Institution: Cardiff University

Unit of Assessment 7: Earth Systems and Environmental Sciences

1. Unit context and structure, research and impact strategy

1a Overview:

Cardiff University **School of Earth and Environmental Sciences (EARTH)** is recognised internationally for the quality of its research and impact across the breadth of Earth and Environmental Sciences. From tectonics and resource geology to hazard prediction and climate change policy, we are tackling some of the central problems facing humanity today. Our focus on both fundamental and applied research questions has sustained our excellent standing within the global research community. Since REF2014 our progress can be summarised as follows:

- New research structure with development of **three new Research Centres** and 10 affiliated research groups (Section 1b);
- **>1,300 ISI-listed research outputs** published with a total citation count of >21,000 (Scopus) and **~10% of which have citations in the top 5%** (field-weighted; SciVal);
- Enhanced wellbeing initiatives and attainment of the **Athena SWAN bronze award** (Section 2a);
- Increased Postgraduate Research (PGR) student support (including >£2.7M from Cardiff) has enabled us to **graduate >75 PhDs**;
- Improved **grant proposal quality** (33% success) and **research income** (>£17M awarded; Section 3a);
- **Major upgrading of analytical facilities** including **new Multicollector Inductively Coupled Plasma Mass Spectrometer (MC-ICP-MS) laboratory** and **3D visualisation suite** plus additional acquisition of 2x ICP-MS, Laser Ablation (LA)-ICP-MS and ICP-Optical Emission Spectrometer (ICP-OES) (£1.5M; Section 3b);
- New strategic partnerships with external institutions such as **British Geological Survey (BGS) Wales**, **University of Bremen** and **University of Campinas** (Section 4a);
- Enhanced engagement and interdisciplinary collaboration, including leadership within two **University-wide research institutions** (URIs; Section 4b).

These achievements have been underpinned by improved research support mechanisms for individual researchers at all stages of their careers (Sections 2, 3) and a major recruitment drive, including 14 new teaching and research (T&R) academics (a net increase from 33 to 37, total staff number 85, including professional services, the largest in EARTH's 130-year history), strengthening our research into environmental challenges. This strategic direction is reflected in our **name change from School of Earth and Ocean Sciences on 1st October 2020**. Since REF2014 our constant goal has been to strengthen our research excellence and the breadth of our impact while allowing staff to expand their own horizons. Our attainment of the Athena SWAN Bronze Award in 2017 reflects our commitment to achieving equality across the breadth of our staff (see Section 2a). Our new research structure and associated strategies, as outlined below, place us in a strong and sustainable position to tackle future research grand challenges.

1b Structure and strategy for research:

EARTH has benefited from the critical evaluation and advice of our **External Advisory Board** (established in 2015: Prof. Dame Jane Francis (BAS), Prof. Tim Jickells, (UEA), Dr Paul Maliphant (Mott McDonald Group), Prof. Kathryn Monk (NRW) and Prof. Sir Stephen Sparks (UoB)) which meets annually. Since REF2014 our strategy has been to increase our capacity for environmental research while supporting our strengths in fundamental Earth science disciplines. Accordingly, we have redesigned our structure to develop **three new Research Centres** (see below), each encompassing several affiliated research groups. Individual research groups were conceived and collaboratively developed by their members (a bottom-up approach) and therefore provide a genuine reflection of research activities and priorities across EARTH. All academics, Early Career

Researchers (ECR; PDRA and Research Fellows) and PGR students belong to a single Research Centre and one or more research group, encouraging interdisciplinary collaboration across EARTH.

Research Centres:

CSEN: Centre for Solid Earth and Natural Resources (Director Fagereng): Affiliated research groups: ***Economic Geology***; ***Sustainable Geoenvironments***; ***Tectonics and Geophysics***. The Centre deals with the composition and dynamic evolution of Earth's mantle and crust, including its mineral and petroleum resources. CSEN hosts 12 academic staff, 4 PDRAs and 28 PGRs. **Funding awarded since REF2014: £6.2M.**

Developments and highlights since REF2014: Recent research successes include new insights into mid-ocean ridges, showing, for example, volcanic roots deep in the lithospheric mantle (Bennett et al., 2019), that melt-rock reaction in crystal mushes plays a central role in mid-ocean ridge melt fractionation (Lissenberg and MacLeod, 2016), and that the depleted mantle beneath mid-ocean ridges is highly heterogeneous (Lambart et al., 2019). At convergent margins, Buchs et al. (2019) have demonstrated previously unrecognised effects of volcanism on the obstruction of the intra-oceanic strait in Panama. CSEN also develops field- and laboratory-constrained models for the strength and rheology of subduction plates (Fagereng and den Hartog, 2017) and dynamic numerical models predicting the evolution of subducted slab morphologies (Garel et al., 2014).

Further highlights include insights into ore-generating processes, sustainable mining and hydrocarbon extraction, used by industry and funded by both industry partners and UKRI directed calls (**see Impact Cases** by Maier and McDonald; Blenkinsop and Lambert-Smith; Alves). Additional research impact includes quantitative assessment of potential oil spills in the Mediterranean Sea to assist civil protection authorities (Alves et al., 2016) and analysis of regions proposed for carbon capture and storage (CCS; Roelofse et al., 2019).

CSEN is highly active within the **International Ocean Discovery Program** (IODP, Section 4d). For example, MacLeod Co-led IODP Expedition 360 to drill to the Moho at a slow spreading ridge.

Future priorities: CSEN will utilise EARTH's expanding analytical and computing capabilities to address emerging topics, both fundamental and applied in nature. For example, sustainable resources and ore systems critical to the future supply of minerals, future energy solutions, environmental aspects of hydrocarbon exploration and production, CCS, geological hazards, as well as mantle heterogeneity, plate boundary seismic styles and whole Earth dynamics and rheology. Continued leadership and involvement in ocean (IODP) and continental drilling (International Continental Scientific Drilling Program) will ensure that CSEN maintains its international status in planetary discovery.

CGEO: Centre for Geobiology and Geochemistry (Director Berry): Affiliated research groups: ***Geochemistry***; ***Geomicrobiology and Biogeochemistry***; ***Palaeobiology***. Research focuses on the Earth's surface, including in and under its oceans, where life has evolved and affected environments over billions of years. CGEO hosts 12 academic staff, 5 PDRAs and 10 PGRs. **Funding awarded since REF2014: £3.9M.**

Developments and highlights since REF2014: Recent research successes include novel insights into the Mid/Late Devonian 'transition to a forested Earth' (Xu et al., 2017) and discovery of the world's oldest forest (Stein et al., 2020). New constraints have been placed on the terrestrial uranium cycle (Andersen et al., 2015). Mitra et al. (2016) redefined planktonic protist functional groups to incorporate diverse mixotrophic strategies, implicating radical changes to food web representation in biogeochemical models. **National Research Network for Low Carbon Energy and Environment (NRN-LCEE)** Returning Fellowship funding (£20k) for coral drilling fieldwork in Fiji has allowed development of partnerships with Malaysian scientists and led to the NERC-funded 'Reefugia' project (Sosdian collaboration with NHM; ~£104k to Cardiff) looking at the sustainability of turbid reef environments in the Coral Reef Triangle. While collaboration with **Dŵr Cymru Welsh Water (DCWW)** has identified the triggers for cyanobacteria that result in taste and odour problems in potable water (**see Impact Case** by Perkins).

