Institution: University of Aberdeen

Unit of Assessment: 7 (Earth Systems & Environmental Sciences)

a. Overview

Research in the areas of Earth Systems and Environmental Science in Aberdeen is brought together in the School of Geosciences. There are two broad strands to our research – one looking at Earth surface processes in the modern world and geologically recent past, the other focusing on subsurface Earth science and its deeper time record. We have developed strong collaborations with researchers internationally and nationally in our fundamental research, and have excellent links with industry-based and government scientists especially in the oil and gas sector. These industrial collaborations have allowed us to create state-of-the-art research facilities for seismic interpretation and in petrophysical rock characterisation that enhance our long-term laboratory strengths in geochemistry with specific reference to geofluids and stable isotopes in water. Our industrial research partnerships grow from a strong portfolio of undergraduate and postgraduate teaching, as well as professional training. The collaborations built from these partnerships greatly enhance the employment prospects of our students and provide unrivalled access to subsurface data gained from petroleum exploration for fundamental research. The research feeds onto the University of Aberdeen's institutional research themes in Energy and in Environment and Food Security.

Researchers from the School of Geosciences brought together in this submission were submitted to RAE2008 under two separate panels: (UoA17 - Earth Systems and Environmental Sciences, together with UoA32 – Geography and Environmental Studies). Our joint submission here to REF2014 recognises the integration of research that increases our critical mass with cross-fertilisation, especially in the areas of fluid and fluvial processes, sedimentology, digital technologies structural geology and geophysical expertise. This restructuring is represented in a new grouping of researchers based on expertise, rather than the topic-based approach extant during RAE2008. The expertise base is drawn together for transient theme-based projects as appropriate, an agile structure that provides greater flexibility in responding to new research opportunities, such as our BG/CNPq (National Council of Technological & Scientific Development) PhD school currently being developed through Brazil's "*Science without Borders*" programme.

b. Research strategy

We carry out fundamental research into aspects of the Earth system, and work in partnership with various end-user communities to apply this research to key societal and commercial ends. We work on modern Earth systems, especially on Earth surface processes, and take these back into geological time to understand the evolution of sedimentary basins; the tectonic processes that form and deform them, the depositional processes that fill them, and the interpretation of the records they contain. This ambition draws together a broad range of Earth scientists, from those using rock, sediment, water and ice records to track surface processes active today, through to those reconstructing these processes from geological records, integrating with geophysical, geochemical and palaeobiological data to investigate the various tectonic and climatic underpinnings of these processes.

Since RAE2008 we have developed from our core strength in sedimentary systems, integrating existing expertise in Earth surface processes within the School while expanding capacity in tectonics and geophysics. This refocusing has been achieved, within the context of staff retirements and mobility, enhanced with new posts. Our recent priority has been to create a strong grouping in solid Earth geophysics, especially in characterising the structure of the lithosphere using seismic methods to make fundamental advances in elucidating the tectonic processes that form and deform sedimentary basins, and to resolve better the structural, igneous and sedimentary structures within them. Future plans include staffing investment in geochemistry, palaeobiology and water resources while maintaining, and enhancing where necessary, our existing strengths. We will continue to develop partnerships nationally and internationally to enhance our research. Increased partnerships and staffing will allow us to continue to engage in world-class research addressing the formation and filling of sedimentary basins as well as their underlying lithosphere geodynamics, their structure and sedimentary fill, the evolution of the deposits and their fluids, and the generation, location and exploitation of resources. Furthermore, we will continue to study

fundamental geoscience questions concerning Earth surface processes, including the impact of rapid environmental change on contemporary systems which has received significant support from NERC, the EU and the Leverhulme Trust. We will also support industries in the development of resources for societal benefit, through the extraction of hydrocarbons, to the use of geological reservoirs as repositories of societal waste. We will continue to maximise the use of surface and subsurface geosciences data for fundamental research through these partnerships, especially the oil & gas industry. We expect to continue delivering our research through PDRFs and PhD projects, thereby attracting further PDRFs and PGRs from around the world. We expect funding to be through research councils, Joint Industry Projects and, increasingly, with individual national oil companies. Industrial funding for our research, through a diversity of companies (especially in the buoyant oil & gas sector), makes our research funding base resilient at times of reduced public funds.

