Institution: UCL

Unit of Assessment: UoA 7 Earth Sciences

a. Overview

The Institute for Earth and Planetary Sciences (IEPS) provides a flourishing, dynamic environment in which to pursue our shared aims of research excellence and the beneficial application of knowledge. The IEPS comprises the two departments of the University of London located in Bloomsbury: the Department of Earth Sciences at University College London, and the Department of Earth and Planetary Sciences at Birkbeck College London. The two departments are knit together at all levels by: a common management group consisting of the two HoD's and their deputies, shared PhD students, sharing of laboratory facilities, and abundant research collaboration. There is strong institutional commitment to the discipline as shown by the support for expansion within the UCL and Birkbeck components of the Institute as well as for two new joint staff appointments.

Research in the IEPS is organized in themes spanning the entire Earth system from the atmosphere to the inner core, while emphasizing bridges among sub-disciplines with staff typically active across several themes: i) Polar Environmental Change; ii) Environmental Hazards; iii) Palaeoclimate, Palaeobiology, and Palaeoenvironments; iv) Dynamics and Evolution of the Crust; and v) Structure, Dynamics, and Evolution of the Earth and Planets. Our research strategy looks beyond the Institute to leverage collaborative opportunities at the Faculty, University, National, and International level.

b. Research strategy

Ranked 3rd in RAE 2008, we have generated substantial growth in research income (7% per annum), research outputs (8% pa), citations (18 % pa), and training of young scientists (20% pa) since RAE 2008. 29 papers in *Nature*, *Nature Geoscience*, *Nature Communications*, or *Science* are included in this REF submission.

Our research strategy seeks i) broad-based engagement with our understanding of all components of the Earth system, ii) depth in key areas that forge links among sub-disciplines, and iii) to strengthen external links and build new ones to disciplines that enrich our understanding of the Earth as reflected in joint appointments between UCL and Birkbeck, and joint appointments with Physics and Astronomy, Space and Climate Physics, the London Centre for Nanotechnology (LCN), and Geography, and Life Sciences. The IEPS takes full advantage of the wider strengths of the respective Universities through engagement with inter-disciplinary research centres and institutes, including the Institute for Origins via our leadership of the Centre for Planetary Science, and the UCL Grand Challenges in Global Health and Sustainable Cities.

IEPS academic staff has been rejuvenated and further strengthened since RAE 2008 by carefully planned and strategic growth with 12 new appointments with the result that we are well placed to continue building on our accomplishments beyond REF 2014. Eight of these new appointments are at the lecturer or senior lecturer level (of which 3 are ECR). Four new Professorial appointments strategically balance the young hires with their experience and leadership.

Some of the highlights in each of the research themes with references to papers included in this submission:

1. **Polar Environmental Change** includes the Centre for Polar Observation and Modelling (CPOM), and uses satellite-based observation including Cryosat-2 to monitor and understand the effects of climate change at high latitude (Giles†, Laxon†, Lishman, Sammonds, Stroeve). This group has been devastated by the untimely deaths earlier this year of two outstanding researchers (Seymour Laxon and Katharine Giles) whose careers were recently honoured at a session of the Living Planet Conference in Edinburgh (http://www.livingplanet2013.org/programme.asp). We include some of their important discoveries here to illustrate the central role of CPOM in IEPS strategy. To ensure strategic objectives, and as detailed in § c1, we have taken decisive re-

staffing action including hiring Prof. **Stroeve** from the US.
- **Shrinking arctic sea ice**. Analysis of satellite data produced the now iconic documentation of shrinking Arctic sea ice cover (**Stroeve** et al., *GRL*, 2012), while radar altimetry measured circumpolar thinning of Arctic sea ice (Giles et al., *GRL*, 2008), and determined the contribution to sea level rise (Shepherd et al., *GRL*, 2010).
- **Polar oceanography**. Satellite observations revealed the increase of Western Arctic Ocean freshwater storage by wind-driven spin-up of the Beaufort Gyre (Giles et al., *Nature Geo.*, 2012), and the contribution of Arctic ocean warming to reduced polar ice (Polyakov et al., *JPO*, 2010)
- **Antarctic Ice Shelf Stability**. Experimental measurements of ice rheology in UCL cold rooms and the Hamburg large-scale ice-tank facility constrained models of the stability and potential collapse of the Larsen C ice shelf (Jansen et al., *J. Glaciology*, 2010; **Lishman** et al., *JGR*, 2011; Luckman et al., *Crysophere*, 2012).

