Institution: Durham University

Unit of Assessment: Earth Systems and Environmental Sciences (UoA 7)

a. Overview

Durham University's collegiate system accommodates 15000 students (3500 of whom are postgraduates), with 1900 international students from over 120 countries. Earth Systems and Environmental Sciences research is carried out by Durham Earth Sciences (DES). It is one of 7 departments within the Faculty of Sciences and is a thriving centre of both research and education. Located in a purpose-built building opened in 2004, DES has an international cohort of 34 research-active academics, 25 postdoctoral researchers (PD), 59 postgraduates (PG; all PhD) and 14 admin/ support staff. Since RAE 2008, research grant awards have risen ~168%. This growth in funding has led to a >50% increase in PD and PG researchers and an upgrading of existing infrastructure and investment in new research facilities (£6.3M). DES is committed to research-led teaching and has improved its national ranking from 14th (2008) to 4th (2013) in the Times Good University Guide. DES has climbed in the QS World University Subject Rankings from 32nd in 2011 to 23rd in 2013 (7th to 5th in the UK). DES is 18th in the world for citations per paper, the highest Departmental score outside of the USA. Our world ranking based on h index is 16th (3rd in the UK).

b. Research strategy

i) Strategy: Current strategic aims follow from those described in RAE 2008 and are in line with the Durham University Research Strategy for 2010-20 (www.dur.ac.uk/about/strategy2020 /summary). The size of DES is such that we choose to specialise in areas where we can lead internationally (Fig. 1; Table 1). Our strategy and approach to recruitment (see Section c) have been designed to achieve this aim. In our RAE 2008 report, we recognised the need to extend our research income streams beyond our historic heavy reliance on UK research councils. We therefore continue to aspire to obtain funding from a diverse range of sources in order to deliver high-impact research and make key contributions to the discipline (see Sections 5d, e and REF1, 3). Since RAE 2008, DES research awards have risen ~168%, including ~£10.6M from RCUK, DECC and ERC (a rise of 147%; see Section d). We have developed a range of forums, processes and strategies designed to engage industry and other external stakeholders (see REF 3a). This has enhanced our impact delivery and has led to substantial inward investments in Durham research activities, people and facilities (~£8.1M, +335% since RAE 2008). Our user-inspired research approach is founded on the principal that the parallel execution of blue skies and applied research are mutually beneficial. Our growth in funding has led to increased numbers of PD (25/fte) and PG (59/fte) researchers (50% and 67% higher compared to RAE 2008, respectively) and we have invested £6.3M in the improvement of our existing research equipment and facilities (Section 5d). 36% of our research outputs have been published in some of the highest impact journals (Nature, Nature Geoscience, Science, PNAS, Geology and EPSL; REF 1).

ii) Research Structure: In 2010 we reorganized our activities into 4 interdisciplinary *Research Themes* (Table 1) with scientific expertise drawn from 9 discipline-based *Research Groups* and underpinned by Department- and University-based equipment *Facilities* (see Figs 1a, b; Table 2). Theme Leaders automatically belong to the Research Committee (RC) which organises and co-ordinates all Departmental research activities. The research scope and activities conducted under each Theme (summarised in Table 1) align with the activities of the University's Research Centres and Institutes (Fig. 1c), and also with priority areas of RCUK funding such as resources, hazards and climate change. We favour this thematic approach as it encourages interdisciplinary collaboration and >50% of our current academic staff conduct research under more than one Theme. All research activities are founded on regional, national and international cooperation and partnerships (Fig. 1d, REF 1, Section 5e). Other departments, and the University Institutes and Centres also link naturally to external end-users, and in some areas, e.g., Chemistry, CeREES Centre for Geoenergy, the research is substantially funded by industry and other external stakeholders. Translational research activities include research collaborations, consortia and consultancy-based partnerships with spin-out companies (Fig. 1d; see REF 3a).

iii) Strategic infrastructure: Opened in 2004 the DES building was designed to maximise research effectiveness and delivery. Academic staff, PD and PG researchers are located on Floor 3. Staff are assigned individual, glass-fronted offices which open onto 2 large open plan areas housing our PG students, whilst PD researchers are located in 3 spacious multi-occupancy offices. The co-location of staff, PD and PG researchers, ranging from professors to 1st year PG students, allows the natural development of a collegial and mutually-supportive research environment.

Figure 1: The Research Structure of Durham Earth Sciences (DES)