CGEO has become host to the new 'CELTIC' isotope and refurbished 'ELEMENT' trace element laboratories (see Section 3b).

Future priorities: Future research will focus on potential side-effects of a carbon-neutral energy economy, for example the fate of compounds used in CCS and the effect of CO_2 on microbial communities in the subsurface. The CELTIC/ELEMENT laboratories will continue to diversify their research portfolio, building on recent cutting-edge developments, for example ultra-trace elements in organic rich samples, to strengthen our position within the international geochemistry community.

CREC: Centre for Resilience and Environmental Change (Director Lear): Affiliated research groups: ***Cold Climates***; ***Earth Surface Processes***; ***Ocean and Climate Systems***. Investigating the causes and consequences of changes in the Earth system, in the ocean, atmosphere and on land, from the geologic past into the present and future. The Centre hosts 13 academic staff, 6 PDRAs and 18 PGRs. **Funding awarded since REF2014: £7M**.

Developments and highlights since REF2014: Recent research successes include development of the longest absolutely dated and annually resolved record of ocean climate variability spanning the last 1000 years (Reynolds et al., 2016) and successful development and deployment of a new generation of sub-ice sensors (Bagshaw et al., 2018), also supported by a (NRN-LCEE) Returning Fellowship. CREC has continued to support a range of internationally leading paleoceanographic research and hosted the first meeting of a new UK-wide Paleoclimate Society in 2017. Centre members have played leading roles in the IODP (e.g. Hall Co-led Expedition 361 'South African Climates') and participated in several recent cruises (Section 3d). New CREC appointments have expanded EARTH's expertise in environmental modelling (Ekstrom, Chappell, Hobley, He) and observation (Andela, Cuthbert, Earlie, Marrero, Singer, Mao).

Future priorities: CREC will build on emergent strengths in the development of decision-support tools for assessing and aiding climate adaptation, for example improving community-centric adaptation and resilience to droughts in Ethiopia, Kenya and Somalia within our recent H2020 'DOWN2EARTH' award (see Section 4b). Our established strengths in quantitative palaeoclimate and climate research will focus on extending the observational climate record, abrupt climate change, and past ocean and atmospheric CO_2 variability to improve climate system understanding and aid future climate prediction.

In addition to the above Centres, the ***Geoscience-Africa Research Group*** (GARG) spans all three Centres, collaborating with local partners to meet the geoscientific challenges of Africa, in both infrastructure and human development, for example demonstrating that groundwater resources in Africa may be resilient to climate change (Cuthbert et al., 2019). See also CSEN Impact Cases.

1c School-wide strategies for future research vitality and impact:

Our vision combines the aims of our three Research Centres to provide real-world solutions to key societal challenges. Consequently, many of our strategies for sustaining research vitality are school-wide. For example, we hold annual **research awaydays** to which all staff and PGRs are invited. The event, which typically involves an element of CPD training (e.g. grant writing, research ethics), research talks and a poster session, provides a showcase for current research and an opportunity to promote a broader sense of community. We also hold regular '**flash presentation**' events where researchers test their new ideas for research funding bids (Section 3a). These events provide critical feedback at the earliest stage of research proposal development, foster collaboration and promote wider engagement and dynamism across the School. The School hosts a vibrant internal and externally invited research seminar series, including slots arranged solely by the ECR community.

Building on the bottom-up development of our research groups we have further developed an inclusive mechanism for identifying future priority research themes and objectives that maximise commitment across EARTH. Each year (or biannually) all academic staff are invited to an open event at which they explain or pitch their suggestions of emergent research avenues or strengthening existing areas, after which staff identify their two preferred research priorities and the most popular two or three are selected. These areas then hold 'priority status' for the next 12

to 24 months, which means, for example, they may gain additional support under the 'wish-list' scheme for new equipment (Section 3b) or, when other factors allow, provide the basis for new academic/professional service appointments. Our most recent event (Feb 2020) highlighted the following areas for support: "Sustainable Resources" (championed by Maier) and "Drivers of Natural Hazards in a Changing World" (Fagereng and Hales). These have formed the basis for new lecturer positions in Geo-Environmental Hazards and Geospatial Sciences, currently under recruitment.

Enabling impact (see also Sections 2c and 4): Following REF2014 we have increased the breadth and visibility of impact associated with our research, extending considerably beyond our REF2021 impact cases. We have established an Impact Management Team and have implemented a formal structure for facilitating impact by regular internal reviews of impact reporting, training for impact, financial support for impact activities and liaison with impact case study development within the College of Physical Science and Engineering. Training in 'impact awareness', and more specifically in communicating impact, is delivered annually (2015-17) by external consultants.

We have initiated an annual **Research Impact Open Day** to promote impact development and increase engagement with external stakeholders, at which pump-priming awards for emerging impact activity are distributed. Known as the **Hazel Prichard Impact Awards (HPIA)**, in memory of a professorial staff member who made a deep impact in the area of mineral resources, these awards have supported staff and PGRs to develop innovative routes to impact. Since 2017, a total of 14 HPIAs (>£12k) have been made with generous support from SRK-Consulting (UK) Ltd, including for each REF2021 Impact Case. Impact highlights arising from HPIAs include seed-funding for '**Time for Geography**', a spin-out open access resource for the next generation of geographers, and support for Blenkinsop's (GARG) involvement in the Royal Academy of Engineering, **Higher Education Partnership in Sub-Saharan Africa,** Spoke University Award with Midlands State University, Zimbabwe. SRK-Consulting also support access for all staff and students to Geologize's critically acclaimed CPD course **'Practical Geocommunication'** (A Geological Society endorsed training event; in-kind £335 per person).

1d Support for interdisciplinary research:

Since REF2014 EARTH has focussed support (both staff time and equipment investment; see Section 4b) on interdisciplinary research development within Cardiff and beyond. We support staff through direct workload allocation and via the **University Research Leave Fellowship Scheme** (URLS; Section 2b and REF5a). For example, the development of the interdisciplinary project '**Resilience to EArthquake-induced landslide risk in CHina** (REACH; See section 4b) was supported by a URLS fellowship to project director Hales, with additional research time supported through workload allocation (e.g. see systematic review by Ran et al., 2020). We have also provided direct support for the highly visible and multidisciplinary heritage conservation project, '**Heritage in the Crossfire'** (Blenkinsop), through provision of Scanning Electron Microscopy (SEM, Section 3b) and photogrammetry support (e.g. post-bombing deterioration of the Royal Garrison Church, Portsmouth funded by EARTH and a HPIA). Another recent success for interdisciplinary research originating in EARTH saw Bagshaw as a finalist in The Engineer's '**Collaborate to Innovate Awards 2019'** (Energy and Environment category) for her work on the '**Cryoegg**' project (wireless communications for subglacial environments). The award celebrates innovative applications of technology achieved by collaboration across disciplines and consolidates existing links between EARTH and Cardiff School of Engineering (e.g. Prior-Jones et al. 2021).