2. Environmental Hazards includes the Institute for Risk and Disaster Reduction (IRDR), the Aon Benfield UCL Hazards Centre; and the Bloomsbury Environmental Isotope Facility (BEIF), and studies the origins and effects of earthquakes, volcanoes, groundwater pollution, and tropical storms (Bristow, Hudson-Edwards, Kilburn, King, McArthur, Oelkers, Sammonds, Saunders, Vermeesch, Washbourne).
- **Arsenic in groundwater**. Field and laboratory studies demonstrated that palaeosols exert a major control on groundwater flow and Arsenic distribution (**McArthur**, *Env. Sci. Tech.*, 2011).
- **Hurricane activity**. Analysis of global climate records showed that sea surface warming is a major contributor to increases in Atlantic hurricane activity (**Saunders** et al., *Nature*, 2008), a perspective that informs forecasts of U.S. insured hurricane losses (Jagger et al. in *Climate Extremes and Society*, 2008).
- **Sand-dune motion**. Novel processing of satellite imagery and cosmogenic nuclides constrain the rate of sand-dune motion including the world's fastest barchans (**Vermeesch** et al., *GRL*, 2008), and what may be the world's oldest dunes in the Namib sand sea (**Vermeesch** et al., *Nature Geo.*, 2010).
- **Carbon Sequestration**. Discoveries have focused on mafic rocks and minerals as a sink for carbon in natural analogs of large-scale carbon sequestration (Flaathen et al., *Appl. Geochem.*, 2009), studies of the carbonation of forsterite (**King** et al., *Env. Sci. Tech.*, 2010) and in the availability of silicate minerals for sequestration (**Washbourne**, *Env. Sci. Tech.*, 2011).

3. Palaeoclimate, Palaeobiology, Paleoenvironments reconstructs the past from geochemical and fossil evidence from the Quaternary to the Archean (Bown, Bristow, McArthur, Oelkers, Papineau, Pickering, Pogge von Strandmann, Shields, Underwood, Upchurch, Wade).
- **Past Warm Climates**. A new, organic proxy (TEX86) showed that the early Cretaceous had an unexpectedly stable climate with very low latitudinal gradients (Littler et al. *Nature Geo.*, 2011). New records show a decline in atmospheric CO_2 prior to major ice growth around 34 Ma (Pearson et al., 2009 *Nature*) which occurred in a series of steps (Katz et al. *Nature Geo.* 2008).
- **Global Biogeochemical Cycles**. New modelling explores the role of the nitrogen cycle in restricting the spread of sulphide in the oceans (Boyle et al., *Nature Comm.*, 2013). Discovery of a new link between methanogenesis and nickel enzymes links mantle evolution to the redox evolution of Earth's atmosphere in the early Precambrian (Konhauser et al., *Nature*, 2009).
- **Weathering**. The first study of Mg isotope fractionation during silicate weathering shows that Mg-poor secondary clays can dominate riverine signals to the ocean (**Pogge von Strandmann** et al., *EPSL,* 2008). Direct evidence for the feedback between climate and weathering show how weathering rates are increasing due to global warming (Gislason et al., *EPSL*, 2009).

4. Dynamics and Evolution of the Crust uses field observations, laboratory experiments and numerical modelling to determine the response of the crust and lithosphere to tectonic forcing as the bridge between the inner earth and the atmosphere (Brantut, Carter, Faure-Walker, Ferreira, Lithgow-Bertelloni, Meredith, Mitchell, Sammonds, Roberts, Song, Vermeesch).
- **Seismogenic Magma.** Novel high-temperature experiments show that seismogenic fracturing can occur in both crystal-rich and crystal-free magmas at eruptive temperatures when they are subjected to the high strain rates associated with volcanic eruptions (Tuffen et al., *Nature*, 2008; Lavallee et al., *Nature*, 2008).

- **Fluids in Earthquake slip**. High frequency seismic scattering data show that slow slip events are associated with very slow seismic velocity and strong anisotropy near the plate interface (**Song** et al., *Science*, 2009), indicating clays controlling local pore-fluid pressure and frictional behaviour. High velocity friction experiments show that coseismic frictional heating can induce thermal decomposition and amorphisation of clays in fault zones (**Brantut** et al., *JGR*, 2008).
- **Time-dependent crustal failure.** Long-term experiments have shown that all major crustal rock types are able to deform and fail at a constant applied stress that is well below their apparent strength by time-dependent, chemically-activated subcritical crack growth; i.e. *brittle creep* (Heap et al., *JGR*, 2009; Heap et al., *EPSL*, 2011; **Brantut** et al., *JGR*, 2012).

5. Structure, Dynamics, and Evolution of the Earth and Planets includes the Centre for Planetary Science and covers the Earth's mantle and core, the surfaces and interiors of solar and extra-solar planets and moons, the origins of meteorites and astrobiology (Alfè, Brodholt, Crawford, Dobson, Downes, Ferreira, Fortes, Jones, Grindrod, Hunt, Lithgow-Bertelloni, Price, Roberts, Song, Stixrude, Vočadlo, Wood).
- **Evolution of the Core**. Ab initio calculations provided the first robust constraints on the thermal evolution of the core, changing our views of magnetic field generation (**Alfè** et al., *Nature*, 2012). Predictions of the elasticity of iron at extreme conditions are changing our views of the dynamics by providing unique constraints on the origin of inner core structure (Martorell et al., *Science*, 2013).
- **Earth's mantle**. Ab initio calculations showed that the lowermost mantle is weak, impacting our views of mantle convection (Ammann et al., *Nature*, 2010). A new thermodynamic model points to pervasive chemical heterogeneity in the mantle (Xu et al., *EPSL*, 2008). Ab initio calculations showed that melt may be trapped at 400 km depth in the Earth (Mookherjee et al., *Nature*, 2008).
- **Icy Moons**. Experimental and theoretical calculations showed the long-term stability of oceans inside icy moons including Titan (**Grindrod** et al., *Icarus*, 2008) prompting the design of an in situ sub-surface penetrator of Europa (Gowen et al., *Adv. Space Res.*, 2011).
- **Origins of Topography**. Dynamical simulations showed that topography in the Argentine Pampas is controlled by flow in the underlying mantle (Dávila et al., *EPSL*, 2008). Records of erosion help to constrain the tectonic stresses responsible for building the Himalaya (Najman et al., *EPSL*, 2008). Thermochronology shows the importance of flat subduction in generating the Andean foreland of central Argentina (Dávila and **Carter**, *Geology*, 2013).