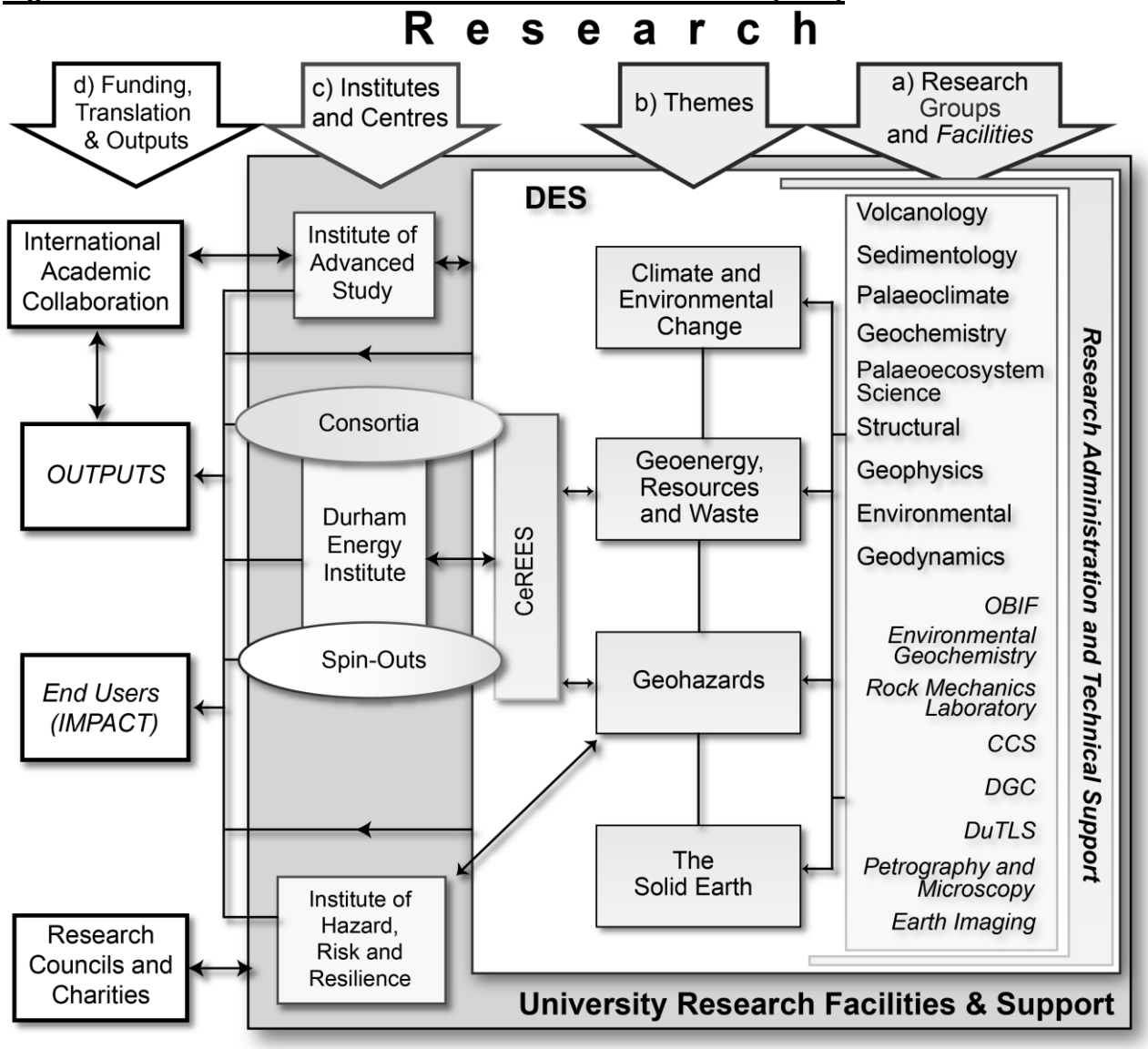

Table 1: DES Research Themes (with staff, PD numbers, REF outputs & goals)

Research Themes	Scientific (strategic) Goals
The Solid Earth *Allen, Burton, Davidson, Foulger, Goulty, Hobbs, Llewellin, Mathias, Macpherson, Niu, Nowell, Peirce, van Hunen, Selby, Williams* ***12**PDs; 47 outputs*	Investigating the nature and evolution of all aspects of the solid Earth, from crust to core, from µm to km length-scales, and from second to billion-year timescales. Processes that shape our planet - such as core formation, the initiation of plate tectonics, subduction, the formation and deformation of continental and oceanic crust - are addressed by researchers from a wide range of disciplines using an array of techniques and methods, such as fieldwork, numerical models, laboratory-based rock mechanics, isotope and geochemical analysis and seismology.
Climate and Environmental Change *Allen, Armstrong, Baldini, Burton, Foulger, Gluyas, Grocke, Harper, Jones, Macpherson, Selby, Williams, Worrall* ***4**PDs; 40 outputs*	Researches almost all of geologic time, from reconstructing the timing and severity of billion-year old 'Snowball Earth' episodes to estimating how land management may affect terrestrial carbon reservoirs in the future. Specific areas of interest include reconstruction of atmospheric systems, major biotic diversifications and extinctions in deep time, exploring the effects of climate on the ancient oceans, and investigating the link between climate and tectonics. Research aims to help predict future shifts in climate by better understanding how the Earth's climate and environment have altered in the past and helped