1e Research integrity and an open research environment:

Cardiff is a signatory of the **San Francisco Declaration on Research Assessment (DORA)** and EARTH is committed to the fair assessment of research based on its intrinsic value when considering applications for employment, promotion and internal funding. We are committed to improving accessibility and reproducibility of data and other research outputs (see also REF5a). Our staff are helping to develop and utilise several platforms with these goals in mind, for example Blenkinsop and Fagereng have contributed to the development and testing of 'StraboSpot', an NSF-funded initiative for sharing of observational geological data. Hobley is a Fellow of the

Software Sustainability Institute, advocating software as a valid research output and promoting the role of those who develop such software to improve reproducibility, and lead developer of 'Landlab', a modularised open-source software resource for modelling the Earth's surface. Our **School Ethics Officer** oversees the research integrity of new proposals and ongoing projects within EARTH, for example when sampling species that appear on the CITES list (e.g. Sosdian's work on coral reefs) or when human participation is required (e.g. Ballinger's stakeholder engagement). We also employ an online Research Integrity and Ethics training programme achieving 100% completion for all academics, ECRs and PGRs. EARTH supports an Open Access (OA) coordinator, who ensures that all research outputs conform to UKRI requirements. We support the Gold route to publication in journals where the Green route is not an option. **All staff returned to REF2021 have an ORCID iD.**

2. People

2a Equality, Diversity and Inclusivity (ED&I):

Comprehensive support for staff is central to our research strategy and we were proud to be awarded the **Athena SWAN bronze award in 2017**. The self-assessment exercise, delivered by EARTH Self-Assessment Team (SAT), provided an opportunity to reflect on our approaches and attitudes towards ED&I. Through this exercise we have identified areas for improvement as well as existing good practice. We have implemented new policies to improve gender balance within recruitment (Section 2b), promotion (Section 2c) and workload allocation (Section 2c) processes. We have also improved gender representation on strategic committees and within senior management roles. As part of our plan to improve ED&I we have introduced a revised core time for School meetings (10:00 to 16:00, avoiding half-term holidays).

We are transforming the way we understand and facilitate ED&I. Since achieving the Athena SWAN bronze award, the SAT has developed into a new **School Inclusivity and Diversity Committee**, which oversees ED&I matters, including monitoring and implementation of the Athena SWAN Action Plan. All staff are now required to undergo Unconscious Bias training and we are constantly increasing the proportion of staff to receive training in Mental Health First Aid and Suicide Safety. As part of Cardiff's strategy for improving wellbeing (see REF 5a) we have **three Dignity and Wellbeing contacts** within EARTH (Ballinger, Barker, Earlie) who have received additional training in Mental Health and Wellbeing in the Workplace ('i-act'). This training has also been completed by many of EARTH's senior management team (Head of School and Centre heads). We also promote and support opportunities for staff returning to work after periods of absence (e.g. maternity leave); Sosdian and Bagshaw were awarded NRN-LCEE Returning Fellowships (Section 1b). We host regular visits from Cardiff leads for ED&I and the LGBT+ network, to ensure EARTH activities align with institutional objectives, for example Cardiff ranks in the top 10 (#1 HE performer) in the Stonewall Workplace Equality Index 2020 (see REF5a).

Aligned to Cardiff's REF2021 Code of Practice, consideration was given to diversity within EARTH's REF2021 development committees (2/6 output reviewers are female, as are half of the impact team). All REF2021 output reviewers attended additional training workshops on unconscious bias and ED&I considerations associated with this particular task. **The final output selection is gender balanced in line with T&R staff as of July 2020**.

2b Recruitment:

In line with our restructuring, we have increased capacity across our three Research Centres, with a focus on, for example, environmental science and sustainability. Since REF2014, EARTH has grown from 33 to 37 FTE core-funded academic staff, including 8 professors of whom 2 are FRS: Edwards and Parkes (now emeritus). New appointments since REF2014 include: climate change impacts (Chappell); climate risk and resilience (Ekstrom); environmental sustainability (He); physical geography (Marrero, Mao); basin analysis (Hobley); geomorphology (Singer); remote sensing (Andela); coastal processes (Earlie); Earth observation (Forootan); isotope geochemistry (Millet, Andersen); geomicrobiology (Chi Fru); volcanology (Degruyter); seismology (Thompson); and exploration and resource geology (Lambert-Smith).

We engage with institutional initiatives for ECRs (see REF5a) including the **Darlithwyr Disglair (Brilliant Lecturers) Scheme** (Marrero, Mao). Wherever possible we consider further support,

via proleptic academic appointments, to begin upon termination of research fellowships. Since REF2014 these include **Disglair, Sêr Cymru and NERC IRF fellows**: Cuthbert, Hobley, Mao, Marrero and Mitra (3M, 2F). We host externally (part-) funded positions in Environmental Geoscience (**BGS lectureship**) and Climate Change Impacts (**BGS Research Fellowship**). Since REF2014 we have lost one professor due to illness and a further nine academics have retired or left the School to pursue other opportunities, for example Forootan (now Professor at Aalborg University) and Constantine (Assistant Professor at Williams College). This has given us the opportunity to invest in early career academics (see above).

In line with the national drive to improve gender equality across the STEM fields we are striving to increase the proportion of female applicants to our advertised positions, as well as the proportion of female applicants that are shortlisted and ultimately successful. To these ends we have introduced several strategies since REF2014 (not exhaustive): search committees proactively targeting female scientists (aim: increase female applicants from 22% in 2017 to 35% in 2020); application vacancy packs are written in positive language, with the guidance of an online 'Gender Decoder' tool; alignment of % female applicants with % females shortlisted by 2020; improving gender balance of recruitment panels (33% by 2019/20); and ensuring panel members' training (e.g. unconscious bias, panel chairing) is current. For six academic posts advertised between 6/2019 and 3/2020 applications from females ranged 21-37% (mean 31%). Three of the five posts filled were secured by female applicants.

2c Staff development:

EARTH's Research Executive (led by Director of Research, Davies) provides strategic leadership and management across all research activities. EARTH aims to provide our researchers with the adaptability, flexibility and resilience they need to succeed in the global research economy (building on **The Concordat to Support the Career Development of Researchers** – see below and REF5a). We offer a range of development opportunities across the breadth of specialism and seniority within EARTH through both internal mechanisms and as part of the Cardiff Researcher Programme and the Leadership and Management Programme (see below and REF5a). These award-winning schemes provide workshops, one-to-one coaching and online modules that, for example, equip ECRs with the knowledge and skills to manage their project, grow their research group and develop into independent scientists.

Cardiff employs a **Performance Development Review** programme whereby all staff complete an annual review of performance and development needs by their respective line manager. Since REF2014 we have promoted seven staff to Senior Lecturer (6M, 1F), five to Reader (4M, 1F), four to Professor (2M, 2F) and one ECR to Principal Research Fellow (Reader equivalent R-only, M). As part of our ED&I action plan, we are taking further steps to decrease the gender difference in the average time taken to apply for promotion (linked to the national tendency for a lower proportion of females reaching senior positions across STEM). To this end we organise annual School workshops on career development and promotion and a '**Career Development for Female Academics**' course within EARTH.