b4. Future Research Strategy

Following RAE2008, we instigated an international review of our plans by an external committee consisting of 4 FRS and one member of the US National Academy of Sciences. Despite a good RAE2008 outcome, they criticized our Research Strategy as not being as visionary or as coherent as it might be. We have taken these comments to heart and have reformulated our strategy. The outcome is a future research strategy that will carry us forward into the next REF period and beyond, while already showing benefits within the current REF review period. We have addressed the concerns raised in RAE 2008 and by the external review. We have produced a new research vision for the Institute, identified key drivers of research excellence, and developed a plan to ensure continued and sustainable progress over the long term.

Our research vision seeks:
- **Breadth**: The evolution of our environment on geologic and human timescales arises from interactions among the solid-Earth, the hydrosphere, cryosphere, and atmosphere, which modify and are modified by the biosphere. The centre of gravity of the IEPS will remain over the foreseeable future within the solid Earth, as the vast majority of the planet's mass and the unique record of its history. At the same time, engagement with all components of the Earth system, and with other planets is essential for addressing the challenges of understanding Earth's origins and habitability, a commitment underlined by re-staffing strategy for CPOM including new hire **Stroeve**.
- **Bridges**: Leveraging breadth by recognizing the importance of building programs in areas that naturally forge links among existing strengths via engagement with several sub-disciplines. We identified three research areas in which future growth would lead to the greatest additional benefit: Seismology (new hires: **Song**, **Ferreira**), which links existing strengths in studies of Earth's interior,

crustal dynamics, and natural hazards; environmental isotope geochemistry (**Oelkers**, **Pogge von Strandmann**), linking studies of palaeoenvironments, modern environmental change, and environmental hazard; Polar observation and modelling (**Stroeve**), linking studies of rock and ice physics, meteorology, palaeoenvironments, and other planets via leadership in space missions.
- **Benefit**: Renewing our commitment to, and building in research areas that address directly key societal needs in the areas of resources, especially groundwater, environmental hazards, including earthquakes, volcanoes, and pollution, and environmental change, especially at the poles. Our Breadth and Benefit agendas mesh well with NERC strategic themes in Adapting to Environmental Change, Resilience to Environmental Hazards, and Securing Natural Resources, all areas in which the IEPS has growing strength.

A key driver of our research strategy is the ongoing transformation of the field of Earth sciences by discoveries made possible by the impact of technology including:
- The ever-increasing capability of high performance computing to simulate the complex interactions that result in the Earth, at the atomic and continuum scales, with wide application to understanding thermodynamic and dynamic processes in and on the Earth and planets. This has been a major strength of the Institute with its position being reinforced by promotion to Professor (**Dobson**) and new hires in mineral physics (**Cohen**, **Fortes**, **Hunt**), new hires in seismology (**Ferreira, Song**), and promotion to Professor in mantle geodynamics (**Lithgow-Bertelloni**).
- The impact of space missions in observing the Earth and other planets. The Institute has ensured its position in this area with new hires active in the use of space mission data and the design of new missions (**Papineau**, **Grindrod**, **Fortes**), and by our re-staffing strategy for CPOM including new hire **Stroeve**.
- The impact of powerful particle sources including synchrotrons on laboratory-based investigations of Earth processes. The Institute is the second-largest UCL user of the ISIS neutron facility, and is in an excellent position to maintain leadership at ISIS as well as in the development of new capabilities at Diamond with new hires (**Fortes**, **Hunt**) and promotion (**Dobson**) of major users of these facilities.
- The discoveries made possible by increasingly powerful means of characterizing natural samples, including advances in mass spectrometry and nano-scale imaging. New hires place the Institute at the forefront of these areas including nano-characterization of the earliest fossil evidence for life (**Papineau**), and the use of non-traditional stable isotopes to characterize palaeoenvironmental change (**Oelkers**, **Pogge von Strandmann**).