	drive biotic change.
Geoenergy, Resources and Waste *Aplin, Allen, Armstrong, Baldini, Burton, Foulger, Gluyas, Goulty, Greenwell, Grocke, Harper, Hobbs, Holdsworth, Imber, Jones, Macpherson, McCaffrey, Mathias, Selby, Worrall,* ***5****PDs; 25 outputs.* *Aligned with CeREES/DEI.*	From fossil fuels, the mainstay of our energy systems, through to new developments in unconventional oil and gas, as well as the capture and storage of the CO_2 produced (CCS), we tackle some of mankind's most pressing societal and technical challenges. Renewable energy is represented by bioenergy and geothermal working groups, with further expertise in the extraction of both conventional mineral resources and recovery of valuable metals from, and the reuse of, waste materials. The translation of research to end-users and generation of impacts is a key driver in this Theme, with strong international participation from industry through the CeREES Centre for Geoenergy and the DEI.
Geohazards *Brown, Davidson, Davies, De Paola, Foulger, Gluyas, Holdsworth, Horwell, Humphreys, Imber, Llewellin, Mathias, McCaffrey, McElwaine, Nielsen* ***4****PDs; 23 outputs.* *Aligned with IHRR.*	Motivated by hazards arising from geological phenomena, such as volcanoes and active fault zones, we apply our multidisciplinary approaches to answer fundamental questions regarding the nature of geohazards, their causative geological processes and the risks that they pose to society. Research topics include physical-chemical controls on volcanic eruptions, fault zone weakening mechanisms, modeling gravity-driven flows and health hazards of natural and industrial mineral dusts. The theme links naturally to the cross-Faculty Institute of Hazard, Risk and Resilience (IHRR) in Durham.

Research support and administrative staff are housed on Floor 2, which includes 4 large teaching and seminar spaces, whilst technical staff occupy Floor 1 where the research facilities are located in purpose-built laboratories (occupying ~1000m^2; Section 5d).

iv) Process and Planning: Our research plans are defined and managed by the RC, chaired by the Director of Research (DoR) and reporting to the main body of academic staff, the *Board of Studies* (BoS). The plans are annually updated and incorporated into a rolling 5 year Departmental Plan produced by the *Management Advisory Group* (MAG), including the HoD and DoR. Specific issues addressed in this Plan are: Research Performance (Financial, Infrastructure, Impact, Partnership Sustainability); Research Student Recruitment; Student Experience; International Profile; Staff Support; Outreach; and Future of Earth Sciences. The overarching nature of the Plan ensures that UG, PG and PD teaching/training are integrated with, and led by research activities.

The *DES Advisory Board* (DESAB) meets bi-annually, extending our ability to consult with external stakeholders. Members are leaders from industry, business and other institutions who act as independent advisors on research strategy, planning and training (see REF3a). The strategy and performance of Department-affiliated Research Institutes and Centres (Fig. 1c) are monitored by the *Faculty* and *University Research Committees*, on which the DES has representation (DoR). In 2009, the University established a *NERC Liaison Group* (Chaired by **Holdsworth** since 2012) comprising selected senior academic staff from NERC-facing departments in Durham (Earth Sciences, Geography, Biological Sciences, Archaeology). It is specifically responsible for strategic interactions with NERC staff and research funding programmes and, with the help of the Research Office (RO), for the peer review of draft research grant proposals to NERC (Section 5c).

v) Future strategies: We plan to continue to diversify our research and income sources, attracting UG, PG (22 incoming Oct 2013), PD and leading academic researchers from around the world (Section 5bi). We will build on our established areas of expertise that underpin the Research Themes and Groups through industry partnerships, doctoral training and internationalisation. For example, the recently approved NERC-funded IAPETUS Doctoral Training Partnership (DTP) is led by DES in collaboration with the Departments of Anthropology, Archaeology, Biological and Biomedical Sciences, Geography and Mathematical Sciences, in partnership with equivalent departments at the Universities of Glasgow, Newcastle, St Andrews, Stirling, the BGS and CEH. The DTP builds on NERC-recognized, collaborative research strengths in the areas of: (1) Global Environmental Change; (2) Geodynamics & Earth Resources; (3) Carbon & Nutrient Cycling; (4) Hazard, Risk & Resilience; and (5) Biological Resources & Ecosystems. A proposal for a further Oil and Gas CDT has been submitted to NERC by DES in partnership with university Earth Sciences departments at Heriot-Watt, Imperial College, Manchester, Oxford, Newcastle and Aberdeen. The activities of both the DTP and CDT map directly onto DES Research Themes. Our involvement in

University Research Institutes and Centres will be strengthened to further enable cross-disciplinary partnerships that open up new funding opportunities (Section 5d). For example, with the help of the DEI and CeREES Centre for Geoenergy, we are working with BP on the development of a BP Research Hub, in which Durham will network with the UK's leading universities and those in North America to bring the leading geoscientists together. The Hub builds upon 10 previous research projects and consortia funded in DES by BP in this REF 2014 period. External developments, such as the 2013 publication of the new NERC Research Strategy, will inevitably influence the future development of our Research Themes as we move towards REF 2020. Our user-inspired research and impacts (see REF 3a, Section c) will also continue to shape the thematic and disciplinary structure of DES and will certainly influence the content and development of our research-led training of UG and PG students. Utilising DESAB and CeREES-hosted consortia, we will continue to seek inward investment from industry through the active involvement of external stakeholders in research projects. An internal infrastructure (£1.1M) bid has been awarded by the University to refurbish geochemistry laboratories in order to support research activities in DES.