Our research is undertaken by three groups.The **Tectonics and Geophysics** group represents a new area of expertise for Aberdeen, with the appointment of eight staff (**Alsop**, **Bond**, **Butler**, **Cornwell**, **Healy**, **Iacopini**, **Rawlinson**, and **Stephenson** - joining **Macdonald**) since RAE2008. This concentrates expertise in lithosphere tectonics and structure, notably the tectonic influence on sedimentary systems and the dynamics of lithosphere deformation, in particular how sedimentary basins are formed and deformed. The group studies deformation processes in the Earth system across a wide range of scales, from intra-granular to lithospheric, using data and observations from outcrop alongside geophysical data and imagery of the subsurface. All group members contribute to research on the heterogeneities and anisotropies of the Earth and their dynamic effects, using geophysical data at different scales. Building on Aberdeen's established expertise in the interpretation of commercially-acquired seismic reflection surveys, the group is developing strength not only in the novel use of seismic attributes, but also in passive seismology to image deformation and the integration of this into tectonic deformation models. This strategy for appointments and the development of the group has already produced research highlights including demonstrating the impact of lateral compaction on shortening in thrust belts; calculating the impact of anisotropy on fracture stability under elevated pore fluid pressures; calibrating the seismic properties of deformed materials and up-scaling these to seismic wavelengths; demonstrating how interactions between the lithosphere and the deeper mantle contribute to defining the internal architecture of sedimentary basins, and the role of magmatic processes during rifting; development and application of new passive seismological techniques including ambient noise and the simultaneous inversion of complementary datasets; showing for the first time that technique use is more important than the knowledge of experts in the successful interpretation of seismic reflection datasets. On-going and future research involves collaboration with industry on the dynamics both of continental margins and intracontinental basins (with BG, BP), including linking with Basin Fill researchers on depositional systems in deepwater settings and on magmatic processes in basins. A parallel theme uses investment in our petrophysics facilities (supported with funding from BG and Total), again linking with Basin Fill researchers, to quantify and model deformation localisation, fracture patterns, and their stratigraphic controls to predict fluid flow. Across the group our research draws on a wide range of localities that gives us global reach (Arctic and North Atlantic to the South Atlantic, Antarctic and Australia, SE Asia, South America, around the UK and through the Tethyan belt from Mediterranean to central Asia) and tectonic basin settings (intracratonic, intramontane / foreland, forearc and backarc basins, rift basins and continental margins).

Investigations into the rock deposits, their fluids and biota of sedimentary basins are the prime focus of the **Basin Fill** research group. The pre-2008 staff (**Bowden**, **Hartley**, **Hole**, **Hurst**, **Kneller**, **Jolley**, **Parnell**) have been strengthened over the past five years by the appointment of **Archer**, **Howell**, **Neilson** and **Schofield** to diversify and expand key skill-sets in stratigraphy, carbonate sedimentology and igneous geology in basins. We study modern and ancient sedimentary systems, using a range of techniques that combine to produce a cohesive approach to understand Earth surface and shallow-Earth processes through deep time by creating testable, quantitative predictive models. Highlights include novel approaches to understanding controls on sediment accumulation and dispersal from continental to deep water systems; high resolution climatic reconstructions that give important insights into key periods of environmental and atmospheric change in Earth's history; reconstruction of shallow crustal stress history and shallow hazard potential through sediment burial and remobilisation; changes in sea water chemistry

through deep time. We have enhanced capacity and expertise in quantification of stratigraphic packages, especially using outcrop analogues to reduce risk and uncertainty in models of subsurface hydrocarbon reservoirs. Going forward, our strategy is geared to facilitate greater quantification of these processes through better evaluations of the links between source and sink in sedimentary systems, including reconstruction of drainage basin size of fluvial and submarine clastic systems, and particularly quantifying the impact of climate change upon them, together with the interactions and feedbacks between sedimentary and igneous processes. The last of these is exemplified by the StratLIP project which has grown from stratigraphic and sedimentary research, to integrate geochemistry and petrology expertise and combinations of fieldwork and seismic interpretation, to quantify geometries of igneous bodies and to draw out implications for interacting processes. The group develops novel technologies for high-resolution in-situ analysis of enhanced oil recovery in porous media. Our deep biosphere research combines S-isotopes, fluid inclusion and thermal modelling to track bio-colonisation of bolide impact sites, and organic chemical traces to track microbial life in hydrothermal systems. Research on how lithospheric evolution controlled atmosphere and biosphere evolution has shown how intensive periods of anorogenic magmatism in late Palaeoproterozoic/early Mesoproterozoic, and accompanying metallogenesis, enhanced availability of key metals to organisms, promoting diversification of eukaryotes and the evolution of multi-celled life. Microbial sulphur isotope fractionation in late Mesoproterozoic terrestrial environments reflects oxygenation of the atmosphere earlier than had hitherto been understood, and transgression of the early Cambrian ocean across numerous exhumed Precambrian ore deposits released an unprecedented flux of metals into the ocean, and contributed to the exceptional chemistry of the ocean which hosted the Cambrian 'explosion' of life. Work on the evolution of the biosphere and atmosphere linked to the evolution lithosphere and its migrating geofluids (the limits of Deep Hot Biosphere) has led to participation on International Ocean Drilling Program cruises (331 - Sept 2010; and 337 - Aug 2012).