Supporting Early Career Researchers: We apply the principles of the Concordat to Support the Career Development of Researchers. In 2017 EARTH developed its own ECR Forum to promote the integration and participation of ECRs within EARTH, and to implement a cohesive, stimulating and dynamic environment for their career development. Amongst its activities (including social events) the forum organises workshops providing guidance on preparing fellowship applications, applying for academic positions and interview practice. These have involved internal speakers and professionals from Cardiff Research and Innovation Services (see REF5a). To further support the transition of ECRs to independent researchers (e.g. Moffa-Sanchez, now Assistant Professor, Durham; Lambart, Assistant Professor, Utah; Reynolds, Lecturer, Exeter) the forum has led development of EARTH's ECR policy. This includes agreement, with their supervisor, of dedicated time during their research contracts to pursue their individual research ideas, access to EARTH analytical facilities free of charge (up to £1k) to perform pilot analysis, and access to mentors external to the School. ECR Forum representatives attend meetings of EARTH's Research Executive. Early Career Academics (ECA) are also supported with a reduction in teaching

allocation during their three-year probationary period (Yr 1: 33%, Yr 2: 21%, Yr 3: 12.5%) as well as additional allowance for preparing teaching materials within their workload allocation.

Workload and Dedicated leave for research and impact: We have supported individuals and strengthened our new Research Centres through various research leave schemes and workload management. Since REF2014, 10 staff (27% of total T&R staff) have been awarded research leave of up to 12 months each, totalling 101 months FTE. For longer periods Cardiff provides funds to support teaching replacement with additional support for administration and timetabling coming from EARTH. For shorter leave periods, EARTH supports requests related specifically to deliver research and impact (e.g. writing retreats). Under these schemes, for example (also see section 1d) Davies (CSEN) was able to prepare the groundwork for leading his successful NERC Large Grant submission (awarded 2020, total £3.8M, £804k to Cardiff) and Buchs (CSEN) completed a study on the geology of the Panama Canal to support activities of the Panama Canal Authority geotechnical team (including 2 publications and impact development).

Staff exchanges: EARTH encourages and facilitates exchanges between our academics and those of other HEIs, businesses and other bodies through direct support (travel costs and time) to outgoing staff and through our **Visiting Research Fellowship programme**. Since REF2014 we have attracted 25 incoming scholars (24 from overseas) visiting for a **cumulative total of >10 years FTE since 2017**. We offer office space, bench fees and administrative assistance to all incoming fellows. EARTH is also proactive in applying for external grants to fund staff exchanges. We were successful in securing funding from the UK Department for Business, Energy and Industrial Strategy (BEIS) for a **Rutherford Fund Strategic Partner Grant** to support three incoming fellows from the University of Campinas, Brazil, a Cardiff strategic partner (Section 4a). Chappell received Chinese Government 'Foreign Expert' funding to work at the Chinese Academy of Agricultural Sciences for >1 month per year (2016-19). Success in terms of two-way exchange is evidenced by Hales' interactions with Chengdu University of Technology (CDUT, China) and the **State Key Laboratory of Geohazard Prevention and Geoenvironment Protection**. This enabled visits from three ECA (lecturer) visitors (12 months each) and two Master's students (three months each).

Outgoing exchanges provide support for individual Research Centres, for example Perkins (CGEO) was seconded to Dŵr Cymru Welsh Water (2017-20) via a UKRI-NERC directed internship and subsequently by direct DCWW support, which has been further extended during the Covid-19 pandemic (**see Impact Case** by Perkins). EARTH also benefits from Cardiff's strategic partnerships (see Section 4a), allowing us to exchange staff with relative ease. Partners particularly close to EARTH include the **Universities of Bremen (Germany), Campinas (Brazil), Xiamen (China) and KU Leuven (Belgium)**.

Outgoing PGR and ECR secondments include Westcountry Rivers Trust (PGR von Benzon developing new sensors for WRT catchments), Natural History Museum, London (PGRs Poniecka and Millar received specialised training in DNA extraction, sequencing and data analysis), Universities of Bremen, St Andrews, Tsukuba (PGR Tulley two field seasons forming basis for PhD thesis), Utrecht, and Columbia University (Lamont Doherty Earth Observatory; PDRA Williams joint publication of new Malawi fault database) and many others.

Continuing Professional Development: All staff undertake annual professional development training including: **ED&I, Unconscious Bias** and **Welsh Language Awareness**. Additionally, 100% of the research active staff have undertaken training in '**Research Integrity and Ethics**.' EARTH supports participation in a range of development programmes, for example the '**Cardiff Futures**' leadership programmes for Early Career Academics (McDonald, Sosdian, Renforth), '**Welsh Crucible'** (Reynolds) and '**GW4 Crucible'** (Ekstrom, McKinley) programmes of personal and professional development for the future research leaders, and the Welsh Government '**Academi Wales**' summer School, bringing together leaders and managers to address key issues related to leadership (Pike and School Manager). This has facilitated Pike's involvement in development of Cardiff's ECR strategy (REF5a).

Career pathways and support for part-time and fixed-term staff: We are conscious of the difficult reality faced by those on fixed-term contracts. Such contracts are normally only used for a period of four years or less (predominantly linked to external grants). We offer flexible working

opportunities wherever possible and have accommodated part-time work, compressed hours and job-sharing. As part of Cardiff's policy on redeployment we strive to offer existing staff new opportunities and provide support to outgoing staff in preparation for their onwards career (see Section 2c for examples of onward destinations).

Honorary and Emeritus Staff: We have a vibrant group of 11 honorary and five emeritus staff, who contribute to the research environment through outputs and continued collaboration with current staff, including: Pearce, Rickard, Leake, Parkes, Pearson, Knorr, James, Steed, Lisle.

2d Research students:

PGR students are crucial to our success as a centre of research excellence and their recruitment and development has led to critical growth of our Research Centres. We are active partners in UKRI Doctoral Training Partnerships (DTP) and Centres for Doctoral Training (CDTs) as well as receiving research training support funds from a variety of different sources (see below). This most significantly includes the **NERC GW4+ (Great Western 4 plus) DTP Phase I (2013-2018) and Phase II** (2018-2023). Our engagement with the GW4+ DTP has been facilitated by Hall, as member (2013-present) and Chair (2014-15) of the Executive Board. We are also members of the **NERC 'Oil and Gas'** and **'FRESH' (Resilient freshwaters in a changing world) CDT**s. Since REF2014 these programmes, together with other PGR support totalling >£2.7M from Cardiff initiatives, have enabled us to **graduate 77.5 PGRs with a 90% completion rate** (85% during REF2014).

Recruitment: PGR students are recruited according to Cardiff's Postgraduate Admissions Policy, with additional emphasis on widening participation and gender equality. All incoming PGRs must meet Cardiff's general entrance requirements and satisfy the School that they have experience of, and/or are engaged in, an appropriate level of professional activity to provide the necessary professional context for the completion of the proposed project. All available PGR opportunities are advertised openly and shortlisted for interviews by project supervisors. Appropriate selection criteria and assessment methods are documented and agreed in advance. All recruitment decisions are overseen by the Director of PGR (Chi-Fru).

Funding from major funding bodies: Since REF2014, PGR students have been/are being funded by seven major funding bodies (NERC, ERC, CSC, EPSRC, KESS, Leverhulme Trust, US DoD).