With its strong track record of research and extensive equipment base (e.g. *Durham Geochemistry Centre,* DGC; *Ocean-Bottom Instrumentation Facility,* OBIF) the **Solid Earth** theme will primarily use research council funding (e.g. NERC, ERC) to build durable University, national and international scientific partnerships. A recent (2013) successful illustration of this approach has been the DES-led, NERC-funded VoiLA £3.7M multidisciplinary study of volatile cycling through the Lesser Antilles subduction system with 6 UK universities, the University of West Indies and collaboration with the NERC-funded STREVA (volcanic hazards) and the US GeoPRISMS programmes. Here, and in future proposals, we will centre on the role of deep Earth processes in controlling the dynamics and evolution of our planet through integrated geological, geochemical, geophysical and numerical modelling studies.

The **Climate and Environmental Change** theme will continue to focus on describing how natural and anthropogenic processes have influenced climate in the past and how this may be used to better predict future shifts. The theme research emphasizes high-resolution techniques, and plans to exploit the broad expertise and instrument base in DES to develop innovative new climate proxies that will yield higher resolution records of global significance. **Harper** has helped to establish the new Climate Impact Research Centre (CIRC, www.dur.ac.uk/circ/) strengthening the theme focus on climatic impacts and ecosystem change in deep time.

In partnership with key industry and other stakeholders, the **Geoenergy, Resources and Wastes** theme will further develop research areas central to UK and global energy policy, e.g., CCS; unconventional hydrocarbons (including shale gas) and reservoirs (e.g. fractured basement; complex reservoirs); and the mechanisms of metal enrichment in biomass as tools for hydrocarbon fingerprinting, migration and generation. This will be aided by the appointment of **Aplin** and the development of new and existing research consortia, e.g. Geosciences Project on Over Pressure (GeoPOP3), Shale Research Europe (ShaRE), Researching Fracking in Northern Europe (ReFiNE), CCS Monitoring using Muon Tomography and the development of the BP Hub.

The recent appointments of **McElwaine** as Chair in Advanced Computational Modelling of Geohazards and **Nielsen** in the area of theoretical and experimental rock mechanics significantly strengthen the **Geohazards** theme. Working with the Institute of Hazard, Risk and Resilience (IHRR; where **Horwell** is Co-Director), cross-Faculty international collaborative projects are planned in partnership with the Geohazards Research Theme in the Geography Department into both the processes and impacts of volcanic eruptions, landslides and earthquakes.

c. People, including:

i) Staffing strategy and staff development: DES is committed to recruiting, selecting and retaining researchers with the highest potential to achieve excellence in research. We advertise posts across broad themes aiming to attract world-class researchers related to our existing or emerging strengths, with less emphasis on filling disciplinary vacancies. DES comprises 18% international academic staff. Our female researchers (5 staff, 12 PD) in particular receive maximum recognition for their research activities supported by the University's approach to the Athena Swan charter (Department applying for Silver status). The University actively supports DES, encouraging us to seek funding for posts using either external sources, e.g. **Gluyas** (Ikon-DONG), **Selby** (TOTAL), or a business-case approach where there is a good fit to our research strategy, e.g. **Brown** (Volcanic Margins Research Consortium; VMRC). All DES staff are expected to develop high quality research portfolios that are self-sustaining in terms of funding, are cross-disciplinary

and international in scope. This mandate is supported by both the Department and University using the following strategies and resources:
- *Peer-review of draft research proposals* both informally by DES staff and external colleagues. Since 2011, all NERC grant proposals are peer reviewed by other Durham academics to improve and strengthen applications. In DES this has led to a rise in NERC success rate from 12 to 25%.
- *A workload model* that is maintained and updated annually to monitor and optimize management of staff research, teaching and administration activities.
- *Research seedcorn schemes* made available by the DES, University, IHRR and DEI (individual grants of up to £30K). These support initial investigations, feasibility studies, network discussions, Durham-hosted conferences and other preparative activities that enhance the quality of grant applications, e.g. this scheme led to successful funding collaborations (Leverhulme, £240K; EPSRC, £1.6M) between the DES (**Greenwell**), Chemistry and Oxford University.
- *A Departmental sabbatical-leave policy* prioritised according to: i) the need to nurture and encourage early career researchers; ii) fit to DES research strategy; iii) opportunity (i.e. specific projects and exchanges); iv) re-establishment of research streams after a major administrative burden; and v) enhancement of career progression. On average we aim to exceed the University provision of one term in seven for sabbaticals.

ii) Career development of researchers: All DES research active staff complete an Annual Staff Review (ASR) and Personal Research Plan (PRP). They meet with a senior academic to discuss their past year's research progress, to agree a new set of targets for the coming year and to discuss long term goals. Thus, support and feedback are provided to staff as they develop a research profile, encouraging them to pro-actively engage in their own career development. Informed by the ASR process, the MAG take a proactive role in advising promotion strategies, and in ensuring that all staff are afforded adequate time to focus on research and develop new projects, funding streams and analytical facilities. 'Start-up' funds (typically between £10-50K) are available for newly appointed academics to fund pilot research projects and collaborations. For early-career staff, we also provide targeted mentoring and reduced teaching loads (30%, 50% and 80% in Years 1, 2 and 3, respectively). The effectiveness of this approach is confirmed by successes for early-career staff in several major competitive research grant rounds (e.g. 3 ERC and 2 NERC awards, ~£5M; Section 5d).