Capacity in **Earth Surface Processes** has been significantly strengthened by new appointments since RAE2008 (**Bingham**, **Goode**, **McDonnell**, **Spagnolo**). While maintaining focus on the broad themes of cryosphere and hydrology (funded by ERC, NERC, EU, the Leverhulme Trust and government agencies), there are close linkages with the Basin Fill researchers, especially relating landscape evolution on contemporary hydrological processes (**Soulsby**, **Tetzlaff**, **Hartley**) and on interpreting seabed images (**Spagnolo**, **Archer**). Much of our work in this area has been carried out in collaboration with government research scientists on policy-relevant issues. Interdisciplinary research is fostered through close collaboration especially with Marine Science Scotland, the James Hutton Institute and, nationally and internationally, with other geomorphologists, ecologists, soil scientists, physicists and statisticians. Cryosphere research on climate, ice sheet mass balance and dynamics has been novel in showing that atmospherically-induced dynamic thinning is not a major contribution to mass loss in ice sheets. Work with the British Antarctic Survey has shown that the sensitivity of contemporary patterns of ice sheet dynamics to changes in ocean temperature is preconditioned by the geological setting. Existing research focusing on geomorphic land form analysis and glacial reconstruction has been strengthened by establishing geomorphological signatures of ice sheet dynamics and crevassing processes using landform analyses and centrifuge modeling. An additional focus has been on sea level variability during the Holocene and effects of tsunamis on coastal sedimentary records. A major strategic priority is the continued integration of research on contemporary ice dynamics, landform analysis and chronological reconstructions to contextualise current environmental change with geological records. Hydrological research focuses on (a) the application of advanced tracing and novel tracer-aided mathematical modelling in the characterisation of hydrological systems and (b) the ecohydrology of headwater catchments and is enhanced by the appointment of **McDonnell** (20%), further strengthening collaboration with his principal institution, the Global Institute of Water Security at the University of Saskatchewan. Research highlights include the integration of empirical tracing techniques with advanced mathematical analysis to constrain the geographic sources and temporal dynamics of streamflow generation processes, complemented by the development of novel, tracer-aided rainfall-runoff modelling. Another focus is on the ecohydrology of headwater streams and environmental controls, including sediment transport processes on short and longer-term ecological dynamics. This is complemented by the recent appointment of Goode who investigates how climate-driven changes in streamflow will alter interactions among hydraulics, sediments and channel habitats. **McDonnell**'s work spans these two themes, but has focused on

use of new technologies in tracing techniques to examine vegetation influences on catchment hydrological dynamics as well as catchment classification.

Earth Systems and Environmental Science research is overseen by two directors: **Butler** and **Tetzlaff**. Both represent the Unit on the Research and Commercialisation Committee of the College of Physical Sciences. Their roles are to co-ordinate and motivate strong research across the Unit, linking with the University's central Directorate of Research and Commercialisation Services to disseminate information on external funding opportunities. Research projects are developed from "grass-roots" – proposed and developed by individuals, critically discussed within research seminars and discussion groups, and supported by the research directors. These initiatives are then nurtured within research groups, drawing in additional expertise from elsewhere within the School and beyond as appropriate. The Unit has a successful internal peer-review process in place. This coordinated approach is exemplified by the development of our seismic interpretation facilities (seisLAB and the Halliburton 3D visualisation suite) which was designed and is used by all research groups, from structural geology projects mapping the localization of deformation in thrust belts, quantifying the geometries of the components of submarine channel systems, to investigating palaeo-ice-streams from geomorphology. Recognition of project leadership is proportioned on a case-by-case basis and accounted for in workloads managed by the Head of School (**Soulsby**), who retains overview of the whole activity.