Our research strategy identified key areas in which to build sustainability, including:
- Increase the diversity of funding sources. It is essential that the IEPS looks increasingly to other funding sources including the European Research Council, STFC, and EPSRC, while recognizing that NERC is likely to continue as the primary source of research council funding, as well as industry and charities. Three new hires will look primarily to STFC for funding (**Fortes**, **Grindrod**, **Papineau**). Our EPSRC funding has increased over the census period. The Institute won two ERC advanced grants and one starter grant (**Stixrude**, **Cohen**, **Vermeesch**), and has helped to develop new submissions that have benefited from panel feedback after passing the first hurdle in previous rounds (**Alfè**, **Oelkers**). EU funding more than tripled over the review period. The newly formed IRDR have already won significant funds from industry, charities, NERC and other RCUK.
- Strengthen external links and build new ones to disciplines and initiatives that enrich our understanding of the Earth. New joint appointments with the LCN (**Papineau**, **Cohen**) reinforce our position at the cutting edge of geomaterials science, while new joint appointments between the UCL and Birkbeck components of IEPS strengthen the areas of low-temperature geochemistry (**Pogge von Strandmann**) and planetary science (**Fortes**). These new hires augment existing joint appointments with Physics and Astronomy (**Alfè**), Space and Climate Physics (**Saunders**), Geography (**Shevenell**), and Genetics, Evolution, and Environment (**Goswami**, UoA 5), and strengthen interactions with a variety of initiatives including the UCL Global Challenges via IRDR.

c. People

c1. Staffing strategy and staff development

In order to begin implementing our future research strategy, we decided it was essential to

increase the number of IEPS staff. We have accordingly embarked on a carefully planned and strategic hiring campaign, resulting in 12 new permanent academic staff. Our campaign was fully supported by Departmental, Faculty, and Institutional investment to provide incentives and support for attracting, and retaining world-class intellectual leaders, including competitive salaries, benefits, start-up packges, infrastructure, students, and support staff.

The expansion of the Institute is fully aligned with UCL and Birkbeck estates strategy (cf. § d3 below). We searched broadly, hiring individuals of demonstrated academic excellence with an appetite for cross-disciplinary research of significant impact, and which fit with the aims of our strategic plan while maintaining existing strengths. Our commitment to excellence demanded an international outlook: 2/3 of our new hires are non-UK nationals. We have:
- Maintained breadth by re-staffing in Polar Environmental Change in the face of recent losses to another university (Feltham), NERC leadership (Wingham), and tragic and untimely death (Giles, Laxon). We have taken decisive action by: 1) hiring Prof. Shepherd (University of Leeds) at 20 % to help oversee the technical data processing operation that is the core activity of CPOM; 2) hiring Prof. **Stroeve**, initially at 25 %, and from 2015 taking full responsibility at 100 % FTE for heading CPOM as Prof. Shepherd's commitment winds down, and 3) committing to at least two future hires in this area with full support from the Faculty at the levels of Research Fellow and Lecturer.
- Established strength in other bridging disciplines via new hires in seismology (**Song**, **Ferreira**), and environmental isotope geochemistry (**Oelkers**, **Pogge von Strandmann**).
- Strengthened connections across the Institute and to other departments with joint appointments with the LCN (**Papineau**, **Cohen**), and between the UCL and Birkbeck components of IEPS (**Fortes**, **Pogge von Strandmann**).
- Maintained strength in existing areas of excellence including palaeoclimatology (**Wade**), and rock physics (**Brantut**, **Mitchell**), with the hire of Mitchell in particular strengthening the link between experimental rock physics and field-scale structural geology.

Our hiring program has placed the IEPS in a strong position for the long-term. Staff losses are more than made up for by new hires, with a net growth in REF-submitted FTE from 41 to 43. Of these 4 are fractional appointments (**Boudagher-Fadel**, **Shevenell, Smith; Stroeve** will transition to 100 % in two years), and 9 are early career researchers (**Brantut**, **Faure-Walker**, **Hunt**, **King**, **Mitchell**, **Pogge von Strandmann**, **Shamsudduha**, **Smith**, **Washbourne**). Losses have been primarily at the senior level: to retirement (4), NERC leadership (1) and untimely death (2). Retention has been excellent: we lost only one Reader to a Chair position, and one research fellow to a lectureship at other UK HE institutions.

Equal Opportunities. The Institute's commitment to equal opportunities is emphasized by completion of the Bronze level Athena Swan Charter at both departments, and by its record in hiring and promotion. Among newly hired staff, 3 out of 12 are women, bringing our total to 11 out of 43 submitted FTE, the highest fraction in the Sciences at UCL; the Institute promoted 2 women to Professor over the period and hired 2 others at Professor level, increasing the total from 1 to 5 over the census period. The appointment of a senior academic (**Stixrude**) to the role of Equal Opportunities Liaison Officer helps to ensure that the Institute is a place where staff from a wide cross section of society can thrive. UCL is a Stonewall top 100 employer. Birkbeck is a Stonewall Diversity Champion, member of the Mindful Employer's Charter, and hosted the Stonewall event "Black Pride 2011" on 20th August, 2011.

Support for Young Researchers. All new hires including ECR and more senior appointments are allocated reduced teaching and administrative loads in the first academic year in order to accelerate the establishment of research programs. ECR are normally probationary for three years and unless previously qualified, take the Certificate in Teaching and Learning, which covers doctoral supervision. In addition to the UCL mentoring system, a wide range of staff training is available at UCL and Birkbeck including training in grant writing. Research Fellows are valued: in the last census period three research fellows in IEPS applied for and won permanent academic positions in open competition (**Grindrod**, **Fortes**, **Brantut**). The Institute hosts 5 permanent researchers and currently hosts 15 PDRA. These staff, distributed across all research themes, are provided with high quality research facilities and have full access to College wide support systems

including conference funding and opportunities for further training. In 2013, UCL received the HR excellence in Research Award by the European Commission recognizing its robust and public implementation strategy for improving the career development and management of researchers.