iii) Postdoctoral (PD) researchers: Our 50% increase in PD numbers reflects our improving research quality, facilities and funding, with our current cohort drawn from 10 countries. PDs share offices, typically with others from the same research group. They are trained in research methods and mentored for career development by supervisors and facility managers. Our research environment with its seminars, workshops, group coffee mornings and research reactors encourages extensive peer training and interaction with those from other disciplines. All are involved in the Departmental Research Seminar presentations and all are required to regularly present their research at international conferences.

iv) Research students: Our cohort of 59 PG students represents a 67% increase since 2008. More than 30% are fully or partly sponsored by industrial organizations (including NERC Research and Open CASE awards). This equates to total funding of £**2.8**M for the period 2008-13. Other key funding sources include RCUK (~20%), international research organizations and governments (~20%), with the remainder coming via University sources and UK-based charitable organizations.
PGs are selected on the basis of quality and potential, following screening of projects by the DoR and PG Admissions Tutor for scientific quality, availability of resources and strategic fit to our research strengths. PGs have a supervisory team of at least 2 Durham-based academic staff with relevant research expertise. Progress is monitored formally by an annual report to the Faculty, and a progression report and viva conducted by a Departmental Progression Committee. All PGs are enrolled on the University Doctoral Training Programme for transferable and generic skills, with project-specific skills being provided by individual Research Groups and supervisory teams. Students studying energy-related topics are invited to join the CeREES Geoenergy Scholarship Programme, which includes a small taught component delivered by industry experts and academic staff, designed for developing future careers in the geoenergy sector. Since 2008, 77% of CeREES students have obtained jobs in the petroleum industry, with the remainder continuing in academia. Appropriate PGs also have the opportunity to apply to join the Durham Energy Institute's EPSRC-funded Centre for Doctoral Training (CDT) in Energy, which runs a multi-disciplinary programme of energy-themed workshops, group projects, site visits and seminars. CDT students receive an

additional 6 months funding to enable them to participate in the CDT programme. Durham PGs have co-authored 30% of our REF 2014 outputs, with a PG being the lead author on 59% of these papers. Since 2008, our PGs have received 56 national- or international-level awards including: AGU and VMSG best paper; 3 Tectonic Studies Group Ramsay Medals for Best Publication Related to PhD research (2009, 11, 12). A PhD student who graduated in 2008 (Smith) won the EGU Outstanding Young Scientist Award from the Tectonics and Structural Geology Division in 2013. Since 2008, our PGs studying non-energy related topics have entered employment through further research, become teachers, entered government and / or the mineral or petroleum industry.

d. Income, infrastructure and facilities

i) Income: Utilising our staff development strategy (see Section 5c) DES, Faculty and RO enable our staff to develop high quality research portfolios that are self-sustaining in terms of funding. We have placed an increased focus on building relationships with strategic industry partners and other stakeholders in addition to national and EU funding streams. REF 4 presents our research income (~£15.4M, +171% since RAE 2008) within the REF period. During the same period our total award values (~£20.1M +168% since RAE 2008; Fig. 2) illustrate our success in increasing both the total value and diversity of funding from both research agencies (including EU~+147%; £10.6M) and industry (~+237%; £6.3M), with ~£3M from other sources (e.g., charities) since RAE 2008.

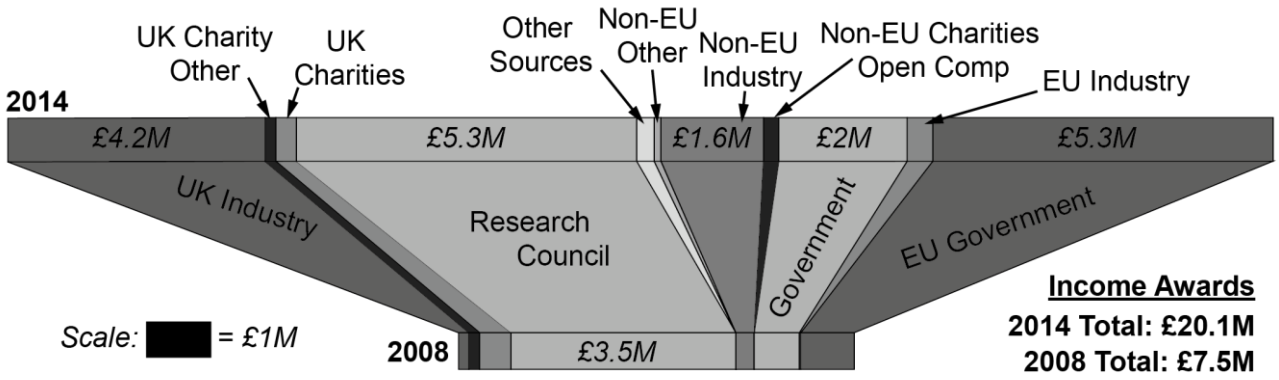

Figure 2: DES total award values and funding sources during RAE 2008 vs REF 2014.