We measure the success of our research by:

- the quality and quantity of our research outputs and their use by other scientists, in academia, government and industry;
- the success of our students in presenting high-quality theses;
- the future careers of our students and PDRFs;
- invitations to give keynote presentations at international conferences;
- invitations to serve on international committees and panels;
- the continued attraction of grants from a diverse range of funders (RC, government, industry);
- the engagement with both scientific, public and end-user communities.

c. People, including:

i. Staffing strategy and staff development

The University of Aberdeen has a long-standing commitment to innovative geoscience research, promoting staff and making new appointments that recognise research excellence. Recruitment since 2008 has involved a mix of experienced researchers to provide leadership together with early career researchers. Within this Unit there are 15 professors, 10 readers/senior lecturers and 7 lecturers, of whom 7 staff are ECRs. Over the next five years we expect to expand further, building upon our excellent and diverse range of research funding, underpinned by a rapid growth, not only in the numbers of graduate students but also in the continued attraction of Aberdeen for undergraduates and vocational masters. The first phase of this expansion has begun with the appointments of three professorial staff and three early career researchers under the University's "Shape the Future" initiative. We expect to grow faculty numbers by a further 5-8 over the next three years. The Unit fully embraces the University's Equality and Diversity policy, which is applied to all aspects of employment within the School, including recruitment, promotion, development opportunities and disciplinary procedures. All staff have access to Equality and Diversity training providing fundamental education in the legislative framework and its practical implementation. This training is mandatory for all staff with supervisory and recruitment responsibilities.

For RAE 2008, the staffing strategy related to supporting a series of theme-based research topics under the collective umbrella of "sedimentary systems" (Earth Systems and Environmental Science panel) and two themes submitted to the Geography and Environmental Studies panel ("cryosphere and climate change" and "environmental hydrology"). We have since developed integrated approaches but recognise that research into sedimentary systems, especially in regard to basin evolution, demands a broader expertise including structural geology, tectonics, and especially geophysics. In the past year considerable investment in new staff (**Cornwell**, **Howell**, **Schofield**, **Rawlinson**) has been achieved by linking ambitions within the School of Geosciences to broader opportunities within the University's "Energy" research theme. It is also aligned with ongoing funding partnerships within Scotland in the oil & gas sector supported not only through the Energy Technology Partnership but also a Scottish Funding Council/Scottish Enterprise initiative for an Oil & Gas Innovation Centre. Our increased expertise in seismology and seismic

interpretation maps onto strong and developing partnerships with industry as they explore frontier basins and continental margins. The expansion of this capability under a geophysics umbrella satisfies this together with the growing use of passive seismic methods not only in tectonic research but also for exploration, production and monitoring fluids in the subsurface. Our aim is to grow these areas, while continuing to maintain core expertise in stratigraphy and geochemistry alongside the strength in sedimentary systems.

The Earth Surface Processes group has built capacity in remote sensing techniques, including shallow ice-sheet geophysics and GIS-based landscape analysis, and has strengthened fluvial geomorphology. These appointments, linked with sedimentologists in the Basin Fill group, will exploit opportunities at the interface of contemporary fluvial process studies and interpretation of environments in deeper geological time. A further appointment in hydrological modeling will be advertised later in 2013.

The development of Early Career Researchers within the School is enhanced at the level of research groups with regular meetings. These groups act collectively to plan research applications, giving early career scientists the opportunities to lead and build their own teams (e.g. **Archer**'s Triassic mudstones and basin research; **Bond**'s perception and uncertainty research, and on CO_2 storage; **Healy**'s petrophysical researches on deformed rocks). The School supports new researchers (PDRFs, ECRs) through generic career development opportunities, delivered by the University's Researcher Development Unit that received the "HR Excellence in Research" award from the European Commission. Postdocs Ali, Hrachowitz, **Iacopini**, **Schofield**, Sole and Torvela now hold permanent university appointments (Manitoba, Delft, two at Aberdeen, Sheffield and Leeds, respectively). Close mentoring of new staff and focus on NERC applications by all staff has resulted in many researchers (e.g. **Bingham**, **Dawson**, **Healy**, **Rea**, **Spagnolo**, **Tetzlaff**) winning their first NERC funding during the period from 2008. The School operates an internal peer-review system for research grants that gives constructive feedback on proposals ahead of submission. There are regular (weekly or more during term-time), discipline-based research seminars and informal discussion groups. Staff involvement in external editing boards, peer review colleges and international committees, together with conference and symposia convening, is actively encouraged within the School, so as to enhance their profile on the national and international stage and to gain broader experience of the research community.

Our research capacity, and especially links with the oil & gas community, is greatly enhanced by our cohort of honorary faculty members including Professor Mark Cooper (structural geology; Sherwood Geoconsulting, former VP new ventures at Encana); Professor Ken Glennie (sedimentology, formerly Shell), Dr Andy Morton (heavy minerals; HM Research Associates), Dr Gary Weissmann (hydrogeology, University of New Mexico).

ii. Research students

Graduate students are the life blood for research within the Unit and a key component in its internationalisation strategy. During this REF period we have actively grown our PhD numbers from 21 in mid-2008 so that by mid-2013 we now host 45 full-time, in-term research students supervised by staff in the Unit. Of these, 20 are UK students, in part funded through NERC algorithm and Industrial CASE schemes, and with many funded by industry. We have a diverse and vibrant body of overseas research students from 13 different countries, funded by national governments, national and multinational industry. Our strategy is to grow our numbers through innovations such as the Brazilian "*Science Without Borders*" scheme which combines international research collaborations with industrial sponsors to deliver 20 new PhD students (2012-2015), and in partnership especially with other institutions in Scotland, through schemes such as the Energy Technology Partnership.