Career Progression. Career progression and advancement are encouraged via the Appraisal system, which emphasizes pro-active engagement in line with the principles of the Concordat to Support the Career Development of Researchers. Appraisers have been formally trained and carry out appraisals once per year for probationary staff and at least every other year for more senior staff in accordance with UCL and Birkbeck policies. Our promotion procedures are transparent and designed to recognize and retain excellent staff at all levels. Nine staff were promoted to Professor over the census period (**Bown**, **Bristow**, **Carter**, **Crawford**, **Dobson**, **Lithgow-Bertelloni**, **Roberts**, **Shields**, **Vočadlo**). Our success rate with departmentally supported promotion applications at all levels is 100%.

Fellowships. 7 submitted members of IEPS staff won or held prestigious fellowships over the census period including: Leverhume Fellow (**Alfè**), NERC Research Fellow (**Hunt**), NERC Senior Reseach Fellow (**Brantut**) NERC Advanced Research Fellow (**Pogge von Strandmann, Wade**), STFC Advanced Research Fellow (**Fortes**), and STFC Aurora Research Fellow (**Grindrod**).

Visiting Scholars. The Institute benefits from a constant stream of visiting scholars from around the world: >30 over the census period including a Leverhulme Visiting Professor.

c2. Research Students

The Institute has been very successful in recruiting high quality PhD students; nearly doubling our graduation rate of 9/year in RAE2008 to 16 in 2011. The current cohort is typical in being funded from a variety of sources including: NERC (12), NERC and EPSRC CASE Industrial partnership (6), STFC (5), and 10 UCL Impact awards, as well as ERC, industry, and UCL Graduate School competition. Students are recruited in an open application process to research projects that are widely advertised.

Our recruitment strategy takes maximum advantage of the UCL “Impact Studentship” scheme in which UCL funds PhD studentships on a 50:50 basis with commercial/industrial partners. NERC and STFC quota studentships are allocated on a competitive basis, with priority given to new hires to help them to establish their research program. Birkbeck also funds Graduate Teaching Assistants who study for a PhD over 4 years whilst helping with teaching. Our PhD students have been very successful as shown by co-authorship of peer-reviewed publications, and many go on to post-doctoral study. In addition, the Institute maintains a cohort of 30 MSc students, and 10 MSci, each of whom completes a research project as part of their training.

Equal opportunities. The Institute’s approach to research student recruitment and training is equitable: all PGR students, including those studying part-time, have equal access to space, facilities and Graduate Conference Funding. PGR students can take unpaid study leave and those in receipt of any UCL administered studentship are also entitled to full maternity leave.

Training, monitoring, and support. Each PhD student is assigned two supervisors from within IEPS and may in addition have a third supervisor from outside the Institute, often from another UK or international HEI. Progress of doctoral students is carefully monitored, both via an on-line Research Student Log and annual reports. There are formal procedures for upgrading from MPhil to PhD status. Both departments, the UCL Graduate School, and a private Birkbeck benefactor fund doctoral students to undertake research trips and attend conferences outside London via open competition. Doctoral student training needs are considered at admissions and confirmed at arrival by supervisor and student. Training involves both generic skills and more specific needs based on the individual’s preparedness and project.

Skills development. The Institute provides various teaching opportunities, for which training is provided. The UCL Graduate School skills development programme, the Bloomsbury Postgraduate

Skills Network for participating institutions including UCL and Birkbeck, and the UCL Careers Group provide a wide range of modules. PGR students are fully integrated into the Institute's research environment through their participation in the weekly Institute Research Seminar series, as well as thematic research seminars in which they are required to make presentations of their own research. We consider conference presentations a vital part of PGR training: PGR students have given >100 presentations at international conferences over the review period including at the Gordon Research Conference, Lunar and Planetary Science Conference, and meetings of the Geological Society of America, Goldschmidt, and the Society of Vertebrate Paleontology.

d. Income, infrastructure and facilities

d1. Research funding

31 submitted staff have active UKRC or European Commission grants (NERC, STFC, EPSRC, Leverhume, Royal Society, ERC) with 49 active research council grants in total. In addition to standard grants and fellowships, we have been awarded large consortia and prestigious grants including core funding in support of CPOM; STFC consolidated grant (**Vočadlo**, **Wood**, **Fortes** £0.7M); **Roberts** is lead PI on a NERC collaborative grant on Earthquake hazard from ^{36}Cl exposure dating involving 4 HEI (£0.9M). Exceptionally, we have three major ERC grants to IEPS staff: ERC Advanced grants to **Stixrude** (MoltenEarth: €2.5M) and **Cohen** (TomCat: €2.7M) and an ERC starter grant to **Vermeesch** (KARSD: €0.6M). IEPS has also won research grants from UK and international industry, including ExxonMobil, DeBeers, UK Sport, and Nexen Petroleum, and from third-stream sources including CAFOD. External funds received through sources not reported in HESA returns include: time on US particle beam facilities: NSLS, APS, and ALS (**Dobson**, **Fortes**, **Wood**); and INCITE grants from the US Department of Energy for supercomputer time at a total value of £5M (HECToR-equivalent, **Alfè**).