Specific funding highlights include (see also REF4; Fig. 2):

- *Major Awards (total value given)*: 3 ERC new investigator awards (~€5M); a NERC consortium (~£6.5M), 5 NERC standard awards (~£5M); GeoPOP3, Muon Tomography, ReFINE and VRMC Industry consortia (~£3.8M); CeREES PhD and PD scholarship programme (~£3.4M).
- *External income:* OBIF has generated £6.3M through grants, contract work and service provision. More than £3.2M was secured in the form of gifts of IT software and software licences (Table 2) from industrial sponsors (e.g. Statoil, Landmark Graphics Corporation, Schlumberger). External funds were also obtained by collaborations and consultancy (£0.4M).
- *Other inward investment in DES:* 3 industrial (Total, Dong-Ikon, VMRC)-funded staff positions (value >£1M); 3 Royal Society Industrial Fellowships (with BP, Badley Geociences and Schlumberger) and a NERC KE Fellowship (combined value £3.2M).

ii) Future Income Plans: Our current research structure and strategy is designed to maximize research opportunities from a diverse range of sources. We will continue to seek external industry funding to support research positions in Durham that strengthen our ability to attract industry funding and projects, e.g. planned BP Hub. We are currently pursuing the recruitment of a senior industry figure to act as a knowledge exchange broker. We plan to expand our research consortia into other industry-critical areas complementary to our existing research strengths, e.g. fractured crystalline reservoir characterization; uncertainty and risk during exploration and production.

iii) Infrastructure and facilities: DES has been housed in purpose-built accommodation since 2004 (Section 5b). Since 2008, Durham University has invested ~£6.3M on Research Facilities (summarised in Table 2). These monies have funded major equipment (e.g. mass spectrometers), large facility upgrades and refurbishments (e.g. DGC air handling upgrade, triaxial deformation rig), IT and software facilities housed by the DES and by the Faculty. Additionally, strategic staff hires to build on our strengths in geochemistry, structural geology and geoenergy have been supported by ~£1M investment from DES in laboratory infrastructure (e.g. Palaeoclimate, Rock Mechanics and Fluid Dynamics, Carbon Capture Storage (CCS) Laboratories; Table 2). One result of this investment is that DES houses 1 of only 4 low to high velocity rotary shear apparatuses in the

world. DES research services are managed by academic staff, 2 Senior Research Officers (DGC) and 2 Experimental Engineers (OBIF). Further support for geochemistry and thin section preparation comes from 3 technicians who are funded by DES and individual research groups. Research computing facilities are supported by a Senior Experimental Officer, with an additional Experimental Office to support Petroleum-related computing needs. IT support is provided by the University CIS, with a Technical Analyst specifically assigned to and accommodated by DES. Administrative / secretarial support for research and education is provided by a team of 9 managed by an Operations Director.

iv) Future Infrastructure Plans: The DES 5 year strategy is to further strengthen our research capability. Using Department and University funds, the DGC will continue to underpin our research theme objectives (Sections 5bv; diii; v) by creating purpose-built, individual, thermal and plasma mass spectrometry labs for newly purchased equipment for novel stable isotope analysis. To support our growing **Geoenergy** theme, DES (with Chemistry) will develop a high pressure flow system laboratory (University funded, £1.1M) equipped with a range of analytical tools and reactor systems to enable new research in carbon capture and storage, coal gasification, shale gas, enhance oil recovery and hydrothermal vent chemistry. The **Climate and Environmental Change** theme will be supported by X-ray tomography instrumentation (a cross-Faculty initiative led by Engineering, EPSRC funded) that allows non-invasive imaging and reconstruction of rock textures and the internal anatomy and morphology of extinct organisms. Given our ever-increasing computing needs, the DES and University will continue to invest in the Durham High Performance Computing Facility Hamilton used by a third of DES staff (Table 2).

Table 2: Department Research Equipment

Facility (area m^2)	***Equipment***
Durham Geochemistry Centre (DGC) [300m^2]	*ICP-AES, 4 ICP-MS, 2 MC-ICP-MS, 2 TIMS, 2 laser ablation systems, 2 gas source stable isotope-MS, laser water isotope analyser, combustion elemental analyser, pyrolysis elemental analyser, 2 Anton Paar HP ashers, Microdrill. DGC includes sample preparation laboratories. Class 10,000*
Palaeoclimate [29m^2]	*Linked to DGC and microscopy facilities. Includes high-precision microdrill, 4 custom-built cave air carbon dioxide meters, 12 T˚C loggers, 4 high-precision barometric P/T loggers, 10 cave drip loggers, radon logger & 2 high-precision acoustic rain gauges.*
Environmental Geochemistry [56m^2]	*Linked to DGC including gas chromatographs (+FID&TCD detectors), ion chromatograph, thermal gravimetric analyser with differential scanning calorimeter, flux tower with infra-red + tunable diode laser detection coupled to closed chamber gas monitor.*
OBIF [68m^2]	*50 seabed instrument platforms configurable for both seismic + electro-magnetic applications + long-deployment broadband seismographs. Facility can translate, process, analysis, model & interpret a broad range of data and timescales. OBIF is a NERC Facility.*
DuTLS field equipment	*Riegl LMS 420i, Leica C10 full-colour terrestrial scanners, Trimble 5800/5700 RTK GPS, GPS, Total Station, Laser Rangefinders and ruggedized PDAs, laptop and tablet PCs.*
Sir Kingsley Dunham Computing Laboratory [50m^2]	*High speed 40Tbyte tier 0 data store with 24Tbyte tier 1 + tape library backup + 5 high specification geophysical Linux + 3 data capture & editing workstations, 160 shared workstations for data processing and modeling. Industry-supported software resources (e.g., Landmark Seismic Suite; Traptester, etc) & Open Source / generally available geophysical & Earth Science applications (e.g., Seismic Unix, GMT, GoogleEarth etc). Microscopy / image capture, A0+ colour / monochrome plotters for chart and seismic section production.*
Rock Mechanics & Fluid Dynamics [46m^2]	*A Low to High Velocity Rotary Shear (LHVRS) apparatus, a triaxial loading apparatus with permeameters, sample preparation facilities (cylindrical grinder, core drill pillar), Flow+ batch reactor that simulates ≤40 MPa & 400˚C. Instrumentation for thermo-gravimetric + calorimetry analysis.*
CCS [29m^2]	*A high mass thermogravimetric analyser with coupled GC-FID/TCD, High accuracy bomb calorimeter, Flow-through CO_2 reactor.*
Petrography &	*Hitachi TM 1000 table top SEM + Swift 1000 EDS, suite of modern Leica*