Within the School of Geosciences all research students are assigned two supervisors who are jointly responsible for their specific training. This is underpinned by generic training provided by the Graduate School within the College of Physical Sciences and the University's Researcher Development Unit. Programme-specific training for each individual is designed and delivered via participation in higher level UG and M-level courses together with one-to-one training by the supervisor(s) and peers (advanced research students) in empirical, analytical and technical skills together with results dissemination. We host international advanced training for PhDs (e.g. **McDonnell**, **Soulsby** and **Tetzlaff**'s annual week-long intensive postgraduate "*Catchment Science Summer School*", with 30 students from 10-15 countries each year). Where appropriate, external

training providers are used (e.g. leading industry participants such as Schlumberger, Halliburton and Midland Valley for specific software). All research students are expected to give annual research seminars and poster presentations within the School, and as research progresses, to present their own work at national and international conferences. Through the REF period our PhD students have won 4 "best-paper" prizes at conferences, and have contributed to 50 research papers. Most of our graduate students are members of the joint student chapter of the American Association of Petroleum Geologists, and the Petroleum Exploration Society of Great Britain. They are supported by the University and societies to run weekly lunch-and-learns, regional student forums and field workshops, together with public engagement events, greatly enhancing our scholarly environment.

Progression is tracked through supervisor meetings, minuted progression reviews and annually (more if necessary) by each student's support committee. Recruitment of PhD students is achieved through open advertisement, but also makes use of our extensive international research networks. This is supported by exhibitions at the AAPG Annual Conference, advertising at international conferences such as American Geophysical Union and European Geosciences Union and especially through our website. We also market nationally at the annual Careers in Earth Science event (Edinburgh).

d. Income, infrastructure and facilities

Our combined research income over the REF period exceeds £12 million. We have actively developed a broad base of **research funding** that encompasses not only public funds dispersed by Research Councils (e.g. NERC, European Research Council) and directly from governments, but also from charities (e.g. Leverhulme Trust), and industry. This diversity allows strategic growth and increased resilience of our research portfolio, especially during periods of financial uncertainty. Much of our industrial income is administered through multi-partner Joint Industry Projects (JIP) that also facilitate access to the substantial surface datasets that underpin several of the outputs in this submission. It also enhances the impact of our research, by linking with commercial end-users. JIP funds are generally used to invest in PhD studentships, an effective way of completing research projects while providing a stream of research scientists with appropriate training and background for the modern oil &d gas industry. We aim to retain this diversity of research funding, increasing activity especially as new Scottish initiatives in oil & gas research expand in the coming years, and continuing to apply for Research Council support where appropriate. We recognise international opportunities for not only increasing our research funding, but also developing collaborations to work on new sedimentary basins and accessing data and facilities. Our key growth areas are in Brazil, through growing joint doctoral training programmes (see below) and in ventures such as the Parnaiba Basins project (funded by BP, in partnership with Oxford and Cambridge universities), and in China (Chinese University of Geosciences, Wuhan).

Twelve research areas (in some cases amalgamated projects) illustrate the **diversity of funding** we have attracted. Much of our research funding is in partnership with other institutions (as outlined in section e), but below we show income to Aberdeen (some running beyond 2013).

Brazil doctoral training (lead **Kneller**): broad-ranging research on sedimentary systems and basins. £4M to fund 20 PhD studentships (14 joint with UFRGS, Porto Alegre) with research costs, plus 5 PDRFs, and staff exchanges through the BG/CNPq "*Science without Borders*" programme.

ClimateXChange (lead **Bond**): total funding £300K to Aberdeen (part of Scottish Government funded centre) focused on science input into climate change policy building on expertise generated by research into interpretation uncertainty of seismic datasets. Supporting PDRF.

Deep-water clastics (lead **Kneller**): Various JIPs totaling £2.26M from BG, BP, ConocoPhillips, DONG, GDF Suez, Hess, Petrobras, RWE Dea, Statoil and Total; PhDs, PDRFs, fieldwork.

Fluvial Systems (lead **Hartley**): five companies (Chevron, Conoco, Total, BG, Apache) worth £750K, supporting 7 PhD studentships and 4 PDRF's on the sedimentology and stratigraphy of fluvial successions, specifically the application of geomorphology to the rock record.