d2. Strategies for generating grant income

Grant income is generated by staff as individual PI's or as part of larger collaborative efforts across the Colleges, the UK, and internationally. These activities are fully supported by the Institute and all staff are asked to submit at least one research proposals to UKRC per year. We maximise income by:
- Rigorous in-house review of all research proposals prior to submission. This policy, instituted under the last RAE census period helps maintain our success rate at NERC at 39% both in terms of funds requested and applications funded, among the highest in the UK, as compared with a total NERC average of <16%.
- Appointment of a senior staff member as research coordinator to assist the development of successful grant applications and to help balance income across a healthy diversity of funding sources.
- Full use of Faculty and University expertise and dedicated support in sourcing and managing external income, provided by the Faculty, UCL Office of Vice-Provost (Research), the Finance Division and the European Office for guidance on ERC grant applications.

d3. Infrastructure and facilities

The Institute will benefit from the total renovation of the Kathleen Lonsdale Building (KLB: budgeted at £28M and planned for completion in 2016). The renovation fulfills a decades-long aspiration of co-location of the UCL Department of Earth Sciences, bringing together for the first time staff and laboratory facilities that have been located in five different buildings around the central quad (KLB, Pearson, South Wing, Lewis', and Chemistry). The KLB renovation complements recent upgrades in Birkbeck space whose staff moved in 2010 from the South Wing to the main Birkbeck building on Malet St, a 5-minute walk from the KLB, giving the IEPS two sites within which to expand its joint footprint.

This dual footprint facilitates future expansion on two sites funded by the respective Universities. Among the opportunities provided by the renovation are plans to build a major new facility in isotope mass spectrometry including a multi-collector ICP-MS that will generate a substantial new

income stream in cutting-edge environmental geochemistry led by new hires **Pogge von Strandmann** and **Oelkers**. Shared laboratory facilities between UCL and Birkbeck will be housed in the renovated KLB, including the London Geochronology Centre, and the Wolfson Lab. Birkbeck space will retain two rock/sample preparation labs, and an environmental geochemistry laboratory.

The Institute provides world-class infrastructure consisting of laboratory facilities, field equipment, IT, an excellent library with extensive e-holdings, computer suites, geophysical field-equipment and rock-analysis facilities (thin-section preparation, SEM, WDX electron- probe, X-ray diffraction) supported by 6 full-time laboratory support staff, and 2 other technical staff. Laboratory facilities form the hub of many of our inter-disciplinary and inter-institutional research networks, including:

- The **Environmental Sedimentology Facility** houses an XRF core-scanner and multi-sensor core-logger which measures elemental abundance and magnetic-susceptibility/gamma-ray density in sedimentary cores for high-resolution reconstructions of climate-induced changes in sediment supply. LC/MS allows measurements of biomarker-based palaeotemperatures from marine and terrestrial organic matter.
- The **Micropalaeontology Laboratories** provide facilities for quantifying microfossil assemblages via optical and scanning-electron microscopy, and geochemical analyses, underpinning (micro-) palaeontological and palaeooceanographical research. They feature clean, controlled environments to prepare organic-walled, calcareous and siliceous microfossils, measure biogenic carbonate and perform taxon-specific geochemical analysis.
- The **Wolfson Laboratory for Environmental Geochemistry** measures the geochemical properties of the Earth's surface materials, underpinning research on biogeochemical cycling and environmental pollution. ICP-OES, ion chromatography and carbon-sulphur instruments allow analysis of major- and trace-element compositions. The Groundwater Tracing Unit provides analyses of artificial and natural tracers in water.
- The **London Geochronology Centre** uses geochronology and thermochronometry to understand continental deformation and feedbacks to the surface environment. It has an international reputation for innovative methodological advances and research that attracts a constant stream of U.K. and international visitors. Papers since 2008 involve co-authors from 22 countries and 73 institutions. Recent awards support 3 PDRA and currently 5 external PhD students are undergoing training.
- The **Mineral Physics** and **Haskel Laboratories** support measurements of the physical and chemical properties of the minerals of the interiors of Earth and icy moons at elevated pressure and temperature by x-ray powder diffraction and deformation multi-anvil press; several of these globally unique facilities were developed in house. These laboratories also support our activities at international synchrotron and neutron diffraction facilities. During the REF period the laboratories provided core support for £3.8M of RCUK/EU/Royal Society research grants. There are currently 2 RCUK fellows, 5 post-docs and 3 Ph.D students using the laboratories.
- The **Rock and Ice Physics Laboratories** support measurements of the evolution of physical and mechanical properties under cryospheric and crustal conditions. Recent developments include: a new polyaxial and tomography cell for deforming EPICA-borehole ice samples to develop anisotropic flow laws for the Antarctic ice sheet; triaxial-deformation ensemble with permeability, wave velocity, electrical and 3-D microseismicity measurements to develop a chemo-thermo-hydro-mechanical model of crustal dynamics; environmental SEM with high/low temperature and deformation stages to study the micromechanics of ice/rock deformation.
- The **Bloomsbury Environmental Isotope Facility** is a stable-isotope laboratory shared with the Departments of Geography [UCL UoA 17] and Chemistry [UCL UoA 8]. Three mass spectrometers analyse C, N, O, S & H in minerals, water and organic matter. Natural radio-nuclides are counted using three gamma- and eight alpha-spectrometers and an ultra-low- background scintillation counter, supporting a ^{210}Pb dating service for lake sediments and the study of U-series radio-nuclides in ground-waters and their host rocks.
- **Mineral Physics** and **CPOM** IEPS, with Chemistry [UCL UoA 8] and Physics [UCL UoA 9], is instrumental in driving UCL investment in supercomputing, currently supporting 2700 cores with 11 TB of shared memory of Legion. The HECToR Mineral Physics Consortium is led by **Brodholt** and uses 8% of the total time on the machine, and 40% of the NERC allocation, amounting to £4M in total over the review period.