Monitoring and support: EARTH implements Cardiff's **Code of Practice for Research Degrees** through procedures laid out in our own **Research Degrees Handbook**, which combines generic and subject-specific procedures. Careful monitoring and regular reporting and evaluation of PGRs (from start to completion) ensures they make optimal progress in their research and skills development. The Director/Deputy Director PGR monitor individual PGRs throughout their degree: initial review, interim reviews, annual reviews, and thesis progress reporting. During each review step, documentation from the supervisor and PGR are provided. During the annual review, there is a formal meeting with the **Review Panel Convenor** to assess the progress of every PGR. If issues arise, they are followed up individually with the PGR student, supervisor, and review panel convenor, to ensure that the proposed contingency or recovery plan is feasible. The GW4+ DTP also offers regular resilience and wellbeing workshops ensuring our PGRs explore a variety of wellbeing techniques to help develop greater emotional resilience. This complements access to skills training available at all the other GW4 Institutions (Exeter, Bristol, Bath). In their final year, each PGR student is contacted individually to further identify any specific support required during their writing-up.

Skills development and onward career: An annual reflective skills audit allows identification of bespoke PGR student training needs related to their field of research and project progression (e.g. Gore completed two secondments at Mount Allison University, Canada, to gain specialist skills in the study of prokaryotes). The audits are reviewed by the supervisor and review panel convenor and training plans are co-designed with the PGR. Through Cardiff's '**Doctoral Academy**' EARTH is part of an employability scheme for PGR students, which involves the identification and active promotion of work placements to help build skills (e.g. placements with Geollect, Welsh Government, Nagoya University and University New South Wales). Additional training and targeted opportunities are offered within the GW4+ DTP (various courses in at least eight different

countries). Our graduating PGR students go on to successful careers both within and beyond academia, for example: Pereira (2013), Senior Geologist (Partex Oil and Gas); Williamson (2015), Lecturer (Bristol); Ciborowski (2015), Lecturer (Brighton); Hughes (2015), Lecturer (Camborne); Piedade (2016), Lecturer (ISCIA, Portugal); Price (2016), Office of National Statistics; Ward (2018), Business Team Leader (Amazon); van Tuyl (2019), Geophysicist (CGG-Llandudno); Martin (2019), PDRA (Memorial University); Ellis (2020), Senior geologist (Rio Tinto); Roelofse (2020), Geophysicist (Shell); Francis (2020), PDRA (GFZ Potsdam); and many others.

3. Income, infrastructure and facilities

Our research success is underpinned by our infrastructure, income and our professional services personnel. **Since REF2014 we have commissioned two major facilities** to strengthen our new Research Centres (see Section 3b). EARTH's facilities are supported by **dedicated technical support (7.15 FTE)** and **specialist analytical managers (3.5 FTE),** representing an investment of ~£2.25M since REF2014**.** We have also introduced **new training and support measures** (see below) that have directly underpinned an increase in funding applications and success.

3a Research income generation:

Since REF2014 we have increased the **number of proposals submitted** (from 163 to **346**) and the **total amount of funding awarded** (from £10M to **>£17M**). In addition, the School has received NERC income-in-kind funding of ~£1.1M, for example for high-performance computing (HECTOR/ARCHER 491 Million Allocation Units), and significant additional benefit-in-kind funding, for example IODP and other ship-time (1037 days), 3D seismic data software (£24M). Our research funding includes 55 UKRI Research Council grants, an ERC Starter Grant (Fagereng) and 17 European Horizon 2020 Programme awards. Since REF2014 we have hosted 11 incoming research fellows, supported by, for example, UKRI, Marie Skłodowska - Curie Actions and Sêr Cymru. We have secured external funding from industry, charities and government, which has enabled not just high-quality research output, but also significant impact. Collaboration with partner institutions has played a vital role in our income generation, for example eight other UK institutions and six overseas partners within Davies' NERC large grant.

Supporting our researchers: We have implemented several new support strategies since REF2014. For example, EARTH now funds a **Research Development Manager (1 FTE)** who provides professional management support for all of EARTH's research activities and, together with the College Research Support team, generates biweekly reports of new research funding opportunities with relevance to each Research Centre. We have also focussed on improving the quality of our research proposals and improved targeting of funding opportunities aligned with our Research Centres. We have introduced several processes and training opportunities aimed specifically at ERCs, but with all staff encouraged to participate. We have organised and funded several **grant writing workshops** using external facilitators to aid in genesis and development of proposals. Most research active staff have now attended one of these workshops. We have also supported additional external **one-to-one consultation** for researchers who required more support. Mock presentation/interview panels are arranged for individual grant applications where this is a component of the review process (recent success of this approach was Fagereng's ERC starting grant). These strategies are in addition to wider institutional schemes (REF5a).

Research funding pipeline: EARTH operates a **research proposal 'pipeline'** that is integrated with the annual **Performance Development Reviews** for all staff. Initial ideas for future funding bids are advanced within each Centre and then aired across EARTH during regular informal 'pitch a research idea' (**flash presentation**) sessions, which provide feedback for any member of staff who is developing ideas for funding proposals. Any researcher who is planning to submit a proposal to a future round is allocated **two internal reviewers/mentors**, whose task is to **support the investigator** during the development phase of their proposal and following feedback from EARTH's review panel (see below). As part of the UKRI-NERC demand management process Cardiff has introduced a NERC Strategic Panel (Chaired by Hall) to determine which proposals can be submitted to standard grant rounds. EARTH has established an additional review panel, which allows us to improve the chances of success of those proposals submitted to the Cardiff panel. Overall, our efforts to improve support for income generation have been rewarded with a **33% success rate in grants applied for and awarded** (119 out of 356 applications).

External consultancy: Research income and activities related to impact are derived from extensive consultancies (e.g. Blenkinsop has held 10 consultancies worth >£100k since REF2014, including with three of the top four largest gold mining companies). PGR student research, for example resource related projects, are supported by mining companies supplying data and samples (e.g. Rio Tinto, Mount Isa Mines, Ivanhoe Mines, Anglo American). Lambert-Smith, Alves and Buchs have also held consultancy positions with companies such as Husky Energy Inc, Exxon Mobil, Oklo Resources Ltd. and Petrobras-Petróleo Brasileiro. See Impact Cases associated with CSEN (Section 1b).

3b Infrastructural and facilities:

Recent investment highlights: We have benefitted from **significant institutional support** for laboratory refurbishment and capital equipment purchases. In 2014 the School invested in a state-of-the-art **electron microbeam facility**, installing a Zeiss Sigma HD FEG-SEM with dual energy-dispersive detectors, as well as wavelength dispersive and cathodoluminescence detectors (University Research Infrastructure Fund, £498k). This facility has underpinned novel approaches to petrology and mineral resource studies (Lambart et al., 2019) and resulting grants (e.g. NERC standard grant HiDe, £412k). In 2016, an electron backscatter diffraction detector was also added (£60k), primarily in support of CSEN (e.g. earthquake deformation studies).

Since REF2014 the School has enhanced its trace element and isotope geochemistry capability (supporting research across all 3 Research Centres). In support of CSEN **we invested £413K refurbishing the 'ELEMENT laboratory',** originally established in 2002 (2xThermo iCAP RQ ICP-MS; Thermo iCAP 7400 radial ICP-OES; Claisse M4 Fusion system; ESI Micromill and video system). The laboratory directly underpins research associated with two CSEN REF2021 impact cases (Maier and McDonald; Blenkinsop and Lambert-Smith) linked to understanding the geochemistry and mineralogy of platinum group element and gold deposits within the minerals industry. Since REF2014 the ELEMENT laboratory has under-pinned >£1M in research grants and supported 24 PhD projects in EARTH plus a further 11 visiting PGRs from other institutions (Bristol, Imperial, Leicester, Exeter, Southampton, Birmingham).