Glacier-climate interactions (leads **Bingham**, **Mair**, **Rea**): total funding (£450K to Aberdeen) through international collaborative projects for two major NERC grants (Standard mode and iSTAR programme) and Leverhulme Trust International Network; support for RA, PhDs, fieldwork.

Ecohydrology in high-latitude ecosystems. (lead **Tetzlaff**): Funding from European Research

Council (£1.3million); NERC (£350K to Aberdeen) and Leverhulme Trust (£125K) for collaborative projects supporting several PDRFs, laboratory and equipment costs, international workshops.

Landscape-scale hydrological processes (lead **Soulsby**): using tracers and novel tracer-aided modelling to upscale hydrological process understanding. Funding from EU (£230K) and Leverhulme Trust (£200K) supporting 2 PDRFs, one PhD and laboratory costs.

Petrophysics (lead **Healy**): Understanding the influence of porosity and permeability on geomechanical and petrophysical responses of rocks. Funding from RCUK and industry (Total, BG, Lundin, AFES and NERC) (£600k) supporting PhDs.

Sand Injectites (lead **Hurst**): Seismic and outcrop studies to quantify subsurface sediment remobilization. Funding from seven companies (Cairn Energy, Det Norske, Maersk, Marathon, Premier, Statoil) (total of £1.2M) funding three PDRFs plus research expenses.

StratLIP (leads **Hartley**, **Jolley**, **Hole**): Funding from companies (Chevron, Statoil, Dong OMV) and the SINDRI consortium, integrating sedimentology, volcanology, biostratigraphy and biofacies analysis to constrain the environmental and stratigraphic impact (£400k) supporting 4 PhDs.

Triassic Mudstones (lead **Archer**): Funding from by companies (BP, ConocoPhillips, Eon, ExxonMobil, GDFSuez, JXNippon, Maersk, Shell, Total), £600K for core, wireline, seismic and outcrop studies. Supporting PhDs and PDRF.

Virtual Seismic Atlas (lead **Butler**): combination of NERC (£146K), industry (Hess), Petroleum Exploration Society GB (£210K) for seismic research and web-delivery for knowledge exchange; supporting PDRF.

Research income and generous donations (both in cash and in-kind through software and hardware) support our main **research facilities**. These are:

Seismic interpretation. 16 industry-standard dual-screen workstations operate in our seisLAB (sponsored by BP and Chevron) that run state-of-the-art seismic and subsurface modelling software, maintained by our in-house computing officer and a geosciences applications support specialist. Seismic interpretation is enhanced by our 3D-visualisation suite, sponsored by Halliburton in 2009. These run both Halliburton's Landmark platform together with SMT's Kingdom Suite together with various basin modelling and petrophysical packages. Both facilities are used for visualisation and modelling, using combinations of Schlumberger's Petrel, ffA's SVI Pro and Midland Valley's Move software. Our partnership with Midland Valley includes NERC CASE studentships and active collaboration (**Bond** is their research science advisor) on developing new capacity in their Move software for fracture modelling.

Seismic datasets made available under licence from seismic and energy companies represent a research resource worth many £millions. These primarily support PhD research and include large numbers of regional 2D lines and major 3D datasets including those from offshore Brazil (Campos Basin and Foz de Amazonas), Sabah, Niger delta, the Mediterranean (Ebro, most of the Nile delta and offshore Gaza), selected parts of the US Gulf of Mexico and PGS's MegaSurvey of much of the North Sea.

The Petrophysics laboratory contains 2 porosimeters and 3 permeameters. One permeameter can operate at confining pressures up to 250 MPa, and uses either nitrogen or water as the pore fluid. Acoustic velocities can be measured on dry or saturated samples using a suite of ultrasonic transducers and a digital oscilloscope. A new mercury injection porosimeter further enhances our capability to quantify pore space. All of the technical development work in the laboratory is funded by RCUK or industrial income, with research projects sponsored by NERC, AFES, Total, BG and Lundin. The facility is maintained and enhanced by a dedicated technician.

Geochemistry suite. The Geochemistry laboratory is focused on analysing sedimentary lipids, pre-oil window biomarkers and petroleum. Gas-chromatography mass-spectrometry (GC-MS) facilities include an AT 6890N GC with an AT5975 quadrupole MS and a CDS Instruments Pyroprobe 1000 connected to a HP 5890 GC with a HP5972 MS, supported by institutional investment. A separate fluid inclusion laboratory is based upon a Linkam microthermometry facility, coupled to an ultraviolet light microscope for detection of organic fluids, and related imaging systems. The suite supported 10 PhD students since 2008 and is maintained by a dedicated technician.