-The **Geophysical Fluid Dynamics Laboratory** provides unique capabilities for joint hybrid digital particle imaging particle tracking and thermometry of slow flows including bespoke automated equipment for 3D stereoscopic imaging with 3-chip CCD cameras, and fiber optic lightlines with positional accuracy better than 4 μm.

e. Collaboration and contribution to the discipline and research base

e1. Collaboration

Institute staff have co-authored peer-reviewed manuscripts with scientists from >100 other national and international HEI, and 90% of submitted outputs are with external researchers. All academic staff are involved in research collaborations, projects, or networks with colleagues from other institutions in HEI, industry, commerce, and/or third sector. Exemplars include:

- Engagement and leadership in London-wide initiatives, such the Thomas Young Centre in the area of materials modelling, based on access to UCL high performance computer (Legion), supported by £1.5M/year institutional investment, and the UCL-Oxford-Southampton-Bristol Tier 2 regional HPC centres IRIDIS and Emerald supported by a £3.7M EPSRC grant. This trans-London Centre includes UCL, Kings College, Queen Mary, Royal Holloway, and Imperial.
- Leadership of the Centre for Polar Observation and Modelling (CPOM). CPOM has revolutionized our understanding of polar environmental change by providing the first measurements of shrinking Arctic ice mass and is built around the launch of the ESA mission Cryosat-2 led by UCL and the core activity of processing data from this satellite at UCL, supported by £0.5M/year in NERC national capability funding, renewed this year, and leveraged three-fold in grant income from NERC NCEO and other sources. CPOM is a multi-institutional collaboration funded by NERC between UCL, Reading, Leeds, and Bristol, and is part of the National Centre for Earth Observation.
- The AON Benfield UCL Hazards Centre (ABUHC). We work closely with end-users on geophysical and meteorological hazards with UK and US government departments, humanitarian agencies, and UK financial institutions. In 2008-14, ABUHC won £184k of NERC, EPSRC, and EU competitive funding, and £1.2M from UK, European and US public-sector bodies, charities, and industry. It also earned £39k for bespoke short-courses on natural hazards to the insurance industry and £7k for consultancy to humanitarian agencies.
- Engagement with UCL initiatives including the Institute for Origins (fellows and PhDs funded by the Faculty for collaboration between ES, P&A and Mathematics), particularly in the area of Earth's interior and planetary science via the UCL-Birkbeck Centre for Planetary Science (together with UCL Physics and Astronomy).
- Engagement with UCL Grand Challenges, as exemplified by the IRDR under the directorship of **Sammonds** and championed by 16 academics from Earth Sciences, Statistical Science, Mathematics, Space & Climate Physics, Civil Engineering, Mechanical Engineering, Population Health and Laws, and invested in by UCL with 4 new staff, including a Chair in Risk and Disaster Reduction (Alexander part of Civil Engineering, UCL UoA 14). IRDR led the successful consortium bid for the NERC £2M programme on Probability, Uncertainty and Risk in the Environment, and co-leads the €4.75M Cascading Crises European project.
- Leadership in a number of multi-departmental laboratory facilities including the Bloomsbury Environmental Isotope Facility (BEIF), which has attracted significant infrastructure investment from UCL and Birkbeck (£0.5M). Our research on Arsenic pollution of groundwater is organized around BEIF, the Wolfson Laboratory, and the London Arsenic Group, which we formed to focus research and direct our Knowledge Exchange priorities. We work closely on arsenic with Dhaka, Lahore, BUET and Delhi Universities, IIT Kharagpur, Eawag (Switzerland) and NCKU (Taiwan), through collaborative research and Commonwealth, Tempus, and UNESCO Scholarships and Fellowships. In 2008-13, we won £860k of NERC and EU competitive funding, and £854k from UK, European and US public-sector bodies, charities, and industry.
- As a unique facility in the UK, the London Geochronology Centre hosts PhD students from other institutions for training and data analysis: 10 over the census period from Oxford (2), Cambridge (1), Leicester (1), Imperial (2), Milan (1), ITT-Kanpur, India (1), Aberdeen (1), Nice (1). The group also participates in the ATLAB (Action towards laboratories enhancement and know-how exchange for advanced research), Research Potential Programme, European Union FP7-REGPOT-2011-1.
- **Brodholt** and **Lithgow-Bertelloni** were instrumental in formulating the first NERC call for strategic funding in the solid Earth, the £8M TAP 4 action: Volatiles, Geodynamics and Solid Earth