To augment the capabilities of CGEO we have recently established the **'Cardiff University Earth Laboratory for Trace Element and Isotope Chemistry' (CELTIC) representing a total investment of ~£1.1M.** The laboratory is home to specialist equipment (Nu Plasma II MC-ICP-MS; Element XR HR-ICPMS; RESOlution 193 nm excimer laser system and two new clean laboratories) for the analysis of isotopes, which are currently being used for a wide variety of research projects from climate change to the formation of planets. The laboratory development has been supported by **two new academic appointments** (Millet and Andersen). The CELTIC lab is enabling new collaborations across Cardiff, including with the Schools of Archaeology and Chemistry and has also attracted external funding (~£300k from NERC Capital Call 2019) for an upgrade including a new generation ICP-QQQ-MS (Agilent 8800), a microwave digestion system and new laminar flow hoods.

We have **established the Cold Climates research group** (within CREC) exploring biogeochemical and microbial interactions in the Cryosphere. The group has gained traction through the appointment of Bagshaw (plus new Lecturer in Climate Science, Buzzard beginning January 2021) and laboratories for low temperature environmental simulation, precision titration facilities and field-based equipment for measurements of meteorological, water and biogeochemical parameters. Recent successes include deployment of new techniques in Greenland to reveal microbial processes on the ice sheet surface (Bagshaw et al., 2016; Williamson et al., 2020) and the first *in-situ* measurements of subglacial methane export (Lamarche-Gagnon et al., 2019). Bagshaw successfully obtained EPSRC funding (~£230k) to develop a 'Cryoegg' wireless instrument for deployment beneath deep ice (see Section 1d).

Since REF2014 EARTH has operated a **'wish-list'** programme for smaller items of research and impact support. The programme is open to **all staff and PDRAs** and invites justified suggestions for equipment or other items of support that will improve research (capability, potential grant capture, PGR training, impact) within EARTH. The scheme represents a total investment of £574k since REF2014 and has included: a Cavity ring-down spectrometer to measure the stable isotope composition of liquid water; broadband seismometers; satellite modems from several vendors to

evaluate their performance during programmed Arctic fieldwork; a high-end titration system; a field calorimeter; acid purification systems; Leica petrological microscope; fluid/melt inclusion temperature controlled stage; 3D visualisation suite; coral drilling equipment; two drones (including hyperspectral sensor); a long-term archival and back-up system for analytical facilities data developed by our HPCDO (below).

Additional research facilities and operational support: EARTH has funded a **High-performance computing development officer (HPCDO) (0.5 FTE)** since 2015. HPCDO Thomas provides computing support to individual researchers and runs a popular Python introduction course for staff and students. We also support and maintain a comprehensive range of additional well-equipped laboratories and facilities which underpin research carried out across our research centres. For example, since REF2014 we have strategically invested ~£250k to upgrade the *RV Guiding Light* (EARTH's own sea-going research vessel) multi-beam echo sounder system, side scan sonar system and single-beam echosounder. Our technical support and specialist analytical managers manage the day-to-day running of our equipment and provide intellectual input to our research through, for example, supervision of research students and co-authoring outputs. Support staff are recognised, for example, through Cardiff Celebrating Excellence Awards (Biggs 2019 finalist) and the University is a signatory of the Technician's Commitment (see REF5a). While our laboratories and facilities are 'owned' by the School, with access available to all academic staff, ECRs and PGRs, they are closely aligned with specific research groups. Key additional laboratories and facilities include: **geomicrobiology laboratories; 3D seismic laboratory; surveying and geophysical facilities; electron microbeam facilities; stable isotope laboratories and sedimentology facilities; and a digital visualisation suite**.

3c Major facilities and collaborative use of research infrastructure:

Members of all Research Centres make frequent use of national research facilities as well as infrastructure at other institutions and overseas on a collaborative basis, which enables us to effectively increase our analytical capacity in an extremely cost-efficient way. We utilise several of NERC's science facilities, which we support through, for example, Pike's membership of the **NERC Isotope Geoscience Facilities Steering Committee** (2013-17), Hall's leadership of the **British Ocean Sediment Core Facility** (2013-2019) and the newly established strategy group overseeing the **National Environmental Isotope Facility** (NEIF; 2020-present). We also make significant use of '**ARCHER**' (formally HECToR), the UK National Supercomputing Service, the UK **DLS Synchrotron** (Harwell) as well as facilities at the Natural History Museum (Molecular labs; Imaging and Analysis Centre). Within the HE sector (notably via Cardiff University strategic partnerships), we have made use of (in collaboration or as a shared facility) the XTM and LA facilities at Bristol University and rock deformation laboratories at MARUM (Bremen) and Utrecht University. We have also received equipment loans, for example, from the BGS for fieldwork in Tanzania and SeisUK + GFZ Potsdam for seismometers. Overseas our collaborations have enabled the use of facilities including LA-ICP-MS (Québec) and microbeam XRF and MAIA mapper (CSIRO, Australia). We also welcome collaborative use of our own facilities, for example the Element mapping facility of our FEG-SEM is used extensively by UK and overseas collaborators and our stable isotope facility has provided the basis for >15 collaborative projects since REF2014, for example ongoing participation in IODP Exp-361 post-cruise research with partners including Scripps and Columbia University.

3d Benefits in kind:

As well as facilities awards (including NERC income-in-kind of ~£1.1M) we receive significant in-kind support for industrial computing software (total value of software donated to the 3D lab: ~£24.5M since REF2014). We have also benefitted from participation on several research cruises, for example with UK-IODP (part of the IODP). Since REF2014 our staff and PGR students have accrued **>1000 days at sea** bolstering activity within the CREC and CSEN. We have also received significant support-in-kind for fieldwork expeditions to, for example, Antarctica (NERC Collaborative Antarctic Science Scheme, CASS) and Panama (Panama Canal Authority).

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

4a Research collaborations, networks and partnerships:

Collaborations with our wider stakeholders are a vital source of vitality and enrichment for the School. Our collaborations and partnerships with external academics and non-academics are supported by EARTH through various mechanisms. For example, direct support (through time and financial travel support) to Buchs and Kerr (CSEN) has established the 'GRIP' (Geological Research on the Isthmus of Panama) project, an integrative study of the Panama Isthmus involving an international network of collaborators from six different countries (Croatia, Colombia, Germany, Panama, Switzerland, UK). An MOU between the Panama Canal Authority and EARTH was signed in 2016, allowing collaborative scientific activities in the framework of the Panama Canal expansion project (the largest project at the canal since its original construction). Several related outputs have already been published, including a high-profile article (Buchs et al., 2019) attracting an Altmetric score within the top 3% of all articles of a similar age.

EARTH hosts the NERC BGS (British Geological Survey) in Wales (six staff and the Chief Geologist Wales), enabling several new collaborative activities, including joint membership of the **NRN-LCEE** and the **Environmental Platform Wales**. Joint initiatives include a lectureship in hydrogeology (Cuthbert), Research Fellowship in climate change impacts (Ekstrom) and PhD projects and participation in the Bridgend County Lower Carbon Heat Network.