Microscopy Lab [19m^2]	*and Nikon microscopes for petrological, digital photography, mineral separation, cathodoluminescence, and fluid inclusion studies.*
Sciences Faculty Microscopy Facility	*Jointly led by DES, Chemistry and Physics. Equipment includes: field-emission SEM, a dual beam FIB-SEM, a field-emission TEM and state-of-the-art sample preparation laboratory.*
XDur	*A University centre for X-ray techniques, which include XRD (a XRD-PSD jointly owned by DES and Chemistry), trace element analysis, reflecto-metry, tomography, photoemission, small-angle scattering and EXAFS.*
Durham High-Performance Computing	*A Linux cluster using Intel processors + Lustre parallel file system. Gives access to ~2000 processors dedicated to solving numerically intensive programming problems.*

v) Consultancy and Professional Services: Since 2008, staff have had individual consultancy contracts (worth ~£0.4M) with over 50 international and national industrial and other end-user organisations including: ConocoPhillips, BP, Chevron, USGS, BHP Billiton Petroleum, Office of Nuclear Regulation, Neftex, Bureau of Economic Geology, National Grid Carbon, Rio Tinto. Three Durham-based spin-out companies have developed through commercialization of research: **Geoenergy Durham Ltd** (2009), ***Geospatial Research Ltd*** (2004) and ***Ikon Geopressure (formerly Geopressure Technology Ltd)*** *(1997)*. *Geoenergy Durham* provides specialist consultancy services in geoenergy to the energy industry and other end users (e.g. Crown Estates and World Bank). *Geospatial Research Ltd* carries out detailed outcrop survey and regional data integration for the hydrocarbon and mineral extraction industries. *Ikon Geopressure* is a consultancy business offering training and bespoke software to the oil/gas industry. Partnerships with our spin-outs are regularly used to engage more effectively with external public/private sector organisations giving access to datasets and funding leading to research outputs and impact (see REF 3a). Spin-out staff are involved in the joint leadership of some research projects (e.g. GeoPOP 3) and supervision of PG and PD researchers.

e. Collaboration and contribution to the discipline or research base

i) Collaborations: Collaborative research is central to the DES research strategy (Section 5b):

- *Strategic Partnerships:* Partnerships with geoenergy companies enable us to develop and fund the CeREES Geoenergy Scholarship programme, our research consortia and individual research projects. We have seconded 4 academics to industry through the Royal Society Industry Fellowship scheme. Our ability to translate research findings has been improved by a 3 year NERC KE Fellowship (**Holdsworth**), hosted jointly by the IHRR (**Horwell,** Co-Director) and DEI (**Davies,** Director 2009-2012; REF 3a). 33 collaborative research projects have funded 44 PG and 13 PD, with a range of geoenergy and mining companies. Industry-related funding is also supported by the Durham University Doctoral Training and NERC CASE schemes. All these collaborative projects have led to 69 joint publications. Other highlights include: BG Brasil Research hub (£3.9M) uniting Brazilian Universities, Heriot Watt and DES to research petroleum geoscience and support BG's petroleum exploration and production aspirations in Brazil; BP-NERC CASE funded research that established the timing of oil generation and oil fingerprinting for the first time; a project funded by the Department of Energy and Climate Change working with Premier Oil that developed a passive continuous monitoring method for carbon stores using muon tomography.
- *Interdisciplinary:* Our strong collaborations across the Science Faculty are enabled by networking through research Institutes and Centres (Fig. 1c; e.g., DEI, CeREES). Highlights include: EC-funded GO-project (€2.7M) to develop seismic methods for oceanography; NERC-funded OSCAR project (£3.7M) to quantify MOR heat & mass exchange, NERC-funded VoiLA consortium (£3.7M); ReFINE consortium (~£**1**M).
- *International and national collaboration:* Our staff collaborated with colleagues in 34 countries leading to 213 international peer-reviewed publications, whilst joint research with other UK universities led to a further 115 publications in international peer-reviewed journals. Highlights include: establishing the trigger mechanisms for the Lusi mud volcano; identifying the trigger mechanisms of the 2009 L'Aquila Earthquake; characterising a submarine volcano magma chamber using seismic imaging; demonstrating systematic isotopic fractionation of heavy elements (Fe) at mantle temperatures; reconstruction of climate change leading to the collapse of Maya (~800AD); the first detailed description and interpretation of the fault rocks cores from the San Andreas Fault Observatory at Depth (SAFOD; 33 citations since 2011); identifying the utility of macroalage for biofuels (186 citations since 2010); quantified the full 3D dynamical process of slab

