged by the indicators of esteem that show recognition of our ECSRs' contributions to the discipline. These demonstrate that the strategy to recruit outstanding ECSRs is recognised beyond our Unit. Over the next 5-years, we will continue to use this approach as the age demographics at SUERC proffer new ECSR recruitment opportunities.

- EGU 2020 Outstanding Early Career Scientist Award, Geodynamics Division. **Keller**
- Meteoritical Society Nier Prize 2018. Outstanding research in meteoritics and closely allied fields by young scientists. **Hallis**
- Lyell Fund Award 2018. GSL - early career geoscientists who have made excellent contributions to applied research in the UK and internationally. **Owen**
- President's Medal 2017. GSL - early career geoscientists who show significant early promise and have potential to be future leaders in their fields. **Hurst**
- European Microbeam Analysis Society 2017. Young Researcher Award. **Einsle**
- Roland Goldring Award 2016. British Sedimentology Research Group noteworthy published research in sedimentology for an ECR. **Owen**