Controls on the Habitable Planet. **Shields** is Science Coordinator of the £4.5M NERC thematic programme: Long-term Coevolution of Life and the Planet

e2. Contributions to the Discipline

- Elected Fellowship. IEPS staff elected as fellows of learned societies include (* indicates election during the review period) Academia Europaea (**Stixrude***, **Price**), Geological Society of America (**Pickering***), American Geophysical Union (**Price**, **Stixrude**), Mineralogical Society of America (**Brodholt**, **Price**, **Stixrude, Vočadlo***), the Geochemical Society (**Hudson-Edwards**), Royal Geographical Society (**Hudson-Edwards**), Mineralogical Society of Great Britain and Ireland (**Hudson-Edwards, Price**), Linnean Society of London (**Upchurch**), Royal Astronomical Society (**Crawford**), and the American Association for the Advancement of Science (**Stixrude**).
- Awards. Awards for outstanding achievement by staff include the European Young Investigator Award (EPSRC-ESF) and Royal Society Wolfson Research Merit Award, (**Alfè**); JSPS Furusato Award (**Sammonds**, 2010); Cozzarelli Prize, US National Academy of Sciences (**Stixrude**, 2009); The Geological Society Wollaston Fund (**Wade**, 2012); Paleontological Society Charles Schuchert Award (**Wade**, 2013); Dana Medal of the Mineralogical Society of America (**Cohen**, 2009); President's Medal, The Palaeontological Association (**Upchurch**, 2008); Hallimond Lecturer award of the Mineralogical Society (**Hudson-Edwards**, 2013); Bullerwell Lecturer of the British Geophysical Association (**Dobson**, 2010), Bessell Award of the von Humboldt Foundation (**Dobson**, 2013).
- Journal Editorship. Half of IEPS staff serve on the editorial boards of 23 journals, including the sector-leading journal *Geology* (**Lithgow-Bertelloni, Roberts**), and one serves as Editor (**Stixrude**, *EPSL*). Staff have provided reviews for 144 different earth science journals.
- International Strategy Boards: European Science Foundation, MicroDICE network Steering Committee (**Sammonds**); European Space Agency Science Definition Team for the proposed Lunar Lander mission and Co-chair of the Site Selection Working Group for the NASA-coordinated International Lunar Network (**Crawford**); US-led Cooperative Institute for Deep Earth Research Steering Committee (**Stixrude**). Steering committee of SIMI6, French national research funding agency (**Ferreira**); Chair, International Subcommission on Cryogenian Stratigraphy (**Shields**); Member of the Hong Kong 2014 RAE Physical Sciences Panel (**Brodholt**). **Price** is the Earth Sciences lead for the current REF exercise. Staff have served as external examiners for >100 PhD students in 13 countries and the UK.
- Research Councils. 16 IEPS staff currently serve on peer review committees at NERC (11), STFC (2) UK Space Agency (2), and EPSRC (1), including a NERC panel chair (**Brodholt**). **Price** is a council member of STFC. 55% of IEPS Staff are or have been members of NERC and STFC peer review college and associated panels over the review period. They have refereed proposals for over 16 international research councils and charities, in addition to UK and EU bodies.
- Society Leadership. Staff serve on learned society councils including the Royal Astronomical Society and Astrobiology of Britain (**Crawford**); Mineralogical Society (**Downes**); Palaeontological Association (**Underwood, Upchurch**); Geologists' Association, (**Underwood**), British Geophysical Association (**Brodholt**); Geological Society of London (**Hudson-Edwards**); **Bown** is President of International Nanoplankton Association.
- Conference Leadership. Over the assessment period 35% of IEPS Staff have led or been on the advisory boards and organising committees of 52 international conferences and workshops including: Chair of the Gordon Research Conference on the Interior of the Earth (**Lithgow-Bertelloni**), International Conference on High Energy Density Physics, Beijing, 2012 (**Alfè**), ECORD/ICDP MagellanPlus International Workshop, 2013, UCL (**Bown**), Joint UK-Japan Symposium on Disaster Resilience, 2013, UCL (**Meredith**), 12th International Conference on Thermochronology, Glasgow, 2010 (**Carter**); Frontiers in Environmental Geoscience, Wales, 2011 (**Hudson-Edwards**). 85% of staff have convened conference sessions at major international meetings including AGU, EGU, GSA.
- Invited Presentations. IEPS staff have given 193 invited plenary/keynote lectures in 38 countries including Goldschmidt (**Brodholt, Price, Stixrude**, 2009 Davos; **Dobson**, **Downes**, 2011 Prague), Gordon Research Conferences, (**Stixrude**, 2009; **Meredith**, 2010; **Lithgow-Bertelloni**, 2011; **Alfè**, 2012) and the European Science Foundation, Austria (**Ferreria**, 2011; **Meredith**, 2011).