EARTH is leading a new University-wide strategic partnership with one of Brazil's major universities (the **Universidade Estadual de Campinas**), with visits by our academics to Brazil (Lambert-Smith, Chi Fru, Perkins, Berry, Hall, Blenkinsop) and vice versa to consolidate the new partnership. EARTH has hosted three incoming fellows from Campinas, funded by Universities UK International (ultimately UK BEIS) as well as two PGRs to date. Although still in its infancy, our partnership with Campinas has already produced several novel outputs (x2 Meira et al., 2019) and forms the basis for multiple GCRF grant awards, a CAPES-PRINT split-site PhD award, an ADIMB (Brazilian agency for industrial minerals) fund award (~£35k to Campinas) and a Society for Economic Geology Hugh McKinstry fund award (£6k) to a Campinas student. The partnership also enabled Blenkinsop's short course and keynote address at the Geosudeste (2019) conference and PGR student Guice's successful fellowship application to the Smithsonian.

Cardiff also has a strategic partnership with **University of Bremen** in which EARTH is heavily involved (e.g. EU Marie Curie IF awarded to MARUM-based Tanuguan to move to Cardiff University). We already have close collaborative links (e.g. Barker et al., 2015; Zhang et al., 2017) between CREC and the **Alfred Wegener Institute Paleoclimate Dynamics group** (supported by an Honorary Research Fellowship to Knorr) and, with additional support for new exchange funding available through the strategic partnership (four outgoing staff exchanged so far), we will increase research collaboration and lever funding from non-UK sources post REF2021.

4b Contributions to the economy and society:

EARTH hosts the **Severn Estuary Partnership** (SEP) through the work of Ballinger (CREC), which straddles the divide between science and policy to develop informed and integrated coastal zone management practices (e.g. CoastalAdaption.eu). The SEP is an independent, estuary-wide initiative providing support to many organisations who have responsibilities or interests in the estuary, including local authorities, statutory agencies and other public and private organisations. The SEP model has been flagged as an example of good practice across Europe (e.g. European Maritime Spatial Planning Conference, 2017). Accordingly, Ballinger is an invited member of various national and international policy-practitioner networks, including the **Wales Marine Strategic Advisory Group**, the UK **Coastal Partnership Network** and the **Marine Social Sciences Network**.

Members of our Research Centres work across the institution, holding leading roles (supported by EARTH through workload allocation) within the University Research Institutes (URIs). These interdisciplinary units have allowed us to accelerate the impact of our research and increase our influence on the international stage. Hales (CREC) is a **Director of the Sustainable Places URI** (PLACE), which addresses planetary sustainable development challenges through the interdisciplinary lens of place-based research. PLACE aims to identify, understand and offer

solutions to address the urgent and complex social, economic and environmental challenges of global sustainability through collaborative research within and across specific locations. The Institute fosters interdisciplinary working among 13 Cardiff University Schools. Hales' 'REACH' project (jointly funded by Newton Fund, NERC, ESRC and NSF-China and a PLACE collaboration between social scientists, human geographers, geologists and engineers from Cardiff and CDUT) seeks to provide an evidence-base for improving the resilience of communities exposed to post-seismic hazards (chiefly landslides and debris flows) in Sichuan province, the region affected by the catastrophic 2008 Wenchuan earthquake (Ran et al., 2020). Also within the Sustainable Places URI is a new initiative ('Regrow Borneo' led by Hales) to offset the carbon footprint associated with our air travel through reforestation in Borneo (Horton et al., 2018). This initiative involves key stakeholders including the Batu Puteh Community Ecotourism Co-operative.

Singer and Hall (CREC) hold **directorships within the Water URI** (WRI) (with 10 additional affiliated EARTH academics and ECRs). WRI was launched in 2015 to address the grand challenge of sustainable water management for people and ecosystems in a changing world. WRI's mission is to foster world-leading interdisciplinary research that will have strong impact and be used as evidence by decision makers. WRI Deputy Director Singer leads the theme on '**Water and Environmental Change**', which has a specific emphasis on water scarcity issues internationally. He also serves on the management board of the **GW4 Water Security Alliance**, a collection of >200 water researchers and stakeholders working on interdisciplinary water problems across the South Wales and West. The WSA is an important vehicle driving collaborations between Cardiff and other GW4 institutions involving water scarcity under climate change in East Africa (funded over several grants from the UK Research and Innovation's Global Challenges Research Fund). These collaborative activities directly led to the recent H2020 award headed by Singer (DOWN2EARTH: a consortium of 14 international partners representing universities, NGOs, think tanks, UN and climate services centres; total €6.6M, ~£1.1M to Cardiff).

Alves is a member of the **Energy Systems URI**, which is tackling the global challenge of how we continue to generate, distribute and utilise energy. The vision is to establish a truly interdisciplinary systems-based research culture which encompasses the physical and social sciences. A key strength is the large number (>20) of partnerships with energy businesses worldwide, which help to drive new innovations in the energy systems field. Alves' research (and REF2021 Impact Case) has been used to improve decision-making processes in the energy industry and ultimately to promote the sustainable management of proven and potential resources.

Fagereng, Blenkinsop and Williams (CSEN and GARG) work on seismic hazard and resilience in Africa through the UK-GCRF PREPARE project (~£1.4M total, £230k to Cardiff) involving ongoing collaborations with the University of Bristol (Civil Engineering and Earth Science) and local governmental and academic institutions in Malawi. The programme is aimed at improving earthquake disaster preparedness in East African countries with Malawi as an initial case study (e.g. Williams et al., 2019). Unlike in higher-income countries, tools to mitigate seismic risk have not yet been fully realised. Since its inception in 2017, PREPARE has been transforming the understanding of seismic hazards in southern Malawi, and fostered productive relationships ensuring benefit to local partners e.g. training local stakeholders in the use of GIS software. This work is now expanding to Uganda, supported by additional EPSRC Impact Accelerator funding (£12.3k) and a Cardiff GCRF Facilitation award (£9k; REF5a).

Research from all Centres impacts the wider economy and other areas of society. Other stakeholders that we engage with include **Welsh Joint Education Committee (WJEC):** MacLeod's research on the ocean crust and seafloor spreading is now being taught across the UK as a compulsory part of the new WJEC and Eduqas' (2017) GCSE and A-level in Geology; **US Department of Defence:** Singer is working closely with conservation officials on military bases to assist them in ameliorating the effects of climate change on sensitive habitats for threatened and endangered species (US-DOD/SERDP grant PI Singer, US$1.7M, £145k to Cardiff); **Tanzanian Ministry of Water and Irrigation:** Cuthbert's research into the sustainability of the Makutapora wellfield - the main supply of freshwater to the Tanzanian capital Dodoma - involves capacity building via field-based training and research results that can underpin decision making with regard to future water management options (NERC Research Fellowship £574k); **Department of Disaster Management Affairs, Malawi:** PREPARE project (see above); **Panama Canal**