Isotope Hydrology laboratory. A stable isotope analyser using Near-Infrared Laser Spectrometry (Los Gatos DLT-100) including an auto-injector system to facilitate process of large numbers of isotopic water samples has been commissioned with University funding in 2009 as part of a new

Isotope Hydrology Laboratory which can provide excellent analytical precision (D/H ~ 1.6‰, $^{18}O/^{16}O$ ~ 0.2‰) cheaply and rapidly (~100 seconds). This provides a flexible analytical tool that has greatly enhanced capacity in tracer hydrology and has supported/is supporting 4 PDRFs and 6 PhD students.

e. Collaboration or contribution to the discipline or research base

Almost all of our research involves **collaboration** with researchers elsewhere in the UK and internationally, with co-publication of research and study visits to other institutions. To illustrate the diversity of the partnerships we present a selection of projects:

Within Scotland we are actively engaged in four major collaborative initiatives – CREW (Centre of Expertise for Waters, **Soulsby**); SAGES (Scottish Alliance for Geoscience, Environment and Society: **Bingham**, **Dawson** on research committee), SURGE (Scottish Universities Research in Glacial Environments, co-ordinated by **Mair**); ClimateXChange (**Bond**).

We are involved in major UK partnership research programmes directed at Antarctica and the Arctic. through the Lake Ellsworth Consortium (**Bowden**, **Parnell**) and ice sheet stability programme (iSTAR, **Bingham**) as well as the NERC Arctic Programme (HYDRA, **Tetzlaff**).

Internationally, the University of Texas in Austin remains a key partner for sedimentary systems, tectonics and geophysics research. **Macdonald** held the Don R. & Patricia Clark Boyd Distinguished Lectureship in Petroleum Exploration at UT (2011: researching Phanerozoic plate reconstructions). Other collaborations include deepwater systems and Antarctic geophysical surveys. The Global Institute for Water Security, University of Saskatchewan, is a major partner for hydrology research - **McDonnell** holds a dual appointment. We are currently developing collaborative programmes in petroleum geology and basin evolution with the University of Bergen (through the appointment of **Howell**) and with the Chinese University of Geosciences, Wuhan, following a British Council award of a Scotland-China Higher Education Research Partnership (2010-2011).

Through 2013 we have formed an alliance that links researchers in Aberdeen, Oxford and Cambridge universities with 5 institutions in Brazil (National Geophysics Observatory together with the Federal Universities of Bahia, Brasilia, Pernambuco and Rio Grande do Norte) as part of the BP-funded Parnaiba Basin project. This involves major geophysical experiments, tied to geological studies to examine intracontinental basin development. It is built upon our major collaborative projects with Universidade Federal do Rio Grande do Sul (UFRGS) that is forming long-term strategic partnerships with Brazilian institutions to study integrated earth processes in sedimentary basins and continental margins. It also builds upon major geophysics/tectonics collaborations such as the Ellesmere Lithosphere Experiment (ELLITE), a linked seismology and geodynamics project with the Geological Survey of Canada, University of Aarhus (Denmark) and the Université de Québec à Montréal – with UK involvement led by **Stephenson**. **Rawlinson** brings his experience setting up the WOMBAT transportable seismic array experiment and, through AuScope, establishing Australia's first national pool of ocean bottom seismometers.

Members of the Unit hold adjunct positions at 11 institutions (**Alsop** - University of Barcelona; **Gibbins** – University of Lleida; **Hartley** - University of New Mexico, Albuquerque; **Howell** – University of Bergen; **Iacopini** – University of Pisa; **Kneller** - University of California at Santa Barbara and UFRGS, Porto Alegre; **Macdonald** – University of Texas, Austin; **Mair** - University of Grenoble; **Stephenson** - University of Aarhus; **Tetzlaff** – Leibniz Inst., Berlin). Beyond these, staff in the Unit co-supervise research students in 11 external institutions (Universities of Adelaide, Auckland, Durham, Leeds, Leibniz Institute, Sheffield, SLU Umea, Strathclyde, Vale do Rio Sinos (Brazil), University Centre, Svalbard; University College Dublin). Joint research projects involving local research funding and short research visits, are held at a further 38 institutions internationally and 20 within the UK.

Here in Aberdeen we have hosted **research visitors** from the UK - British Museum, University of Kent, SUERC; and overseas - Aarhus University, Denmark; Boise State University, US; China University of Geosciences, Wuhan; ETH Zurich; McMaster, Canada; Zhejiang University, China; Kharazmi University, Tehran, Iran; Federal University of Pará, Brazil; IGB Leibnitz Institute, Berlin, Germany; University of Patras, Greece; Universities of Pisa and Sasari, Italy; SPK-Geoservice LLC, Kyiv, Ukraine; Institute for Energy and Transport, Petten, Netherlands; Universidad Nacional de San Juan, Argentina. Such visits are utilised to develop and progress research collaborations and to contribute to the academic environment of the Unit through seminars and training of post-doctoral staff and students.