break-off, which explains observations of the Arabia-Eurasia collision (47 citations since 2011); presentation of new evidence for the formation and evolution of the Greater Tibetan Plateau (54 citations since 2011); the development of the ability to track gas hydrates on 3D seismic data; new evidence for the early oxidation of the Earth's mantle; and detailed modelling of how CO_2 affects proxy records in cave calcites.

ii) Community Contributions:

- *Publications:* 15 DES academic staff hold or have held national and international Journal editorships or membership of editorial boards, e.g., Geology; *J.* of Structural Geology; Solid Earth; Palaeontology; *J.* of Petrology; *J.* of Geology and Exploration; Society of Economic Geologists; Petroleum Geoscience; Lethaia, Geological Journal; Palaeoworld; *J.* of the Geological Society; Geological Magazine; Tectonophysics, Petroleum Geoscience, Q *J.* of Engineering Geology and Hydrogeology; *J*. Petroleum Engineering.
- *Invited keynote/plenary lectures:* Our staff (especially more junior members of DES) are encouraged and supported (either financially when needed, or with teaching cover) to attend national and international conferences. Academics have given 56 invited keynote and plenary lectures at international conferences. Highlights include: Goldschmidt, 2008, 2009, 2012; International Geological Congress, 2008, 2012; European mantle convection workshop, 2011; GEOMED conference 2011; 80th Society of Exploration Geophysicists, 2010; Canadian Society of Exploration Geophysicists, 2010; Geological Society of America, 2008, 2011, 2013; IGCP 2012; AGU and EGU (2008-13)
- *Conference organization:* Durham staff have organized 21 international and national conferences and conference sessions, with 2 large events hosted at Durham (Tectonic Studies Group, 2011 and Volcanic and Magmatic Studies Group, 2012). International conference contributions include serving on program committees for Goldschmidt, 2008-2013, Geological Societ Janet Watson meeting, 2009; American Geophysical Union, 2009; European Geophysical Union, 2008; Cities on Volcanoes conference, 2012; and the 3rd International Palaeontological Congress, 2010.
- *Advisory Boards and liaisons:* Our staff are encouraged and supported to chair and/or be panel members of advisory boards and/or peer-review panels for both industry and academia. Since 2008, 17 academic staff have carried out such roles including: EPSRC / NERC Development Board for the creation of a UK National Centre for Carbon Capture and Storage (CCS) research on behalf of the UK government; N8 CCS Group; British Geological Survey (BGS) Advisory Board; Shadow Energy Team in policy development for the regulation of the shale-gas industry in the UK; Chair elect for the Clay Minerals Special Interest Group; Advisor to University of Kashmir and Jammu, India (2009); Office for Nuclear Regulation Seismic Risk Expert Panel; NERC Radioactivity and the Environment (RATE) programme (member and Panel Chair); EPSRC Supergen interview panel; European Association of Geoscientists and Engineers; International Volcanic Health Hazard Network; the UK Natural Dust and Health Network; Health Protection Agency Expert Panel and Steering Group; UK Government Cabinet Office's Expert Advisory Group for Risk H55 in the National Risk Register; REF 2014 subpanel 7; Committee of Heads of University Research Departments (CHUGD); NERC Peer Review College and associated committees; NERC Geoscience Isotope Facilities Steering Committee (member and Chair); National Oceanographic Centre's Advisory Board; European Earth Science Research Councils, e.g., Portuguese and Swedish Research Council together with Science Panel of the IGCP (UNESCO) and International Subcommission on Ordovician Stratigraphy.
- *Societal:* **Allen** is the secretary of the Northern Regional Group of the Geological Society, **Gluyas** worked on the acceptance of CCS with Anthropology; **Jones** serves as a member of the Geological Society of London Awards and Science committees, and Davies participated in 10 public engagement events on shale gas.

iii) Recognition: Awards for contributions to the discipline include: *UK awards:* **Foulger** elected as Vice President of the Royal Astronomical Society (2013); **Searle** (now emeritus) Price Medal of the Royal Astronomical Society (2011); **Davidson** (Geological Society's Coke Medal, 2011; Volcanic and Magmatic Studies Group Award for 2013/14); **Selby** William Smith Fund (Geological Society of London, 2009). *Overseas awards:* 3 staff members (**Baldini, Van Hunen, Williams**) have received ERC early career research awards. **Greenwell** awarded the Max Hey Medal by the Mineralogical Society; *Election to Membership of Learned Societies:* **Searle** (now emeritus) elected Fellow of the American Geophysical Union, 2012; **Davidson** is President of the Mineralogical Society, 2012-13.