Authority: Buchs' research is helping in the mitigation of geotechnical hazards, for example, landslides associated with the management of the Canal; **Westcountry Rivers Trust:** Bagshaw is working with stakeholders to develop and test new freshwater monitoring techniques; **Natural Resources Wales:** Ballinger, McKinley and Hall assist NRW take a science-based approach to coastal management through the RESILICOAST and CoastWEB projects (total £458k to Cardiff); Cherns also works with NRW to develop and apply methodology for evaluation of the offshore physical and geological landscape (SEASCAPE) as a tool to inform the Welsh National Marine Plan; **UNESCO:** Buchs is leading a collaborative research and outreach project with the Geomôn Geopark Anglesey, UK, which will result in the establishment of a new Geotrail in Newborough Forest and Llanddwyn Island protected area; **New South Wales Government** and **NASA/NOAA:** Chappell and Andela are helping these agencies improve their methods of air quality and wildfire forecasting (e.g. NERC Standard grant £170k); **Conservatoires d'espaces naturels:** Singer is working with forest managers in France to better understand the conditions of water stress that threaten the riparian forest ecosystem; **Dŵr Cymru Welsh Water** and **SANASA Water Company (Brazil):** Perkins is working with these partners to improve drinking water quality (DCWW grant £134k; **see Impact Case** by Perkins); **National Museum Wales:** Edwards, Lear.

4c Diverse Communities:

Many of our staff are actively involved in engagement and outreach at a variety of levels, ranging from Macleod's influential A-Level syllabus work (Section 4b) and national events (e.g. Hay Festival, Lear and Ballinger; Volvo Ocean Race, Hall) to numerous local events at community centres and schools. Several of our female staff and PGR students (Pike, Detlef, Tanner, Snee) have played key roles in establishing **Soapbox Science**, a novel public outreach platform for promoting women scientists and the science they do. The events provide outreach to the general public as well as promoting our female scientists. The PGR community is particularly active, participating in various events including the **National Eisteddfod of Wales,** Soapbox Science and **Pint of Science** – the latter event was led by PGRs from EARTH. Several of our members are involved with the **Cardiff University Grangetown Community Gateway Project**, for example, a recent educational presentation given by Alves on plastic and marine pollution (Sea4All).

We organise and host an annual themed public lecture series within EARTH. Topics have included 'Catastrophes' and 'Sea level and Volcanoes'. Recent feedback from one of our talks: "*The EARTH public lecture series has given me a real insight into the changing world around us and talks are enjoyable to attend and well-pitched for non-experts like myself. Series topics, content and presenters often provide 'cutting edge' examinations of world issues which truly interest me. Please keep them coming!*" (T. Jones, retired architect). In an average year total attendance at these lectures is typically >600.

4d Supporting our discipline:

We dedicate a large amount of time and service to professional bodies within our discipline, including the **Linnean Society of London** (President); **Mineralogical Society of Great Britain and Ireland** (Public Relations Officer); the **WMO/IOC Satcom Forum** (Chair); **Tectonic Studies Group, Geological Society London** (Early Career Representative); **Geochemistry Group, Geological Society of London** (Secretary); **Marine Social Science Task force for Marine Science** (Coordination Committee member); **RGS Coastal and Marine Research Group** (Chair); **Marine Social Science Network** (Founder and Chair); **British Ecological Society Wales Policy Group** (Co-Chair); **IODP/ICDP Magellan Plus Steering Committee** (Vice-Chair); **Geological Society of London Awards, Student Awards and Ramsey Medal committees** (Members); **EGU Augustus Love Medal Committee** (Chair); **NERC British Ocean Sediment Core Facility** (Chair); **AGU Emiliani Lecture Committee** (Member); **Climate Change Consortium of Wales** (Theme leader); **AGU Outstanding Student Presentation Awards** (Judges); **UK Paleoclimate Society** (President); **International Society for Aeolian Research** (President); **Royal Microscopy Society Engineering and Physical Sciences Group** (Committee member); **British Society for Geomorphology** (Secretary); **Royal Meteorological Society Welsh Local Centre** (Treasurer); **Learned Society of Wales** (Council member and Vice President – STEM); **Natural History Museum** (Scientific advisory group member).

4e Wider influence:

Editorship Since REF2014 we have held senior editorship roles in a number of leading publications including, ***Lithos*** (Kerr), ***Solid Earth*** (Davies), ***Aeolian Research*** (Chappell), ***Paleoceanography and Paleoclimatology*** (Barker), ***Results in Geochemistry*** (Kerr), ***Marine and Petroleum Geology*** (Alves). We have also held Associate or Topical Editor roles at *Mineralium Deposita, Ore Geology Reviews, Marine and Petroleum Geology, Marine Geology, Solid Earth, Geophysical Research Letters, PLOS ONE, Aeolian Research, Journal of Quaternary Science, Palaeontology, Results in Geochemistry, The Cryosphere, Frontiers in Water, GCA Bulletin, Hydrogeology Journal, PLOS Biology etc.* We have been Editorial Board members of several journals including *Tectonophysics, Scientific Reports, Geology, Geosciences* and *Journal of Structural Geology*.

National and International Funding Committees We participate in, and lead, a large number of grant and facilities committees including NERC Standard Grant and Industrial Fellowship panels, NERC Peer Review College, NERC Strategic Advisory Committee, NERC Environmental Isotope Facilities Steering Committee, UK Arctic and Antarctic Partnership Steering Committee, UKRI Fellowship committee, European Research Council College of Expert Reviewers, Royal Society University Research Fellowship and International Exchange Scheme panels, Newton International Fellowship panel, IODP Proposal Evaluation Committee, NSF Hydrology Panel, DFG: Priority Programme 'Dome', Agence Nationale de la Recherche evaluation panel, Welsh Government Clean Air Advisory Panel.

Guest professorships and visiting research positions: Since REF2014 various positions have been held in support of our global research strategy, including: **Visiting Professor**, Institute of Botany, Beijing CAS (Edwards, 2014-2016); **Guest Professor**, CUMT, Beijing (Jones, 2000-present); **Visiting Professor**, Chinese Academy of Agricultural Sciences, Beijing (Chappell, 2009-present); **Visiting Professor**, Ecologie des Systèmes Aquatiques, Université libre de Bruxelles (Mitra, 2018-present).

Conference organisation: Support for our discipline has also included organisation of a range of national and international conferences since REF2014, for example the British Geophysical Association Annual Meeting, 2018, the UK Tectonic Studies Group Annual General meeting, 2014 and the 9th International Conference on Aeolian Research, 2016, among others.

Prizes and Fellowships: Finally, EARTH members have received several honours during the REF2021 period, including: **Member of Academia Europaea** (Edwards, 2014); **Honorary Doctorates**, University of Uppsala (Edwards, 2014), Universities of Wales and Edinburgh (Edwards, 2017); EGU **Tectonics and Structural Geology Division Outstanding Early Career Scientists Award** (Fagereng, 2016); **Bigsby Medal of the Geological Society** (Lear, 2017); **Fellow of the Learned Society of Wales** (Hall, 2017); **Geological Society's President Award** (Williams, 2018); **David A. Siegel Director's Award**, Earth Research Institute (Singer, 2018); **Phaup Award of the Geological Society of Zimbabwe** (Blenkinsop, 2019); **Yuva Rattan Award of the NRI Welfare Society of India** (Mitra, 2020); **Natural History Museum Honorary Research Fellow** (Edwards, 2016).