All members of the Unit **contribute to the wider community** of Earth and Environmental Science through the peer-review process of research papers and grant proposals and many have acted as external examiners for PhDs. 8 staff have served on NERC Peer Review College and grant committees (**Bingham**, **Dawson**, **Gibbins**, **Hartley**, **Healy**, **Jolley**, **Macdonald**, **Mair**, **Tetzlaff**), STFC (**Parnell**); and equivalent committees in Norway (Petromax – **Hurst**) and Australia (AuScope – **Rawlinson**); and as proposal reviewers of European Geopark Network (**Alsop**, **Butler**) and World Heritage sites (**Butler**); Ministry of Education and Science of the Russian Federation (**Stephenson**); National Science Foundation NSF US (**Bingham**, **Mair**, **Tetzlaff**); Natural Sciences and Engineering Research Council of Canada NSERC (**Tetzlaff**); Swiss National Science Foundation (**Tetzlaff**); Netherland organisation for Scientific Research (**Bingham**, **Mair**, **Tetzlaff**).

Many staff have convened symposia, international conferences and workshops through the REF period (too numerous to document). Apart from numerous cases of guest **editing** journal issues and special publications, members of the Unit play significant roles in academic publishing as editors (Books editor, Geological Society – **Stephenson**; Andean Geology - **Hartley**; Geography Compass – **Tetzlaff**; Hydrological Processes – **Tetzlaff**; Journal of Structural Geology - **Alsop**; Petroleum Geoscience - **Jolley**; Scottish Journal of Geology - **Alsop**), or on editorial advisory boards (Bulletin of the Geological Society of America - **Butler**; Geodinamica Acta – **Butler**; Geological Magazine - **Macdonald**; Geology – **Mair**; Geophysical Journal – **Stephenson**; Geosphere - **Bond**; Journal of the Geological Society - **Alsop**, **Hartley**; Journal of Hydrology – **Soulsby**; Journal of Petroleum Geology - **Macdonald**; Petroleum Geoscience - **Archer**; Search & Discovery (AAPG) - **Archer**; Tectonophysics – **Rawlinson**; The Cryosphere – **Bingham**; The Holocene - **Dawson**).

A number of staff serve on management **committees of major learned societies** (Committee for Publishing Ethics – **Stephenson**; European Astrobiology Network Association - **Parnell**, Council; Geological Society – **Butler**, Council, external relations and chair of geoconservation committee; International Glaciological Society – **Bingham**, Secretary, UK branch); specialist groups (Petroleum Group – **Archer**, Secretary; **Neilson**, Treasurer. Tectonic Studiers Group - **Healy**, Treasurer; Solid Earth Geophysics Group, GS Australia – **Rawlinson**, chair; Hydrology committee, American Geophysical Union – **Tetzlaff**, chair) and technical committees (AAPG centennial committee – **Hurst**; ExoMars science group – **Parnell**; International Association of Hydrological Sciences commissions – **McDonnell**, **Soulsby**, **Tetzlaff**; North Sea core storage – **Archer**: various NASA and ESA committees – **Mair**, **Parnell**).

Our research has been peer recognised by the following **major awards**: Fellow of the American Geophysical Union (**McDonnell**, 2009; **Soulsby**, 2013); Birdsall-Dreiss Distinguished Lecturer Award, (>40 lectures given in 2011) Geological Society of America (**McDonnell**), John Dalton Medal, European Geosciences Union (**McDonnell**, 2009); Scottish Offshore Achievement Award (**Kneller**, 2009); Member of Royal Society of Edinburgh (RSE) Young Academy of Scotland (**Tetzlaff**, 2012-); Grover Murray Distinguished Educator Award, AAPG (**Hurst**, 2012). In addition, the following have given invited keynote presentations: **Archer** (1), **Bond** (6), **Butler** (7), **Dawson** (2), **Gibbins** (1), **Hartley** (2), **Healy** (2), **Hurst** (4), **Jolley** (4), **Kneller** (1), **Macdonald** (3), **McDonnell** (9); **Soulsby** (8), **Stephenson** (1), **Tetzlaff** (8); together with recognition of outputs: DEVEX 2012 (**Bond/Hartley** – best academic presentation); Journal of Sedimentary Research 2010 (**Hartley** – outstanding paper award); Journal of the Geological Society 2012 (**Schofield** - young author award).